revolutionizes the lab experience

Harshit Jain
Sean Poluha
Wanxi Liu
Yu Hsiao

Carina Them
Joscha Held
Will Kölbener

Alexander Mülli

June 10, 2014 | Stanford University | Mechanical Engineering | Stanford, CA 94305
Executive Summary

Current bio-sample testing platforms perform testing procedures very well but are extremely cumbersome for scientists and laboratory technicians to work with. In a stressful environment, communication and accuracy of machines are extremely important. The bio-sample machines need be one with the lab scientist so they can work together without any disconnection.

Given this context, Merck/EMD has given us, four Stanford University Mechanical Engineering students, three HSG management students, and one University of Zurich Student in Business Information Systems, the mission to develop a bio-testing platform that will enable effective communication within relevant processes and is easily usable for relevant users and stakeholders.

After comprehensive research, we identified critical functions and needs that can innovate the next generation user experience with bio-sample machines. The first critical issue we found was the lack of engineering that goes into Graphical User Interface (GUI). The fonts are often hard to read. The programs produce multiple cascading windows which make the interface hard to navigate through. A second issue is the inability to walk away from the machine and still be able to know the status of samples remotely. Finally, the platforms currently available do not have proper customer support in place to minimize machine downtime. Current devices utilize very limited technical support and debugging features.

From what we learned, we wish to create a user-friendly interface integration for a bio-sample testing system that will include three critical functions: proper customer support, a transparent user interface, and walk-away capability.

The walk-away system will consist of multiple PC’s in the lab that will share a universal GUI and will enable control of any machine from any location in the lab. The lab scientists will also be equipped with walk-away tablet clipboards and that enable a portable device to monitor testing samples from anywhere in the lab. The users also have a large touch screen display at their disposal on the machine for easy accessibility. The customer support service will be robust with visual guidance by a customer support agent with help of movable cameras and still cameras, enhancing communication between the agent and the user (Figure 1).
In addition, there will be a comprehensive database of self-help 3D model videos that display troubleshooting procedures for common mechanical issues. The procedures are broken down step-by-step for the user to follow easily at their own pace, shown in Figure 2.

**Figure 1** Two still cameras + 1 fixed camera enhances communication between user and customer support tech.

**Figure 2** 3D videos demonstrate step by step procedures for troubleshooting. Written instructions also included.
Finally, all features are integrated within a compelling user interface that will be easy to get accustomed to and make any user an expert within seconds after using the interface shown in Figure 3.

**Figure 3 Customizable interface with larger fonts and navigation bar**

With all of these elements, we have created our solution, Tucuxi. Tucuxi will set Merck’s bio-specimen testing platform apart from its competitors and make Merck the leader in this testing industry by creating a platform that is user-centric and allows lab scientists to have an enjoyable experience every day in the lab.
Contents

Executive Summary .................................................................................................................................................. i
List of Figures .......................................................................................................................................................... viii
List of Tables ........................................................................................................................................................ xi
Glossary .................................................................................................................................................................. xii

1 Context ................................................................................................................................................................. 1
  1.1 Need Statement ............................................................................................................................................. 1
  1.2 Problem Statement ..................................................................................................................................... 2
  1.3 Corporate partner: Merck KGaA/EMD Millipore ......................................................................................... 3
    1.3.1 Corporate Liaisons ............................................................................................................................... 3
    1.3.2 Corporate Canvas .................................................................................................................................. 3
  1.4 The Design Team .......................................................................................................................................... 4
  1.5 Stanford Team Coaches and Teaching Team ............................................................................................. 9

2 Design Requirements ........................................................................................................................................ 10
  2.1 Functional Requirements ........................................................................................................................... 11
    2.1.1 Portability ............................................................................................................................................. 11
    2.1.2 Customer Support Visualization ........................................................................................................ 12
    2.1.3 Functional Constraints ....................................................................................................................... 13
    2.1.4 Functional Assumptions ..................................................................................................................... 14
    2.1.5 Functional Opportunities .................................................................................................................. 14
  2.2 Physical Requirements ............................................................................................................................... 14
    2.2.1 Physical Constraints ............................................................................................................................ 16
    2.2.2 Physical Assumptions ........................................................................................................................ 16
    2.2.3 Physical Opportunities ...................................................................................................................... 16

3 Design Development ......................................................................................................................................... 17
  3.1 Fall Quarter Overview ................................................................................................................................. 17
    3.1.1 Benchmarking ....................................................................................................................................... 17
    3.1.2 Needfinding .......................................................................................................................................... 18
    3.1.3 Prototyping ......................................................................................................................................... 19
    3.1.4 Design Framework for Winter Quarter ............................................................................................... 22
  3.2 Winter Quarter Needfinding ......................................................................................................................... 22
  3.3 Winter Prototypes ........................................................................................................................................ 24
14 Appendix H: FUNKtional Prototype Specifications .........................................198
  14.1.1 Hardware .................................................................................................198
  14.1.2 Frame with Overhead Webcam .................................................................199
  14.1.3 RC Car Rail System and Command Center .............................................200
  14.1.4 Servo–laser Pointer System .....................................................................202
  14.1.5 Testing Blocks Specifications .................................................................203
15 Appendix I: Functional Prototype Specifications .............................................205
  15.1.1 Machine Mockup ......................................................................................205
  15.1.2 Graphical User Interface ..........................................................................208
  15.1.3 Walk-away ...............................................................................................209
  15.1.4 First-Person Perspective Glasses .............................................................211
List of Figures

Figure 1 2 still cameras + 1 fixed camera enhances communication between user and customer support tech. ................................................................. ii
Figure 2 3D videos demonstrate step by step procedures for troubleshooting. Written instructions also included. ................................................................. ii
Figure 3 Customizable interface with larger fonts and navigation bar ........................................ iii
Figure 4 Screen shot of Olympus PK7300 Test Results ......................................................... 2
Figure 5 EMD Logo [1] ........................................................................................................ 3
Figure 6 Immucor Neo (left) and DIAGAST QWALYS (right) .................................................. 18
Figure 7 Wristwatch Critical Function Prototype .................................................................... 19
Figure 8 Glasses Critical Function Prototype ......................................................................... 20
Figure 9 Using Leap Motion to Interact with the Machine ....................................................... 20
Figure 10 RoboDog Prototype ............................................................................................... 21
Figure 11 RFID Test Tube Labeler Prototype ........................................................................ 22
Figure 12 Stanford Dark Horse Prototype ............................................................................... 25
Figure 13 Initial version of the Dark Hose Prototype ............................................................. 26
Figure 14 Flow Chart showing the whole testing process ....................................................... 26
Figure 15 Details of various parts of the Prototype ................................................................. 27
Figure 16 Guidance system menu ......................................................................................... 28
Figure 17 Customer Support System Diagram ...................................................................... 30
Figure 18 Overall View of the FUNKtional Prototype ............................................................ 31
Figure 19 RC car in maximum “Y” position ........................................................................... 32
Figure 20 RC car in minimum “Y” position ............................................................................ 32
Figure 21 Moving Laser Device ............................................................................................ 33
Figure 22 Sheet given to customer support representing block orientation ............................. 34
Figure 23 Actual orientation achieved by user ........................................................................ 34
Figure 24 the Test User Arranging Blocks ........................................................................... 36
Figure 25 Hand Drawn Interface .......................................................................................... 38
Figure 26 “Mayday Button” Feature ..................................................................................... 39
Figure 27 Sample & Patient Matching .................................................................................. 40
Figure 28 Decentralized Blood Ordering .............................................................................. 40
Figure 29 Blood Bag and Patient Verification ........................................................................ 41
Figure 30 Order Management .............................................................................................. 41
Figure 31 Functional Prototype System Diagram ................................................................. 43
Figure 32 Mockup machine .................................................................................................. 44
Figure 33 Components of the mockup machine: (a) test tube storage (b) tray hotel (c) incubator ......................................................................................... 44
Figure 34 Machine program flow chart ................................................................................ 45
Figure 35 Walk-away prototype ........................................................................................... 45
Figure 36 Customer service glasses with camera and laser pointer ...................................... 46
Figure 37 3D model of the mockup machine ........................................................................ 47
Figure 38 Step-by-step instructional video series of how to fix a probe problem .................. 47
Figure 39 Customer support command center ...................................................................... 48
Figure 40 Functional system prototype user testing ............................................................... 48
Figure 41 Mockup Machine at EXPE with Tablet Attached and Red Error Lights On .......... 51
Figure 87 2 DOF laser pointer system (each curve show the servo’s moving range, the arrow shows its initial position as shown in the figure). ................................................................. 202
Figure 88 Block Layout with Dimensions ........................................................................ 203
Figure 89 Incubator Dimensions ...................................................................................... 205
Figure 90 Test Tube Rack Dimensions .............................................................................. 206
Figure 91 Tray Holder Dimensions .................................................................................... 206
Figure 92 Stationary Parts Locations ................................................................................ 207
Figure 93 Machine Mockup .............................................................................................. 208
Figure 94 Simplified CAD Model of Machine Mockup ...................................................... 209
Figure 95 Simplified Flow Diagram for Graphical User Interface .................................... 210
Figure 96 Walk-away Device ........................................................................................... 210
Figure 97 First-person Perspective Glasses ...................................................................... 211
List of Tables

Table 1 Corporate Business Model Canvas ................................................................. 4
Table 2 Functional Requirements - Portability ............................................................. 11
Table 3 Functional Requirements - Customer Support Visualization ............................. 12
Table 4 Physical Requirements ................................................................................. 14
Table 5 Summarized Tests Results for FUNKtional Prototype .................................... 35
Table 6 Bill of Materials ............................................................................................ 70
Table 7 Spring Hunting Plan ...................................................................................... 86
Table 8 Spring Deliverables ..................................................................................... 92
Table 9 Spring Milestones ......................................................................................... 93
Table 10 Project Budget Summary ............................................................................ 96
Table 11 Stanford Catagorized Budget .................................................................... 97
Table 12 St. Gallen Budget Distribution ................................................................... 98
Table 13 Webcam Specifications ............................................................................... 196
Table 14 Micro Servo product specifications ............................................................ 199
Table 15 All block layouts dimensions .................................................................. 203
Glossary

- **API**: Application Programming Interface specifies how some software components should interact with each other

- **Arduino**: The name of the micro-processing board as well as the associated programming environment that allows for integrated and simplified implementation of electronic circuits

- **Benchmarking**: Exploring current technology and processes relevant to current project

- **Bio-Specimen**: Bodily fluid intended for testing

- **Blood Chemistry**: The testing of blood samples, this includes typing and infection testing

- **Blood Donor**: A person who donates blood at a blood center or a blood drive

- **Blood Transfusion**: Process of infusing foreign blood cells into a person intravenously

- **Blood Typing**: Process of determining the blood group of a sample

- **Breakdown**: Sudden loss of ability to function efficiently

- **CEP**: Critical Experience Prototype, simulates a critical experience to gain insights

- **CFP**: Critical Function Prototype, Tests a single critical function of the design

- **Dark Horse**: A prototype that is unlikely to succeed but may provide insights

- **EXPE**: An event held at Stanford in June in which all teams display their final project

- **FOV**: field of view

- **Functional Prototype**: A prototype that approximates a complete system. It is more refined than a FUNKtional prototype and gives an idea of what the EXPE final product will be
• **FUNKtional Prototype (FUNKY):** A prototype for which existing parts have been hacked and brought together in a manner that approximates a system without making a costly commitment to any one configuration, technology, or geometry

• **Gadget:** A specialized mechanical or electronic device

• **GUI:** Graphical User Interface

• **HIS:** Hospital Information System

• **Lab Scientists:** The people who operate bio-specimen testing machines in the lab

• **Leap Motion:** A device that transforms hand motions into control inputs

• **LIS:** Laboratory Information System

• **Loft:** Stanford classroom and design space designated for this course where prototypes are built and weekly SUDS occurs

• **The Machine:** The device that does automated bio-specimen testing

• **Needfinding:** Determining the needs of the potential user

• **Part X:** One non-trivial part of the final design to be completed in its final form at the beginning of Spring Quarter

• **POTC:** Point Of Care Testing

• **Patient:** An individual in the hospital who may need blood draws for blood typing or transfusion

• **Phlebotomist:** The person who draws blood from the patient

• **POCT:** Point Of Care Testing

• **QC Run:** Quality Control Run, similar to a calibration, QC makes sure everything is running smoothly before running an official sample
- **QR Code**: Two dimensional barcode system

- **REST**: Representational state transfer (REST) is a software architectural style consisting of a coordinated set of architectural constraints applied to components, connectors, and data elements, within a distributed hypermedia system

- **RFID**: Radio Frequency Identifier. Wireless non-contact identification system

- **SUDS**: Stanford class dinner sponsored by a different team each week

- **Walk-Away**: The ability of a lab scientist to leave an automated machine and work on some other processes

- **Wizard of Oz**: Testing that is not completely autonomous, i.e. voice activation feature where a hidden person hears the input and clicks the appropriate input
1 Context

1.1 Need Statement

The Graphical User Interface is the single most important tool that helps you control a gadget smoothly and seamlessly. In recent years, there has been tremendous progress in the development of GUIs, particularly for smart phones. A good GUI must be clear, concise, responsive, consistent, attractive, efficient, and most important of all, forgiving. Although these features are prominent in most of the gadgets that we use in our daily lives, there are still machines that have a lot of room for improvement, particularly those that are not used by the general population.

One such field is bio-specimen testing. The current GUI of most of the machines used for bio-specimen testing is extremely difficult for lab scientists to operate. They require special training to get familiarized with the interface before being able to operate the machine. Even after that the GUI is extremely difficult to navigate and they have multiple problems such as freezing of interface, functionality issues with icons, and breakdown of machine. Figure 4 shows the interface of the Olympus PK 7300 blood typing machine. As you can see in the figure, the icons are small, making it hard to navigate from screen to screen, and it is also very difficult for a new user to understand the meanings of different functions.

This is just one of the issues in this field. These machines encounter many breakdowns. During that time, important work is stalled. Hence, there is a need for an enhanced and efficient customer support system that can guide the lab scientists operating the machines in case of any functionality loss and help them recover from breakdown faster. The seamless integration of the GUI with this customer support system would aim to make the lives of these scientists easier. Apart from the problem of frequent breakdowns, the lab scientists have to work on multiple machines in the lab and hence they have to go back and forth to each machine to ensure that everything is running smoothly. This is not an ideal situation for someone working in this environment. Hence, we needed to create a device that scientists can carry with them and use to control all of the machines in the lab from anywhere.

Keeping these points in mind, our aim is to address these issues that are currently being ignored in this environment, to make the work of lab scientists more efficient and easier.
1.2 Problem Statement

The challenge lies in creating a bio-specimen testing platform that enables communication between relevant processes and stakeholders and is easily usable within the lab environment. The technology developed for this purpose should be able to reduce human related errors, enhance customer support, and establish “walk-away” capability. It should also assist the user in case of any severe issues, such as machine failure, and be able to guide them through the process.

The notion being, “for Merck to break into the already-established field of bio-specimen testing solutions, they will need to develop new elements that will better address the needs of their users.”
1.3 Corporate partner: Merck KGaA/EMD Millipore

The corporate partner for this project is EMD Millipore, which is a division of Merck KGaA. The name Merck KGaA is used in all countries except for the United States and Canada where it is referred to as EMD Millipore. EMD Millipore is headquartered in Billerica, Massachusetts while Merck KGaA's world headquarters is located in Darmstadt, Germany. EMD provides products and services based in the life science industry. Originating in 1668, EMD is the world's oldest pharmaceutical and chemical company. Today, EMD Millipore offers more than 40,000 products. The design team is working mainly with the Temecula, California location.

![Figure 5 EMD Logo](image)

1.3.1 Corporate Liaisons

**Mahmoud Zubaidi**  
Research Scientist  
EMD Millipore, Temecula, CA  
Contact: mahmoud.zubaidi@merckgroup.com

**Jagat Adhiya**  
Information Manager R&D  
EMD Millipore, Billerica, MA  
Contact: jagat.adhiya@emdmillipore.com

1.3.2 Corporate Canvas

To better understand EMD Millipore as a company, the team created the corporate canvas shown in Table 1. This is the team's interpretation of how EMD Millipore operates. This exercise forced us to expand our thinking beyond what is important for the user and look at how Merck can profit off of this system. We learned that there is an interweaving web between all of these factors. We also revealed some surprising insights such as the importance of FDA compliance in production costs. Probably the most interesting element is in the "Channels" section. This is very
important as Merck is trying to establish their reputation in this field. Communication between potential buyers will ultimately determine their success assuming they present a quality product.

Table 1 Corporate Business Model Canvas

<table>
<thead>
<tr>
<th>Key Partners</th>
<th>Key Activities</th>
<th>Key Resources</th>
<th>Value Proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Companies</td>
<td>Testing Devices</td>
<td>Research and Development</td>
<td>Technical Support &amp; Training</td>
</tr>
<tr>
<td>Raw material Suppliers</td>
<td>Pharmaceuticals</td>
<td>Project Management</td>
<td>Reliability, Efficiency</td>
</tr>
<tr>
<td>Production Line</td>
<td></td>
<td>Brand</td>
<td>Safety and Health</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brand</td>
</tr>
<tr>
<td>Channels</td>
<td>Customer Segments</td>
<td>Revenue Streams</td>
<td>Customer Relationship</td>
</tr>
<tr>
<td>Pharmacies</td>
<td>Patients</td>
<td>Software Companies</td>
<td>Technical Support &amp; Training</td>
</tr>
<tr>
<td>Trade Shows</td>
<td>Lab Scientists, Nurses, Doctors</td>
<td>Raw material Suppliers</td>
<td>Value</td>
</tr>
<tr>
<td>Advertising</td>
<td>Hospital Management</td>
<td>Production Line</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insurance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Companies, FDA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.4 The Design Team
Team EMD Merck consists of four members from the Mechanical Engineering Department of Stanford University, three members from St. Gallen University, a top business school in Switzerland, and one member from the University of Zurich. The team is diverse in academic backgrounds, personal interests, thinking preferences and cultural backgrounds.
Harshit Jain

Status: 1st Year M.E. Graduate Student
Contact: jharshit@stanford.edu
Skills: MATLAB, Coding, Design, Technical Writing, CAD

I grew up in the small town of Bhilwara in Rajasthan, India. I completed my undergraduate from Indian Institute of Technology, Delhi one of the premier institutes of engineering in India. Academically, I have interests in Design, Modeling and Simulation and have done a lot of projects in this field. Apart from that, I love sports. I am a Field Hockey player and used to play for my College team back in India. I love watching Tennis, F1, and, am a big fan of Real Madrid Football Club.

Wanxi Liu

Status: 1st Year M.E. Graduate Student
Contact: wanxi@stanford.edu
Skills: Programming - C++, Python, MATLAB, Arduino and other embedded system Mechatronics, Soldering, Piano and accordion

I was born in a small city in South China. Then I went to Hangzhou where I spent four years for undergraduate study in Optical Engineering. I have a passion in smart product design and implementation. I am taking ME310 because it enforces this enthusiasm and provides me a higher level design vision. While seeking the charm of technology and engineering, I also enjoy playing the piano and occasionally composing music.
Sean Poluha

Status: 1st Year M.E. Graduate Student
Contact: spoluha@stanford.edu
Skills: CAD, MATLAB, Fabricating, Video Editing, Soldering

I was born in Burlington, Ontario but spent most of my childhood in Woodbury, Minnesota. I earned my BS in Mechanical Engineering from the University of Minnesota in May 2013. I have always been interested in design and finding creative solutions to problems which is why I am taking ME310. In my spare time I enjoy playing hockey and tennis.

Yu Hsiao

Status: 2nd Year M.E. Graduate Student
Contact: yuxsjao@gmail.com
Skills: CAD, MATLAB, Prototyping, Drawing/Sketching, Soldering, Video Editing

I was born in Hsinchu Taiwan but have spent most of my life in Cupertino, California after I immigrated here as a young twelve year old in 2001. I’ve always been fascinated with things that go fast such as bikes and racing cars. I studied Mechanical Engineering in UCLA for my undergraduate studies and have continued my interest in design with ME310 at Stanford. I spend my spare time racing professional triathlons and playing/composing music.
Joscha Held

Status: 2nd year Master of Arts in Business Innovation
University of St. Gallen
Contact: joscha.held@student.unisg.ch

I was born in Würzburg, Germany, where I spent most of the time in my live before moving to St. Gallen for studying. In 2004/2005 I lived in Saudi Arabia for one year together with my family. After graduating from school in Germany I did nine month of mandatory civil service. I graduated as Bachelor of Arts in Economics from University of St. Gallen in April 2013 and spend one semester abroad at Singapore Management University in fall 2011. Currently I am doing my Masters in Business Innovation also at the University of St. Gallen. During a 6 month internship in a mid-size consulting company I gained several valuable experiences for my professional career. Since May 2013 I am part-time working as a consultant for a mid-size company in the construction business. I am passionate about technology in general and a big fan of LEGO Technics. When I am not studying or working I love traveling, spending time with my friends and doing sports like scuba diving or skiing.

Will Kölbener

Status: 1st year Master of Arts in Business Innovation
University of St. Gallen
Contact: will.koelbener@student.unisg.ch

I was born in Johannesburg, South Africa, where I spent the first nine years of my live. After completing my High School in Switzerland I did ten month of mandatory military service. Thereafter I spend nine month in Zambia, Africa on different humanitarian projects. I’ve been revisiting Zambia several times since then. I did my Bachelors of Arts in Business Administration and Business Education in St. Gallen, where I’m currently earning my Master of Arts in Business Innovation. I’m interested in all kinds of technologies and innovations that change our daily lives. In my spare time I love meeting friends, doing sports and working on projects I run with some friends in Zambia, Africa.
Carina Them

Status: 2nd year Master of Science in Business Innovation
University of St. Gallen
Contact: carina.them@student.unisg.ch

I was born in Vienna, Austria. I started my university career in 2009 at the Vienna University for Economics and Business. I did my majors in Finance and Entrepreneurship and Innovation. Besides studying I have gained significant working experience. I have worked part-time for one year at the second largest Bank in Austria, did internships at an Asset Management company in Zurich, in a small funds firm in Vienna, at a global industrial company in Munich, for 4 month and at the biggest media group in Austria for M&A. After focusing on the financial industry, I am now concentrating on the innovation field. I wrote my bachelor thesis in this topic and currently doing my master at the University of St. Gallen, Switzerland, in Business Innovation. In my spare time I love to practice sports, as playing tennis, go skiing and running.

Alexander Mulli

Status: 1st year Master in Business Information Systems
University of Zurich
Contact: alexander.muelli@uzh.ch

I was born in a small town near Zürich, Switzerland. After high school I lived for half a year in Brighton, GB. After initially starting to study Economics in St. Gallen I changed to Business Informatics in Zurich. Graduating my Bachelors in Business Informatics I continued with my Masters at the University of Zurich. Besides my studies I’m also involved in the student association. I recently took up sailing on lake Zurich.
1.5 Stanford Team Coaches and Teaching Team

Scott Steber  Stanford Coach  scott@radicandlabs.com
Jeremy Dabrowiak  Stanford Coach  jdabrowiak@gmail.com
Larry Liefer  Stanford Professor  leifer@cdr.stanford.edu
Mark Cutkosky  Stanford Professor  cutkosky@stanford.edu
George Toye  Stanford Professor  toye@stanford.edu
Daniel Levick  Stanford Teaching Assistant  dlevick@stanford.edu
Stephanie Tomasetta  Stanford Teaching Assistant  sltomase@stanford.edu
Aditya Rao  Stanford Teaching Assistant  adirao@stanford.edu
2 Design Requirements

The bio-sample testing lab is a very demanding environment that is high stress, fast pace, and time dependent. The scientists and lab technicians depend highly on the bio-sample analyzer machines to be reliable and run smoothly without faults. In addition to reliability, blood sample analyzer machines shall be smart and conform to the needs for the scientists and lab technicians in order for them to have a pleasant working experience where maximum possible amount of unnecessary hassle and stress are removed.

This is where the bio-sample testing platform comes into play. Though Merck/EMD manufactures high quality products with great reliability, unforeseen faults and errors may still occur. In order to make the customer experience robust, the customer support must be robust. The purpose of the integrated customer support solution is to provide a platform for the user to troubleshoot with ease. There is an option of self-fixing as well as additional communication with customer support agents in order to resolve an issue with minimum downtime and confusion.

The second purpose of the platform is to conform and adapt to how users interact with machines as part of their daily routine. The solution of portable devices enables walk-away, where users are able to control and monitor the machine from afar within the lab. In this way the lab technicians are not forced to stay in the proximity of the machine to perform tasks.

Identifying the design requirements is crucial for obtaining the desired results. The design requirements can be broken down into two categories:

- **Functional**: Describes the practical aspects of the design
- **Physical**: Details design’s size, shape, configuration, materials, etc.

The following section outlines the details of the functional and physical requirements that were taken into consideration while developing prototypes.
2.1 Functional Requirements

2.1.1 Portability

The machine will integrate a user interface system that allows the user to walk away from the machine and monitor it remotely. While being away from the machine, the user is able to check the status of samples and the machine.

The walk-away device should also be easy to use in many situations. The device must be able to stand on its own while still being handheld, so that it is easily accessible for the user. The requirements are further defined in Table 2.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Metrics</th>
<th>Rationale</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk-away Capable: The user is able to walk away from the machine and monitor the machine.</td>
<td>The user can monitor the interface with a portable device at least 50 feet away. The user can stay away for up to the duration of the test.</td>
<td>The target users have to work on multiple machines in a lab. Keeping up to date with the machine without excess movement is important as it may cost valuable time or induce injury from collisions.</td>
<td>A walk-away tablet and smart watch is Wi-Fi enabled to communicate with main PC interface at the machine. A remote desktop app is used to communicate.</td>
</tr>
<tr>
<td>Adaptability: The walk-away device shall have multiple physical configurations for ease of use for the user.</td>
<td>The device can adapt to at least 3 different configurations such as handheld, propped up on stand, and laid flat.</td>
<td>If the user would like to hold the device, it shall be comfortable to hold. If the user would like to set it on the table, it shall be set securely on the table and easily accessed.</td>
<td>The walk-away tablet can be configured in 3 configurations, handheld, laid flat, and propped on stand. The tablet is integrated in a clipboard for ease of use.</td>
</tr>
<tr>
<td>Transparent User Interface: The user is able to navigate to any desired screen from the home page within 30 seconds. The user shall</td>
<td>The user must be able to navigate to any desired screen from the home page within 30 seconds. The user shall</td>
<td>It’s important to make interface user friendly and minimize learning time.</td>
<td>The user interface has customized icons for each functional button that is easily understandable. The</td>
</tr>
</tbody>
</table>
2.1.2 Customer Support Visualization

The machine will have multiple surveillance cameras mounted to the inside of the frame monitoring critical areas of potential faults. The cameras can be remotely accessed by a customer support technician in case troubleshooting is necessary.

In addition, the user will be equipped with a moving camera that provides the customer support agent with an additional viewing angle into the machine. This device is designed to enhance communication between the user and customer support.

Lastly, visualization tools will be available at the user’s disposal. Troubleshooting videos will be made using 3D CAD models to illustrate clear, step-by-step procedures to fix errors. The requirements are further defined in Table 3.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Metrics</th>
<th>Rationale</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Machine</td>
<td>The customer support agent can view all key areas using fixed cameras</td>
<td>When there is an error, the customer support agent should have as much access to the machine as possible (visuals, software, control) for diagnostics. Having camera surveillance will help to pinpoint the issue.</td>
<td>There are 3 IP cameras: 2 fixed and 1 movable that can monitor the entire space within machine.</td>
</tr>
<tr>
<td>Surveillance</td>
<td>where potential fault might occur.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Surveillance:</td>
<td>The customer support agent is able to instruct the user to point a movable camera to any location in the machine.</td>
<td>The communication between customer support and the user is oftentimes a mere phone conversation. It can be enhanced by having a</td>
<td>There are 3 cameras: 2 fixed and 1 movable that stream the video to the customer support technician and the technician can access it</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
occur. moving camera to bring the customer support technician closer to the problem. and diagnose a particular problem.

| Troubleshooting Visualization Guide: The user is able to perform basic self-fixes to troubleshoot problems. | The user is able to perform standard troubleshooting steps solely with the visualization software provided by customer support without further assistance. The amount of time required shall be at least 50% faster than conventional text instructions from user manuals. | We have found that lab technicians and scientists are willing to fix the machine themselves to prevent downtime. Visualization tools using 3D CAD model will enable clear step-by-step procedures. | 3D CAD videos are developed with step-by-step instructions on how to fix a problem. The videos give the user complete spatial awareness of all components in the machine to fix problems. |
| LED locator: The customer support technician is able to point the user to where the problem is located. | The customer support technician is able to locate and point the user to the problem by turning on LED lights at a particular location where there is an error. | Provides a tool for the customer support technician in addition to a surveillance monitoring system (cameras). The communication between user and customer support technician is therefore improved. | LED lights are installed at strategic locations and controlled by an Arduino, which communicates with the interface waiting for commands from the customer support technician screen for input. |

2.1.3 Functional Constraints

- HIPPA is enforced in all major hospitals in order to provide protection of patient health information. The walk-away device and customer support visualization tools shall be secure to prevent any breach of patient health information.
- The battery life of the walk-away device must be sufficient to last through one whole shift of at least 10 hours without charging.
Wireless communication will rely on 2.4GHz 802.11b WIFI standards.

2.1.4 Functional Assumptions

- All the changes in the machine system such as walk-away, cameras, customer support, etc. are in compliance with FDA regulations for bio-specimen testing.
- The user has knowledge of bio-specimen testing and is familiar with the terminology used in this area.
- The user is accustomed to using common computer input devices such as mouse and keyboard as well as operating a touch screen.
- The users of these machines are qualified and trained personnel in bio-sample testing field with certification.

2.1.5 Functional Opportunities

- The single walk-away device can be used to control multiple machines in the lab.
- The additional walk-away device can be a wearable to provide monitoring and simple control capabilities.
- The main walk-away device can be charged while propped on a stand.
- The customer support system can use 3D visualization videos to show the users how to fix common errors by themselves.
- Additional customizability can be added to the interface to make it more intuitive and easy to learn. The interface can be customized personally for each user’s needs.
- The 3D CAD models can be manipulated by the user in order to change perspective of the space for individual users to recognize the components easier.

2.2 Physical Requirements

The main physical requirements concern the dimensions of the walk-away device, location and number of cameras to be used for customer support, dimensions of the machine, and clarity of the interface. Table 4 elaborates these requirements in details.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Metrics</th>
<th>Rationale</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension of Walk-away device</td>
<td>Walk-away device must lay flat within a 1</td>
<td>The device should be small enough so that it</td>
<td>The Nexus 10 tablet is 0.865 x 0.583 and it</td>
</tr>
<tr>
<td><strong>Transparent Interface: Fonts and icons shall be readable at a distance.</strong></td>
<td>foot by 1 foot square and weigh less than 2 pounds.</td>
<td>can be considered handheld and large enough so that all the relevant information is clearly visible.</td>
<td>weighs 1.3 pounds. It is very minimal in size and weight and is compatible with a lab scientist’s daily routine.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Location/Number of Cameras and camera coverage.</strong></td>
<td>Every font and every icon on the interface shall be easily read by anyone holding the tablet an arm’s length (20 inches) to 35 inches away.</td>
<td>The GUI must be easily readable for the user. The information must be conveyed effectively using necessary colors, sizes, and sounds in order for the user to work more efficiently.</td>
<td>The icons and font size are large and clear. The main interface display is 21.5 inch in size. The tablet has a 10 inch screen for easy readability.</td>
</tr>
<tr>
<td><strong>Movable Camera</strong></td>
<td>Cameras must be oriented so that any mechanical component can be viewed.</td>
<td>The location and number of cameras inside the machine must be strategically placed in order for customer support to pinpoint faults in case of a breakdown.</td>
<td>2 fixed cameras are placed in the machine that monitors the whole range of the machine (adjustable). The movable camera is handheld and wireless.</td>
</tr>
<tr>
<td><strong>External power source</strong></td>
<td>The movable camera’s range shall be able to reach every space in the 24’x44’x22’ space in the mock up bio sample analyzer.</td>
<td>The movable camera has to cover all areas in the machine space in order to provide proper troubleshooting and communication visuals between the user and the customer support technician.</td>
<td>The movable camera is wireless and communicates via Wi-Fi with unified modem. It can reach anywhere within the Wi-Fi range which is covers more than the machine space.</td>
</tr>
<tr>
<td><strong>Footprint and Weight</strong></td>
<td>The overall system shall be able to be powered by an AC-DC converter from typical 120V American</td>
<td>The device shall be usable in most laboratories with wall plug in US as well as Europe.</td>
<td>The machine is powered by an AC-DC power source (12V, 5A) that powers all internal electronic components.</td>
</tr>
<tr>
<td>Standalone</td>
<td>Standards as well as European standards (230V).</td>
<td>components and machinery.</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------</td>
<td></td>
</tr>
<tr>
<td>Internal power source</td>
<td>Overall internal subsystems, cameras and sensors shall be powered by an internal voltage regulator with necessary power (12V or 5V with proper supply of current up to 2A)</td>
<td>The sub-systems shall be provided proper power in order for proper operation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>From the main power supply, power is distributed by using voltage regulator (12V and 5V up to 2A for 12V sources and 1A for 5V sources).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2.1 **Physical Constraints**

- The bio-specimen testing functionality cannot be altered.
- All new customer support elements must fit within the footprint of the pre-existing machine.

2.2.2 **Physical Assumptions**

- The user should be able to repair the machine through guidance from customer support.

2.2.3 **Physical Opportunities**

- The location of cameras can be such that a minimum number of cameras provide access to all the components of the machine.
- Currently, remote desktop software is being used to control the machine through the walk-away device. A device dedicated to just this feature could be developed for better performance.
3 Design Development

Our team’s design process involved a continuous evolution of the understanding of the problem and persistent refinement of our approach to find a solution for the design challenge. Each stage in the design process provided valuable insights that guided subsequent decisions and steered the direction of the project’s development.

3.1 Fall Quarter Overview

Most of our time during Fall Quarter was spent gathering information through benchmarking and needfinding to better understand our design space. Since our understanding of the scope of the project has evolved, not all of the information that we gathered is still relevant. The main insights that have continued to drive our design vision are summarized in the following sections. The rest of the information is provided in Appendix A. Out of all the Critical Function Prototypes that were built in the Fall, three in particular are early concepts of ideas that we are still using at this point of the project. While the physical products that we developed will not be used, they provided a foundation for our work going forward. Finally, we will review how our work from Fall Quarter is still relevant at this point of the project.

3.1.1 Benchmarking

Our Fall benchmarking was focused on two main ideas: machine interfaces and Merck’s competition. As the project has evolved, we have expanded the scope beyond that of just developing a Graphical User Interface, therefore interface benchmarking has been omitted from this section and can be found in Appendix A.

From researching our competition, we determined that Immucor and DIAGAST are the two companies with platforms most similar to what Merck would like us to produce. Immucor has the Galileo, Echo, and NEO line of products. Each model is an evolution of the previous model. DIAGAST has a line of devices under the name QWALYS (as shown in Figure 6).

Both companies are established in this particular field with models evolving over the last 15 years. All devices have similar look and layout featuring large testing machine with a separate computer screen. While advertising focuses on being the fastest, most intuitive and most reliable device, only the recent machines feature advertising focused on the interface. Touch screen interfaces with the ability to schedule when samples are read is the new standard. From this
research, we concluded that just claiming a new device to be faster, more reliable, and more intuitive than the competition does not set anyone apart. We concluded that for Merck to establish a new platform in this field, they will need to bring innovative elements that have not been seen before in this industry.

![Image](image.png)

*Figure 6 Immucor Neo (left) and DIAGAST QWALYS (right)*

### 3.1.2 Needfinding

Our needfinding from Fall Quarter consisted of six interviews. We talked with a nurse, the Stanford Hospital Transfusion Service Manager, the Stanford Blood Center Manager, Lab Technician, and Donation Manager, and finally a hospital patient. Our main insights and conclusions are summarized below.

- In the bio-sample process, mislabeling samples can be potentially fatal. The high-paced hospital environment increases the probability of these errors occurring.
- New devices require integration with the hospital's information system.
- Fully integrating a new system in a lab can take up to five years. Therefore, labs tend to stay with the same company when purchasing new machines.
- Managers tend to buy from companies that are already established in the field. New companies tend to get their start in research labs.
- Smaller labs are more concerned with customer support as opposed to capacity and scheduling ability. If a lab only has a few machines, downtime is incredibly costly.
- Lab technicians and scientists do not want to be replaced; they just want their jobs to be more efficient.
3.1.3 Prototyping

The three prototypes from Fall Quarter that helped to influence our current design were the walk-away watch and glasses, RoboDog, and the portable RFID test tube labeler. The walk-away system developed by Stanford consisted of three parts. The first was a wristwatch that notified the user of a completed test or an error in the machine using LEDs and a vibrating motor. A green light would mean that the sample was complete, and a red light would indicate an error. The second element was inspired by Google Glass. We basically used the same LEDs and vibrating motor and attached them to a pair of glasses. The prototypes are shown in Figure 7 and Figure 8. The final component of the prototype utilized Leap Motion technology to control a virtual reality machine provided as a marketing tool by DIAGAST for their QWALYS 3. The Leap Motion device was attached to the wrist not containing the wristwatch. The idea of the entire system is that once you are notified of an error, you can access a computer screen anywhere in the lab which allows you to look into the machine and address the issue. By using the Leap Motion, we were able to navigate through the DIAGAST model using hand gestures without needing a mouse or surface, as shown in Figure 9.

![Wristwatch Critical Function Prototype](image)

*Figure 7 Wristwatch Critical Function Prototype*

Our main findings from testing were that vibration and lights attached directly to the user are very effective for gaining their attention, but did not provide adequate information to make the user aware of the specific issue. This meant that the user would have to utilize the virtual
machine to find the issue himself. The Leap Motion technology took some getting used to and is probably not developed well enough to be useful in this application at this time.

![Figure 8 Glasses Critical Function Prototype](image)

*Figure 8 Glasses Critical Function Prototype*

The second Critical Function Prototype was the RoboDog created by St. Gallen. The prototype built off of the walk-away concept to keep the user constantly aware of the current status of the

![Figure 9 Using Leap Motion to Interact with the Machine](image)

*Figure 9 Using Leap Motion to Interact with the Machine*
machine. This prototype consists of a screen that follows the user while working on other tasks. It utilizes an adjustable screen that can be moved to any orientation depending upon the needs of the user. Figure 10 shows the prototype with its adjustable screen. A modification to this is a screen that has a built-in motion sensor that automatically adjusts to the user position and displays the most relevant information. The machine can switch itself to screensaver mode and displays the most relevant information that is readable from further distances.

![Adjustable Screen](image)

*Figure 10 RoboDog Prototype*

The final Critical Function Prototype was a Portable RFID Test Tube Labeler from Stanford. Since mislabeling of samples is the most common source of error in the bio-sample process, we developed a system that would perform the labeling automatically while the patient was getting blood drawn. The device linked the information of the pre-labeled test tube to an RFID number on the patient’s wristband while the sample was being taken. Figure 11 shows the device in action.

We found this system to be easy to setup and use. The main concern with the design was potential misreading the RFID or the wrong patient data on the RFID.
3.1.4 Design Framework for Winter Quarter

The work done in Fall Quarter gave us a foundation to build from for Winter Quarter and our EXPE product. Two of our main themes from our solution, walk-away capability and transfer of information, relate directly to our three Critical Function Prototypes. While not all of the information that we gathered though needfinding was within our current vision, it gave us some key insights into what unmet user needs could be addressed to set Merck apart from the competition. Most importantly, it developed working relationships with potential users. Our collaboration with the Stanford Hospital Transfusion Service has proven to be critical in developing our EXPE prototype and overall design vision.

3.2 Winter Quarter Needfinding

During Fall Quarter, most of our insights were gained through research. As we moved to Winter Quarter, we shifted to gaining insights by building prototypes. Still, there was some needfinding performed in Winter Quarter. The focus shifted from gathering new information to confirming our assumptions and proposing our ideas to potential users for feedback.

All of our needfinding Winter Quarter was with the Stanford Hospital Transfusion Service. We established contact with them from our Fall interview with the lab’s manager. We tried to
establish a lab tour during that interview, but ran into issues filing HIPAA paperwork as we would be exposed to patient data. We were finally able to get into the lab mid-Winter Quarter. We made multiple visits to the lab over the course of the Quarter. These were set up by the Education Coordinator for the lab. She was able to answer some of our logistics questions as well as put us in contact with lab workers. The first thing that we learned is that Lab Technicians do not work with the machines in the Transfusion Service; this work is done by Lab Scientists. This has essentially changed how we labeled our user.

During one of our visits, we witnessed the lab’s new Immucor Neo machine experience a technical difficulty resulting in the lab needing to contact customer support. We learned that the process begins with the Scientist calling Immucor using a lab phone. The Scientist is then given a password to enter into the machine’s interface which allows customer support to control the machine. The customer support agent cannot view the machine, so if there is a mechanical issue the Scientist needs to take a picture and email it to support. Another issue arises when the interface freezes, as the password to grant control to customer support cannot be entered.

While viewing the NEO in operation we noticed the Scientist responsible for the sample was running from her workstation across the lab to the machine every five minutes or so to check on the status. Later we learned that a lab worker had recently recovered from an injury that was caused by running from her workstation to the machine. While being shown the machine, the Scientist also noted that it “is definitely not a walk-away machine.” This would usually not be an issue, as ideally someone should be assigned to that machine at all times, but the lab is often short-staffed so this is not always the case.

Finally, we asked about the Graphical User Interface. While there were not many specific complaints, we did notice that the font on certain parts of the screen was incredibly small and hard to read. The main complaint came from a feature on the ECHO model that has been resolved in NEO’s interface. Each patient’s data is summarized in a pop-up window at the end of the test. If the machine is not monitored, these windows cascade and pile up which can slow down the system and eventually freeze the computer. This results in lost test data and samples needing to be retested.

These issues were the driving force for our FUNKtional and Functional Prototypes, which will be discussed later. Our Dark Horse, by definition, took a different direction.
3.3 Winter Prototypes

3.3.1 Stanford Dark Horse Prototype

For the dark horse prototype, we were encouraged to explore the edges of the design space to push the limits and gain potential insights and probable hints of the final vision. We had dealt heavily with the problems with bio-testing Fall Quarter. We thought it would be a good change to explore the area of blood drawing and blood taking. This was an exciting direction as it allowed us to change our user since anyone could need to have blood drawn. The goal was to create a blood drawing experience that was pleasant and enjoyable, opening possibility for more people to donate blood and be comfortable with it in the future. In addition, we saw a possibility for this system to be available in very accessible locations such as Starbucks, local drug stores, etc. This, in theory, would make the experience more casual and comfortable. Figure 12 shows the final version of the prototype that was used for testing.

During the whole experience and testing, we made the assumption that the blood drawing would be done completely automatically with a robotic arm and that everything would be approved by the FDA for operation.

3.3.1.1 Questions Addressed

We aimed to answer the following questions with our prototype and user testing:

- What will motivate people to give blood more regularly or at all?
- What will enable people that are afraid of needles or the idea of giving blood to be more comfortable with the donating process?
- Are there distinct trends of people who fear needles and those who do not? What environment would they most prefer and can we create these environments on a customized basis?
- Will people be comfortable with the idea of a “robotic phlebotomist,” knowing that it would be more accurate than a human?

3.3.1.2 Concept: The Key Idea

The concept was analogous to that of a photo booth, where a user can enter a comfortable and private space that allows them to enjoy entertain systems (YouTube, Facebook, email, etc.) and give blood quickly. The assumption is made that the booth will also carry out blood testing if necessary and results will be shown 10-15 min after the test is complete. During waiting, the user may enjoy the entertainment systems provided. The intended goal was for the entertainment system to distract the user and put them at ease while having their blood drawn.
The blood drawing process involves a visually comforting screen which hides the reality of the machine phlebotomist (hiding the needle from users who do not want to witness the process) and provides an option for the user to either monitor the process live or avoid it with a still image of their arm which is taken by a webcam on the other side of the screen. This is shown in Figure 13 below where the screen is on the blue wall. The user will stick their arm through a slot in the blue wall for the needle insertion.

The procedure started with a user who is assumed to be pre-registered entering the booth. Preregistration allowed the current user to instantly be able to access their personal YouTube, Facebook, and email accounts. The user then chooses the option of avoiding the insertion of the needle via still image (and the opposite) as well as avoiding the sight blood drawing (live feed or still image). After these selections are inputted (verbally), the blood drawing process commences. The system is voice activated which makes the process smooth and seamless. During this process, the user has the luxury of checking personal. The complete process flow is shown on the Figure 14 flow chart.
Figure 13 Initial version of the Dark Hose Prototype

Figure 14 Flow Chart showing the whole testing process
3.3.1.3 Prototype Details

The prototype consisted of four components: a wall, two monitors, and automatic guidance software for navigation as shown in Figure 15. The frame of the wall was constructed with PVC pipes and the wall was made out of cardboard with blue cloth added for visual comfort.

Each monitor was run by a laptop. The front screen displayed options while the side screen showed either the still or live view of the blood drawing. The automatic software was made using PowerPoint with tabs of options and operated via Wizard of Oz so it seemed like voice activation to simulate the experience. The various option menus are shown in Figure 16.

![Figure 15 Details of various parts of the Prototype](image)

The set up was flexible and could be set up in multiple locations for user testing to simulate the concept of having a blood drawing experience anywhere easily accessible to you.

While the user was accessing their information, the needle insertion was simulated by snapping a rubber band on their arm in a similar location to where a needle would be inserted. This was meant to be noticeable but not cause excessive pain. We did not tell the user when the snap would occur.
3.3.1.4 Results

Through numerous tests, the following conclusions were drawn:

- Everyone has a relatively predictable profile based on their personality or preferred activities.
- There are a lot of different preference types.
- Even if they didn’t want to see the process, users wanted to know what would occur beforehand.
- Eye contact was with front screen occurred approximately 90% of time (as opposed to the side screen where their arm way placed).
- Distraction from “needle” was quick, attention returned to front screen almost immediately.

Overall, we found that most people were either very excited about the concept that blood drawing could be more accessible or completely uncomfortable with the idea of having an automatic phlebotomist machine insert a needle into their arm. We also found that there is not a huge motivation factor to encourage people to donate more blood. This experience did not have the “wow factor” that we were looking for. Though this prototype did not lead us closer to a final
direction, it taught the team a lot about user-centric design and putting oneself in the shoes of the user so that the design can come out of that frame of mind instead of engineering the structure or implementation alone.

3.3.2 St. Gallen Dark Horse Prototypes

St. Gallen created many prototypes for this assignment. These are mainly concepts that were not fully built, but acted as concepts to present to users for feedback. Some of the main concepts are summarized below:

- Blood Insurance: Getting rid of blood banks and having correct blood delivered when needed
- Artificial Blood: Produce O- blood that is compatible with everyone eliminating blood testing
- Internal Lab Pill: A pill that constantly monitors your blood
- Decentralized Testing Device: Bring the blood typing device directly to the ward
- Electronic Patient File: Uniform database of patient data over the course of their lifetime
- Disposable Tester: A one-sample disposable blood testing device
- Autonomous Distribution System: Drones deliver blood to the necessary location

3.3.3 Stanford FUNKtional Prototype

A FUNKtional Prototype is a prototype for which existing parts have been hacked and brought together in a manner that approximates a system without making a costly commitment to any one configuration, technology, or geometry.

After completing our Dark Horse Prototype, the Stanford team decided to take a path that was closer to the initial design challenge that Merck had proposed. From our needfinding, we determined that one of the main issues with current devices in the market was customer support.

To better understand the problem, we developed a system diagram that tracked how communication is conducted between all relevant stakeholders (Figure 17).

The amount of communication and connections was daunting. Therefore, we decided to focus our efforts directly on the communication between the customer support agent and the lab scientist. Currently, this is done through phone calls and customer support taking control of the interface of the machine. We wanted to look at how we can optimize this communication to reduce downtime of the machine.
3.3.3.1 **Questions Addressed**

We aimed to answer the following questions with our prototype and user testing:

- Can we provide customer support with effective visualization of the machine space to diagnose issues?
- How can we maximize communication between customer support and the lab scientist?
- Can all of the communication be performed though the machine?

![Diagram](Image)

*Figure 17 Customer Support System Diagram*

3.3.3.2 **Concept and Design**

With our questions in mind, we decided to develop a moving camera system that would allow the customer support agent to view the precise area of the machine that they wanted to see. We also wanted to make sure that both the scientist and customer support agent were looking at the same point, so we decided that lasers could be used to pinpoint certain areas and enhance communication. Our final design is shown in Figure 18.

The design consists of two RC cars on rails to allow both “X” and “Y” motion within the workspace. Figure 19 and Figure 20 shows the RC car in two possible positions in the workspace. One RC car is attached to a rail on the frame, while the other one is on a rail that spans the width of the machine. The cars were controlled by separate RC controllers operated by
the customer support agent. A webcam was attached to the bottom of the RC car that spanned the width of the workspace. We also created a laser system for pinpointing problem areas. This was built by attaching a laser to two servo motors that allowed for linear and angular motion within the machine space. This was fixed to the frame to act as the origin (Figure 21).

![Overall View of the FUNKtional Prototype](image)

*Figure 18 Overall View of the FUNKtional Prototype*
Figure 19 RC car in maximum “Y” position

Figure 20 RC car in minimum “Y” position
3.3.3.3 Testing

For testing we developed a scenario with a user and a customer support agent. The user stood in front of the workspace where six different colored blocks were placed. The customer support agent sat facing away from the machine and could only see the workspace through the webcam. We gave the customer support agent a sheet with a scale model of how we wanted the blocks to be arranged in the workspace (Figure 22). The goal was for customer support to guide the user to set up the block in the same orientation as they appeared on their given sheet. Since the sheet was to scale, we could measure success by the final (X, Y) coordinates of the actual blocks compared to where they should be placed. We also timed each trial to provide a second metric. A comparison from the sheet to the final result is shown in Figure 23 (compared to Figure 22).
For the first trial, the communication was purely verbal as the camera and laser were turned off. For the second trial, we allowed customer support to turn on and control the webcam. For the final run, the laser was also able to be controlled by customer support.
3.3.3.4 Results

The results from our testing were quite surprising and are summarized in Table 5. The “Time” was the amount of time from the start to when both the customer support agent and the user were satisfied with the block orientation. The “Results” were the total distances that each block was placed away from where it should have gone based on the reference sheet. Figure 24 illustrates one of the test users in action.

Table 5 Summarized Tests Results for FUNKtional Prototype

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Support</strong></td>
<td>Vocal</td>
<td>Moving Webcam</td>
<td>Moving Webcam &amp; Lasers</td>
</tr>
<tr>
<td><strong>Time (s)</strong></td>
<td>57</td>
<td>64</td>
<td>44</td>
</tr>
<tr>
<td><strong>Results (in)</strong></td>
<td>9.67</td>
<td>8.03</td>
<td>10.4</td>
</tr>
</tbody>
</table>

In general, we found that utilizing more technology led to faster times. The surprising part was that the blocks were placed less accurately as more technology was introduced. This was most likely due to the participants relying on the technology. When communication was purely verbal, there was an excellent sense of teamwork and communication was back-and-forth. Once the webcams were turned on, the only communication was instruction from customer support of when to place the block in the middle of screen. When the laser was added, the blocks were placed exactly where the laser was pointed with no verbal confirmation of the accuracy.

The system that we established only allowed the customer support agent to see a small portion of the machine at one time, therefore they we only guessing where they were looking at within the machine. Since there was nothing else located in the workspace besides the blocks, there was nothing to reference other than the walls. We believe that providing the customer support agent...
reference points from fixed camera views of the entire space as well as items placed in the workspace will help to increase accuracy. Our main take away from this experiment was that while technology is a powerful tool, we need to make sure that it is effective enough to not provide a false sense of security.

Moving forward, we knew that we would have to establish a space to work which better represents a bio-testing machine. This would allow us to perform more relevant user testing that better mimics the actual lab environment.

3.3.4 St. Gallen FUNKtional Prototypes
The St. Gallen Team worked towards improving the Graphical User Interface for the machine and information management. During the last phases of our design process we learned a lot from our lab visits and through the different prototypes we built and tested with various users from the medical field. From our needfinding, we noticed that current user interfaces are often relatively unattractive, not very flexible, and not very intuitive. The testing devices often use state-of-the-art technology, but when it comes to the interface the devices lack behind today’s standards and expectations. Vendors seem to place far less importance on the user interface then on the device itself. However, when visiting different events and exhibitions (World Usability Day and
MEDICA) we saw that this is changing. Vendors are recognizing the importance of the interface and they see chances to differentiate themselves from competitors.

On the one hand, we see that the interface currently is not what will win users from competitors. On the other hand however, we believe that many pain points can be resolved if a good interface is built. In order to do so, the interface needs to go beyond the software that runs on the screen. The connectivity with other IT systems and the interaction between the interface, the device itself, and the user are of utmost importance.

For the second prototype we attacked the issue of information management. Talking to different stakeholders in the blood transfusion process, there was one prevailing theme: the biggest (and maybe only) source of severe errors in the blood transfusion process comes from patient misidentification. This means that the potential of making the process safer lies outside the lab. Our approach is therefore to integrate the whole patient process into a bio-specimen testing platform. The patient process mainly consists of:

- Patient identification before and while the blood sample is drawn.
- Requesting blood type testing from the lab.
- Ordering blood products for the patient.
- Collecting the blood product at the blood bank.
- Patient identification before and while the blood product is transfused.

In addition to making the transfusion process safer, the integration of the patient process also is able to increase process efficiency by improving the information flow among the stakeholders.

3.3.4.1 Questions Addressed
We aimed to answer the following questions with our prototype and user testing:

- What basic functions will we need to accomplish through our interface?
- Can we connect the interface with other IT systems and the device itself?
- Can we limit the information shown to only what is relevant at that time?
- Can we improve information flow between stakeholders to reduce errors in the process?

3.3.4.2 Concept and Design
In our first user interface prototype, we tried to address the basic functions needed. We drew mockups that were intended to include most basic functions. From there we evolved to a higher level. We started to come up with different design ideas. We decided to go for a tile solution, similar to the current interface found on Windows 8. The idea is to make a flexible user
interface. Depending on what the user finds most important, the sizes of the tiles can be adapted. The larger tiles provide a better overview for that specific aspect of the user interface. When clicking on the tile, the user is led into a deeper level of the user interface, where more details can be found. By pressing the home button, the user is led back to the main screen. Figure 25 below shows one screen of our hand drawn mockup.

![Hand Drawn Interface](image)

*Figure 25 Hand Drawn Interface*

Further we tried to think of possible solutions to increase the customer value of the interface. One idea was to improve the remote control through a visual aid for the support team. Furthermore we thought of a “Mayday button”. The idea came after benchmarking the Kindle by Amazon. The user should be able to press a button, when something is unclear and the issue cannot be solved by the user. By pressing the “Mayday button” the user is directly connected to a free support agent. *Figure 26* below shows first mockups in this direction.
A next important function we want to implement is an integrated ordering and stock management system for reagents and blood. The blood ordering connects to our other prototype, the “Transfusion Management Platform”. This should help the scientist to automate the ordering processes and reduce mistakes through better IT integration.

The prototype "Transfusion Management Platform" is a combination of the best ideas from previous prototypes for integrating the patient process in the bio-specimen testing platform. The prototype is thought to be implemented as an app which runs on a standard tablet operated by the ward staff (physicians or nurses). Thus, it would serve as a module of the bio-specimen testing platform which integrates both the input (patient sample) as well as the output (assigned blood bags for patient). In ward environments already several POCT (Point Of Care Testing) devices are used. Most of them are standalone solutions, which means that for every task there is a dedicated device. The idea to use a standard tablet for running the ward module of the bio-sample testing platform tries to address the issue of an increased amount of devices as it could be also used for other applications (i.e. electronic patent files). The prototype app brings together four functions:

i. **Sample & Patient Matching** (Figure 27): The patient wears a wristband which carries a QR code for patient identification. The QR code is linked to the patient file in the HIS (hospital information system). The samples are pre-labeled also with a QR code. The number of the patient sample is matched to the patient ID by scanning both QR codes. The advantage of this procedure is that dangerous mix-ups of samples and patients are
not possible anymore. Thus, it eliminates the source of error which arises from wrong sample labeling or patient identification.

ii. Decentralized Blood Ordering (Figure 28): The order function allows the ward staff (physician or nurse) to directly order the needed amount of blood products after drawing the patient sample. The order is placed in the LIS (laboratory information system) and will be automatically processed when the patient sample enters the bio-specimen testing platform in the lab. That function replaces the time consuming paper-based order process.

iii. Blood Bag & Patient Verification (Figure 29): The blood bags are assigned to the patient in the blood bank based on the testing results. In order to ensure that the patient receives right blood bag, the blood bags also carry a QR code which is linked to the patient ID in the LIS. By scanning both the blood bag and the patient's wristband at the bedside, it is verified that the right blood bag is being transfused to the patient.

iv. Order Management (Figure 30): In order to track the blood orders and get information on the availability of the ordered blood the user is able to see an overview of all blood orders in the app. This function replaces the time consuming process of checking the status of a blood test or the availability of ordered blood with the lab staff on the phone.

3.3.4.3 Results
We explained our ideas and showed our prototypes to various hospital workers. A summary of our findings for the GUI is shown below:
The users liked the idea of a flexible interface: Depending on what is important, they could change their “Home screen”.

During our discussions we noticed that the “Walk-Away Functionality” is important to the user. A solution could be combined with user recognition and therefore take more advantage of the flexibility.

The test-users loved the support aspects. They liked the idea that more problems could be solved remotely and therefore faster.

The users liked the “Mayday button”. However not all users would like to be seen by the tech support. Therefore we will add a function to switch this off in our next version.

The way the cameras are placed in the device matters, as some user don’t want to be seen. As an alternative we discussed using Google Glass in order to share a video with the tech support. The users liked this idea a lot.

We will continue to work on a user interface prototype in order to include our new findings, integrate more functions and also to do more testing.

Finally, we obtained feedback from our information management system:

- Basically the prototype was regarded as very helpful, as it makes the transfusion process easier and safer. Especially the integrated blood ordering was seen as very helpful.
- Documentation of transfusion was not a part of this prototype at the moment. However, our test users mentioned that automated documentation of the transfusion in the app
would be great, since documentation is necessary and regarded as very burdensome, especially in times of scarcity of labor force.

- Devices that are used in patient rooms need to be disinfected after every use. Thus, tablets or any other devices need to fulfill the hygiene criteria which are in place in hospital environments.
- Using live data on the POCT requires Wi-Fi. In some or even many hospitals Wi-Fi is not available. However, in the hospital we visited, the IT department just started an infrastructure project, which also covers Wi-Fi expansion to all hospital departments.
- The implementation of new technology might create resistance from older employees who are not as technologically inclined.
- Depending on the current task responsibility in the transfusion process, the “Transfusion Management Platform” might cause some shifts in task responsibility from physicians to nurses or the other way around. Since boundaries between these two occupational groups are typically quite high, the caused shifts in responsibility might hinder the implementation.
- The use of a wristband for patient identification caused some dissent. First it was mentioned by a physician that patients might not accept wristbands, as they give the impression of a non-personal treatment (patient is only a number). Second, for some therapies the nursing staff needs access to the patient’s wrist, during which a wristband would interfere. However, in many bigger hospitals patient wristbands are already standard. Further, a nurse who we talked to stated that as long as the patient gets the impression that the measure is good for his own safety, there should be no resistance.

3.3.5 Combined Functional System prototype

Combining insights from previous prototypes, including Critical Function and Experience Prototype and FUNKtional Prototypes, the team decided to create a Functional System Prototype that enables better human-machine interaction and communication.

3.3.5.1 Concept: The Key Idea

Through our needfinding, we discovered there are three elements that contribute to the experience of interacting with a machine: interaction between user and machine software, interaction between user and machine hardware, and communication between user and machine
manufacturer. Within these elements, we developed three concepts that aim at creating an overall better interaction experience. This includes a transparent GUI, a Walk-Away device, and remote customer support. The system diagram is shown in Figure 31.

![Figure 31 Functional Prototype System Diagram](image)

### 3.3.5.2 Prototype Details

The following section gives details of each of the prototypes that were built as a part of our Functional Prototype.

a) Mockup Machine

To demonstrate the basic functions and possible errors of a bio-specimen testing machine and provide a feel of the work environment, we created a mockup machine (Figure 32) that consists of an 1-DOF (Degree of Freedom) moving probe, 3-DOF robotics arm and components that represents the test tube storage (Figure 33 (a)), tray storage hotel (Figure 33 (b)), and incubator (Figure 33 (c)).
The whole machine is controlled using a programmed Arduino board. By controlling the speed and direction of each motor and detecting the signals from several bump switches for position detection, the machine can complete an initialization run and a simulated QC (Quality Control) run as shown in the flowchart in Figure 34.
b) Walk-away Device
The team further explored the idea of walk-away devices developed in the Critical Function Prototype stage. As we discovered through needfinding, lab scientists would like to view and
control lab machines remotely, therefore we tried to establish a remote connection between a portable device and the machine software interface. This is realized currently using an Ematic brand tablet [2] and a remote desktop software called Team Viewer [3]. Using the tablet that is connected to the machine computer, the user can view the same GUI and control it as they were standing by the machine (Figure 35). The GUI was developed by the St. Gallen team and is described in detail in section 15.1.2.

c) Remote Customer Support
As learned from the FUNKtional prototype, it is important that the customer support agent have the same point of view visual perspective as the lab scientist. Thus, the team designed customer service glasses mounted with cameras and laser pointers (Figure 36) with the purpose of providing a first person perspective for the customer support agent to coordinate with the lab scientist and diagnose problems.

Figure 36 Customer service glasses with camera and laser pointer

After an error is identified, the next question is how to enable the lab scientists to fix the machine by themselves? To solve this problem, the team created a 3D CAD model of the mockup machine (Figure 37), and used this 3D model to create instructional videos that show how to fix specific issues.

As a demonstration, an instructional video was made to show how to fix a broken probe by locating the problem area, removing the broken probe, obtaining a new probe from the probe storage, and inserting it into place (Figure 38).
Figure 37 3D model of the mockup machine

Figure 38 Step-by-step instructional video series of how to fix a probe problem
We also created a command center that was able to view multiple webcam images at the same time (Figure 39) for the customer support agent to have a better view of the entire machine.

![Customer support command center](image)

**Figure 39 Customer support command center**

### 3.3.5.3 Results

We invited lab scientists from the Stanford Transfusion Service Center to test our Functional System Prototype (Figure 40). Overall, they showed great interest in our concept of a walk-away machine and the remote customer support. They commented that these options will open up new possibilities to their work and the industry.

![Functional system prototype user testing](image)

**Figure 40 Functional system prototype user testing**
• The lab scientists could quickly identify what function the mockup machine is imitating and was able to extract needed information from the mockup GUI based on their working experiences. The mockup hardware and software provided familiarity to the user, so that they could naturally connect the experience of testing our prototype with their real life work.

• The lab scientists enjoyed controlling the machine software remotely using the portable tablet. They felt this would be a large improvement compared to their current work. They added that they would like to control multiple machines using the same portable device.

• The lab scientists were excited about the customer support system, including the glasses with a camera and laser pointer, and the 3D model instructional video. They liked the laser pointer which can focus both sides on the same point in the machine. They saw great possibility of using these technologies to remotely communicate with a customer support agent, reduce machine downtime and even simplify training procedures.

• As opposed to a previous interview finding that lab scientists don’t want to spend time fixing a machine, these scientists said that they are willing to fix the machine by themselves, as long as there is efficient and effective guidance.

• The lab scientists would like to add an earpiece to the glasses so that they would not have to hold a phone by hand. This indicates the requirement of a wearable customer service communication product.

• The lab scientists suggested adding audio notification to the walk-away device. This leads to a similar product that we developed for our Critical Function Prototype.

3.4 Final Prototype: Tucuxi

Our final prototype consisted of a refined mockup machine, an interface to control the machine, walk-away functionality, and a customer support system. The system is called Tucuxi, named after a species of dolphin, as that was the code name for this project.

3.4.1 Part X: Mockup Machine

Part X is the first prototype deliverable of Spring Quarter. It is meant for us to bring one part of our final system to completion to gain an understanding of the work that will be required for the rest of the project and to understand the feasibility of our design. The Stanford team decided to produce a refined mockup bio-testing machine that would act as a platform for our system for
EXPE and for user testing. It was not intended to perform any actual tests, but to complete standard mechanical motions that would be expected in one of these devices. This machine would allow users to interact with our interface, walk-away elements, and customer support solutions. It would also be a proof-of-concept that our interface would actually be able to interact with a real automated testing device.

3.4.1.1 Questions Addressed
We aimed to answer the following questions with our mockup machine and user testing:

- Can we accurately represent the motions and look of an automated bio-testing device without performing actual tests?
- Can we control this machine with our interface?
- Can we accurately simulate and provide customer support for this device?

Most of these questions are answered in the sections dedicated to the particular functions.

3.4.1.2 Concept and Design
In order to answer these questions, we started with a frame constructed from 80/20 T-slotted framing. The dimensions were chosen to be similar to common dimensions of bio-testing devices while still small enough to be shipped to our other presentations. Dimensions are shown in the Design Description section.

We originally considered having a robotic arm move the trays through the device. After the difficulties that we had with the arm from our functional prototype, we decided to instead utilize a conveyor belt system. A linear actuator was used to push plates from the hotel to the belt. All successive tray motions were linear on the belt. This also allowed us to avoid lifting the trays as they were pushed onto the belt from the bottom of the hotel. A linear actuator was used to move our probe arm, which simulated the insertion of samples into the trays. Again, this allowed us to keep complete motion of the trays in one direction. The incubator and measuring device were simulated using empty boxes that the tray moved in and out of on the belt. Infrared sensors were used to control the position of the tray on the belt. The machine was controlled by an Arduino Yun. This was chosen as we felt that it would be the most effective in interacting with our interface. The interface was displayed on a HP Slate touch screen tablet, which we attached to the side of the mockup. The mockup is shown in Figure 41, Figure 42 and Figure 43.
Figure 41 Mockup Machine at EXPE with Tablet Attached and Red Error Lights On

Figure 42 CAD Rendering of Mockup Machine without Tablet Attached
In order to test customer support features, we needed to force certain errors to occur. First, we had the interface notify the user of a “probe error” every other time a sample was run. The user would then be instructed on how to remove a probe and replace it with a new one. Extra probes were located in a storage panel in the floor.

3.4.1.3 Results
We were able to make the machine react to input from the interface. When performing user testing, we were not concerned with the feedback regarding the mockup alone. As mentioned earlier, it was only meant to be a platform so we could obtain feedback regarding the other parts of our design.

The mockup served its purpose of allowing us to perform user testing. The broken probe and fuse replacement were both tested with the aid of our customer support techniques. Results are shown in the “Customer Support” section.

3.4.2 Interface
The interface was developed as a replacement of the one we developed Winter Quarter as a part of enhancing the user experience in the bio-specimen testing lab.
### 3.4.2.1 Questions Addressed

Based on team’s needfinding and benchmarking, we found that current GUIs (Graphical User Interfaces) for bio-specimen testing machine software is not user-friendly, hard to navigate, and not fully integrated into the hospital’s information system. Therefore, the questions addressed in designing the GUI are:

- Can we organize and present information in a way that user can obtain or access needed information efficiently?
- Is the user process easy to learn and can it prevent mistakes?
- Is the data system able to be integrated into other information systems?

### 3.4.2.2 Concept and Design

Technically, the user interface is a web app developed using the AngularJS [4] framework and Bootstrap [5] styles and components. It also has an Android app version. As a web app, the interface can be accessed anywhere on almost any device that has a browser on it, and is also able to send REST style command to directly control the Arduino Yun and thus the machine. This allows the development of the walk-away functionality.

Within the framework, the user interface has several key features:

- A navigation bar that provides menu/submenu links to different categories of information
- A customizable dashboard page that presents all required information in abstract or details based on user preference
- A search box in most views that simplifies the user process of looking for specific information, especially when combined with a Barcode scanner (acting as a keyboard)
- Data service on Firebaseio [6] to store all running data.

Figure 44 shows the navigation bar under Process view of the interface. When an item from the menu is selected, its submenu will appear. Figure 45 shows the dashboard page under customization mode. Figure 46 shows abstract view and detail view of the “Consumable” tile. The amount of information shown on the tile is dependent on its size.
Figure 47 highlights the search box in the Result view. Figure 48 shows detailed test result (all information is fabricated). In the detailed view it also provides the ability to add comments, check detailed testing process, and release or send results. This enables the interface to be fit in the hospital’s information system.
Figure 45 Customizable Dashboard Page

Figure 46 Consumables Tile: (a) Size 1 (b) Size 2 (c) Size 3
3.4.2.3 Results

The interface was tested with our target users in both Stanford and Germany. Overall, we got very positive feedback. Users were impressed by the looking of the interface, the well-organized dashboard, the search box function, and the way detailed information is provided. Based on their current knowledge, they were able to navigate through different part of the interface and find the information they wanted, which took almost zero learning time.

They also provided some suggestions based on their work experience. For example they want the software to check if the remaining consumable is enough for all tests that are about to start.

Figure 47 Search Box in Result View

Figure 48 Detailed view of a test result

Figure 49 shows structured data stored on http://tucuxi.firebaseapp.com. Whenever new data is added to the data space or some information is changed, the data service pushes notifications automatically.
3.4.3 Walk-Away

The walk-away features of the Tucuxi system were designed to give lab scientists the freedom and flexibility to work on other tasks around the lab while still being fully informed on the status of their automated samples and the testing device.

3.4.3.1 Questions Addressed

We aimed to answer the following questions with our walk-away prototypes:

- Can we keep lab scientists updated on sample and machine statuses when they are away from the device?
- Can we deliver these notifications effectively without requiring user feedback or disrupting workflow?
- Can we utilize devices that will not take up too much lab space and will not be burdensome to the user?
3.4.3.2 Concept and Design
This prototype builds directly off of our Critical Function Prototype from Fall Quarter and our Functional Prototype from Winter Quarter. It consists of a Pebble Smartwatch and a Nexus Tablet. An app within the Pebble was utilized to receive notifications from the interface whenever a sample was near completion or if there was an error within the machine. The Pebble vibrated to notify the user and displayed a message, as shown in Figure 50.

![Pebble Smartwatch](image)

*Figure 50 Pebble Smartwatch displaying a message from the device*

The interface software was developed such that it could be accessed from a tablet-based app as shown in Figure 51. This app would allow the tablet to view the exact same interface that would be viewed on the main interface for the device, without giving the user the ability to control the device. This limitation was implemented due to government regulations and us not wanting the device to be controlled from a distance. It is purely to be used to view device and sample information while working on other tasks.
3.4.3.3 Results

We visited users both at Stanford and in Germany to obtain feedback on our walk-away devices. Our main concern was whether or not the watch would be usable with lab coats and if the tablet would be preferred.

We found that most users preferred the Pebble over the tablet. When away from the machine, the lab scientists really only need the short notifications to know whether or not to attend to the machine. Still, some users did see value in the additional information provided by the tablet. There were no complaints regarding use of the smart watch while having to wear lab coats. We also found that these solutions would be more valuable for larger labs with multiple scientists. There were some concerns regarding hygiene. Depending on the lab, there can be strict limitations on what the scientists are allowed to wear in the lab. The users thought that our solutions would help to reduce noise levels in the lab. Currently, some of these automated machined utilize audio alarms to notify users of errors. In labs with multiple machines, these alarms can be overwhelming. They also notify all members of the lab, instead of just the scientist responsible for that machine.
3.4.4 Customer Support

The Customer Support prototype includes three parts:

- A camera system that provides the customer support agent different views of the machine
- An example of CAD video database that instructs the user how to fix a specific error
- A customer support command center where the customer support agent can accept incoming calls, access corresponding machine information, and remotely control the machine under necessary permission

3.4.4.1 Questions Addressed

The customer support prototype is supposed to answer these questions:

- Can user follow the CAD tutorial videos and fix an error quickly without any external aid?
- Is the add-on camera system able to provide smooth video streaming and sufficient image information for diagnosis purposes?
- Is the communication between the customer support agent and the user effective and efficient? (i.e. is the customer support agent able to tell the user where to place the moving camera, and pinpoint a specific area that the user should take notice of?)

3.4.4.2 Concept and Design

In order to answer these questions, the team first created an exact CAD model of the mockup machine (Figure 42 and Figure 43) using SolidWorks. Using this model, we animated the CAD model to produce step-by-step tutorial videos (Figure 52). An exact CAD model ensures users intuitively link the image with the corresponding machine parts. CAD tutorial videos are easier to be created by the manufacturer and easier to be understood by the user compared to videos that are acted out and recorded by professionals.

The team then mounted two fixed cameras on the machine frame to cover an entire view of the mockup machine (Figure 53). The idea was taken from user testing for Functional Prototype. We found that the customer support agent extracts and interprets information most quickly with an entire top view of the machine. Figure 54 is the fixed camera views shown in the customer support command center.
Figure 52 Example of step-by-step CAD tutorial videos

Figure 53 Fixed Cameras (red circles) and Moving Camera (blue circle)
The moving camera (shown in blue circle in Figure 53) provides some flexibility to the overall customer support experience. It allows the customer support agent to instruct the user to pinpoint a specific area and get a more detailed image of a possible error. At the same time, the process helps to establish communication between the two sides. Based on the findings of our FUNKtional prototype, some degree of communication and cooperation ensure a more precise solution.
The team also developed a customer support command center interface which waits for coming call from a remote machine and then provides a link to the support version of the machine interface. The waiting page is shown in Figure 55. The support version dashboard is shown in Figure 56.

Figure 56 Customer Support Version of Machine Interface

Figure 57 Customer Support Command Center Control Panel
Another part of the command center is a Control Panel (Figure 57) that allows the agent to control some of the indicators (LEDs) on the machine in order to draw attention of the user and hence improve communication efficiency.

For demonstration, we mounted an LED close to the fuse holder where the user is expected to replace a broken fuse (Figure 58). In order to draw attention of the user, the customer support agent can click on corresponding area in the image to turn on the LED.

![Position of LED](image)

*Figure 58 Position of Fuse LED*

### 3.4.4.3 Results
We tested the customer support prototype with users from the Stanford Hospital. First of all, they like the CAD tutorial videos very much, and express a will to create these videos by themselves for training purpose. Visitors at the Stanford EXPE design fair all quickly and successfully replaced the “broken” probe by following the instructional videos. Considering these people had never seen the machine and the CAD model before, we concluded that the CAD videos are very intuitive and easy to follow.

The users and visitors at EXPE also saw potential for the camera system for remote hardware customer support. They like the idea of LED indicators in different part of the machine and the control panel for the customer support agent. Compared to the laser pointer solution that we developed in FUNKtional prototype, the users thought that the LED indicator solution is more feasible, stable and effective.
3.5 User Testing and Feedback

The team had the pleasure of collaborating with blood transfusion service laboratory of Stanford Hospital through the course of the project (Figure 40). The partnership provided knowledge of what the targeted users (lab technicians and lab scientists) needed and steered the project in the right direction. Any idea may seem great but unless it has a useful application for actual users it cannot be justified. We made sure that all functionalities of our prototypes satisfied the needs of our users and exceed their expectations.

Our customer support features received very positive feedback from our collaborators. A lot of feedback pointed to future directions in providing 3D CAD tutorial videos for training. The training video can lessen the workload on the staff members and shift the work capacity elsewhere for other tasks. The camera system also aids the communication between the user and a customer support technician if they do contact. The user is able to use three cameras to pinpoint the problem. They felt that the cameras aided communication tremendously.

Here is feedback from a staff of Stanford Blood Transfusion Lab:

“The whole concept (for us in Transfusion) would be a great improvement. Opens [sic] up new possibilities- especially an improvement in the customer service area which is very frustrating for us. It will be a cost saving possibility for the company so they don’t have to send their technical support for minor troubleshooting.’’ – Rose Mallari

The St. Gallen team also had numerous user testing experiences with targeted users in Europe (Figure 59). Customer support features were well received. They said that the CAD tutorials were very helpful and the potential for solving more complicated problems is huge.

User testing from both sides (Stanford and HSG) concluded that the tablet walk-away feature was not received as enthusiastically as the customer support structure and user interface. However, many liked the smart watch as a small messenger and indicator for an event in the machine. The user interface was also well received as it is a huge improvement compared to current GUIs that are being used.
3.6 Future Development

This section gives an overview of the future of Tucuxi that goes beyond the final solution the team developed during last months. In this section the team wants to share its vision, in which the final prototype could be embedded in the future.
3.6.1 Lab Solution Provider

In section 3.4 the team detailed the final solution, the Tucuxi platform, with its three components: interface, support, and walk-away. While developing our final prototype we focused on one specific testing device. Even though many needs described in section 3.4 derived from problems within the whole lab that were not specifically linked to the one testing device, the team focused on one device as this was the original aim of the challenge (see section 1).

However the team feels that it is extremely important to understand the big picture into which the Tucuxi platform should be embedded. Only when the entire lab environment is taken into consideration can the full potential of the Tucuxi solution be achieved. This was also a very important point that came up each time we tested the end solution with the target users. As seen in section 3.4 the users felt Tucuxi was an important improvement to their current situation, however they also gave us very important insights concerning the implementation.

The interface itself brings additional value to the user, even on the level of a single device. The user interface is now optimized to current touch screen technology, customizable, better presents information, and adds valuable new functions such as the search capability. Much of this additional information is currently not available in most interfaces. As a vendor of Tucuxi, the company has to make sure that an integration into the underlying LIS or HIS are possible in order to ensure a seamless flow of information between one system to the other. As a team we suggest that the device should be open enough in order to enable easy implement into an existing laboratory or hospital information system. Only a direct integration would enable the device to seamlessly transfer data produced by the device to the surrounding systems.

The different support functions could also improve the situation of the user on the level of a single device. However our users gave us feedback that suggests they would strongly appreciate the implementation into several devices. First of all, this would improve the entire lab situation and secondly this would enhance the user experience throughout the lab.

For the walk-away components to reach their full potential an integration of several devices would be of high importance. The users gave us the feedback that this function would definitely improve their work environment, however they were skeptical if this would be of big value, when adapted to one device only. As one user often needs to monitor more than one fully automated device, a smart watch or a singular tablet based application would not necessarily
improve their situation. Only if both Walk-Away components are able to integrate several testing devices, would the solution be of high value to the target user. The users would like to be updated on all devices without having to use several smart watches or tablets.

In order to ensure an integration of the device into the surrounding systems partnerships with LIS or HIS solution providers are necessary to ensure that the device can be fully integrated in existing labs. Furthermore a certain degree of openness would allow the users to more easily integrate the new devices into their existing systems, which are often custom-tailored solutions. The ability to easily integrate a device into existing systems was often mentioned by the users as an important buying decision.

The walk-away capability would benefit from partnerships with laboratory solution providers or vendors of other testing devices. We define laboratory solution providers as vendors that not only offer testing devices but also the underlying IT-infrastructure (i.e. LIS) to hospitals. An example we found in one of the hospitals we visited was a solution by Roche. In this specific case Roche was providing the LIS for the hospital. Furthermore most devices run in the lab were either from Roche themselves or from one of their partners. In such an environment the full implementation of the walk-away components would be most realistic, as Roche makes sure that the devices follow the same standards and protocols. However, some users also were skeptical towards such solutions as this creates a strong dependency and they would be forced to always buy devices from either Roche or one of their partners. The users mentioned that there were also independent lab solution providers that offer an IT-system which is able to integrate a number of different devices from bigger vendors. Working closely with such kind of solution providers could ensure that the walk-away components would move beyond the level of a single device.

In conclusion the team believes that Tucuxi has the potential to improve the user experience directly on the level of a single device when taking the support components as well as parts of the interface into account. However in order to bring additional value through the walk-away functions and in order to ensure the full integration of the device into the surrounding IT infrastructure partnerships with lab solutions providers or other large vendors is critical.
3.6.2 Entire Bio-Testing Process

Not only is connectivity among the different testing devices in the clinical lab important, also the integration of the testing process in the overall bio-testing process beginning and ending at the patient’s bed is a hot topic. This vision actually derives directly from an insight we gained at the very beginning of the need finding, which is that most the severe errors in the bio-testing process do not happen in the lab, but at the patient’s bed or on the way to the lab. The main reason for these errors outside the lab is wrong patient identification or wrong labeling of samples.

Talking to physicians, nurses and lab technicians in a German mid-size hospital, we soon realized that a lot of innovation potential lies outside the lab. For example, lab orders are often still paper-based and patient identification is at least in many small and mid-size hospitals not addressed with any technology that helps to prevent wrong patient identification. Further, the bio-sample management bears a lot of innovation potential, since currently most of the related tasks are processed manually by highly trained medical technicians.

Integrating the whole bio-testing process in one platform is thus a vision for further development. Looking closer to the implementation of this vision, it becomes quite obvious that the process integration is less a topic driven by life science, but a topic driven by information technology. Although Merck Millipore is not an IT company, this topic should not be ignored. We believe that the future is characterized by connections within the hospital. Hence, looking into ways of developing a testing platform that reaches out from one end to the other of the bio-testing process is rather a question of “when” than of “if”. Through our prototypes, we already tried to make a step in that direction. Whereas we did not follow this approach any further in favor of the Tucuxi user interface and customer support solution, the topic is still important.

At this point our suggestion is to have the vision of a fully integrated bio-sample process in mind when deciding on the technology and architecture of the software of the platform. Further it might be interesting to find strategic partners for the realization of this vision, because entering the market for hospital information systems may not fit to Merck’s current strategy. The challenge will be to identify which players are already in the market and in defining standards for the communication between the different processes.
4 Design Specifications

This section provides information on how to construct the prototypes that were tested during our design process as described in the Design Development section. For each prototype, a detailed list of equipment and procedure is provided.

4.1 Final Prototype: Tucuxi

4.1.1 Full Bill of Materials (BOM)

The full Bill of Materials is shown in Table 6.

Table 6 Bill of Materials

<table>
<thead>
<tr>
<th>Part</th>
<th>Vendor</th>
<th>Part #</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Series 4108 2-Hole Inside Corner Bracket</td>
<td>80/20 Inc</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>10 Series 3382 Slide-In Economy T-Nut 1/4-20</td>
<td>80/20 Inc</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>10 Series 1010 1&quot;x1&quot; T-Slotted Extrusion x 22&quot; Long</td>
<td>80/20 Inc</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>10 Series 1010 1&quot;x1&quot; T-Slotted Extrusion x 31&quot; Long</td>
<td>80/20 Inc</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>10 Series 1010 1&quot;x1&quot; T-Slotted Extrusion x 42&quot; Long</td>
<td>80/20 Inc</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>10 Series 1010 1&quot;x1&quot; T-Slotted Extrusion x 44&quot; Long</td>
<td>80/20 Inc</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>210 Series 1010 1&quot;x1&quot; T-Slotted Extrusion x 3&quot; Long</td>
<td>80/20 Inc</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Supplier</td>
<td>Part Number</td>
<td>Quantity</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------------</td>
<td>----------</td>
</tr>
<tr>
<td>2.5&quot; x 22&quot; x 0.25&quot; Sheet Metal</td>
<td>Ace Hardware</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4&quot; x 31&quot; x .0625&quot; Sheet Metal</td>
<td>Ace Hardware</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>L16-S Linear Actuator-140mm-35:1-12V</td>
<td>Firgelli</td>
<td>L16-140-35-12-S</td>
<td>2</td>
</tr>
<tr>
<td>T Belt, 5mm, HDT</td>
<td>SDP/SI</td>
<td>A 6R25M360150</td>
<td>2</td>
</tr>
<tr>
<td>TMNG PUL5mmP.TM</td>
<td>SDP/SI</td>
<td>A 6A25-026DF1508</td>
<td>4</td>
</tr>
<tr>
<td>Track Roller Carriage for 1/4&quot; Width T-Slot, 1&quot; High Rail</td>
<td>McMaster-Carr</td>
<td>9904K1</td>
<td>1</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 4&quot; x 36&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 5&quot; x 36&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 4&quot; x 16&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 5&quot; x 16&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 24&quot; x 44&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Gray 1/8&quot; x 4-1/8&quot; x 31&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Acrylic Sheet, Sign Lighting White 60%, 1/8&quot; x 4&quot; x 36&quot;</td>
<td>TAP Plastics</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Item Description</td>
<td>Supplier</td>
<td>Quantity</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Acrylic Sheet, P95 Matte Finish, Matte Black, 1/8&quot; x 26&quot; x 46&quot;</td>
<td>TAP Plastics</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Acrylic Sheet, P95 Matte Finish, Matte Black, 1/8&quot; x 26&quot; x 12&quot;</td>
<td>TAP Plastics</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Acrylic Sheet, P95 Matte Finish, Matte White 1/8&quot; x 20&quot; x 30&quot;</td>
<td>TAP Plastics</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Extruded Acrylic, Clear, 1/8&quot; x 24&quot; x 24&quot;</td>
<td>TAP Plastics</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Alloy Steel BHSCS, Black-Oxide, 1/4&quot;-20 x 1/2&quot;</td>
<td>McMaster Carr</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>18-8 Stainless Steel BHSCS 1/4&quot;-20x1/2&quot;</td>
<td>McMaster Carr</td>
<td>92949A537</td>
<td>18</td>
</tr>
<tr>
<td>Steel Angle Bracket with 1/4&quot; Hole</td>
<td>Garvin</td>
<td>BA-1/4</td>
<td>20</td>
</tr>
<tr>
<td>2' x 4' Duron Sheet</td>
<td>Stanford PRL</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6 Piece Pyrex Glass Test Tube Set with Caps and Rack</td>
<td>Amazon</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Blk-Oxide Steel Coupling, w/o Keyway for 1/4&quot; D Shaft</td>
<td>McMaster Carr</td>
<td>6412K11</td>
<td>1</td>
</tr>
<tr>
<td>D-Profile Shaft, 1045 Steel, 1/4&quot; OD, 12&quot; Length</td>
<td>McMaster Carr</td>
<td>8632T139</td>
<td>1</td>
</tr>
<tr>
<td>Set Screw Shaft Collar, for 1/4&quot; Diameter, Black-</td>
<td>McMaster Carr</td>
<td>9414T6</td>
<td>4</td>
</tr>
<tr>
<td>Part Description</td>
<td>Supplier</td>
<td>Part Number</td>
<td>Quantity</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>----------</td>
</tr>
<tr>
<td>Oxide Steel</td>
<td>Carr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al Base, Stainless Steel Ball Bearing for 1/4&quot; Shaft Diameter</td>
<td>McMaster-Carr</td>
<td>8600N3</td>
<td>4</td>
</tr>
<tr>
<td>MIL Spec Cadmium-Plt Steel Flat Washer, 1/4&quot;</td>
<td>McMaster-Carr</td>
<td>NAS1149-F0463P</td>
<td>84</td>
</tr>
<tr>
<td>Plain Gr2 Hex Nut, 1/4&quot;-20</td>
<td>McMaster-Carr</td>
<td>90494A029</td>
<td>32</td>
</tr>
<tr>
<td>3/4&quot;x3/4&quot;x11&quot; Aluminum Square Tube</td>
<td>Loft</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Zinc-Plated Steel Machine Screw Hex Nut, 10-24</td>
<td>McMaster-Carr</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Zinc-Plated Alloy Steel Socket Head Cap Screw, 10-24 x 1-1/2&quot;</td>
<td>McMaster-Carr</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Pololu Carrier with Sharp P2Y0D810Z0F Digital Distance Sensor</td>
<td>Pololu</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>IM414 Double Sided Prototyping Board, 4x6cm</td>
<td>Amazon</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>SYB-170 Color Board Mini Small Bread Board</td>
<td>Amazon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2 Pole 5mm Pitch PCB Mount Screw Terminal Block 8A 250 V</td>
<td>Amazon</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Googo Wi-Fi Camera</td>
<td>Amazon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Item</td>
<td>Source</td>
<td>Quantity</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>-------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Ergatron LX Wall Mount LCD Arm</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>HP Slate 21-k100 Touchscreen All-in-one Desktop</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stepper Motor-125 ozin, 200 steps/rev</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Arduino YUN</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Arduino YUN Cover</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Vktech DHT22/AM2302 Temp and Humidity Sensor</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SanDisk 8GB micro SD Card, 8GB</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>RSVP Ballpoint Pen, Black</td>
<td>Pentel</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>M3x30 Pan Head Phillips Machine Screw</td>
<td>Ace Hardware</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>M3 Hex Nut</td>
<td>Ace Hardware</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Zip Ties</td>
<td>Loft</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>NTE Heat Shrink 2:1</td>
<td>Amazon</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Dupont Wire Jumper Cables</td>
<td>Amazon</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Cloud Cameras</td>
<td>D-Link</td>
<td>DCS-2132L</td>
<td>3</td>
</tr>
<tr>
<td>Item</td>
<td>Supplier</td>
<td>Quantity</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Halogen Light Bulb</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Wi-Fi Router</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Easy Driver Stepper Motor Driver</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3D Printed Probe Adapter Half</td>
<td>Stanford PRL</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>SST Pan Head Phillips Machine Screw, 10-24 x 1-1/2&quot;</td>
<td>Ace Hardware</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>10-24 Hex Nut</td>
<td>Ace Hardware</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3D Printed Probe Slider Type 1</td>
<td>Stanford PRL</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3D Printed Probe Slider Type 2</td>
<td>Stanford PRL</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Belkin 6 Outlet Surge Protector</td>
<td>Amazon</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Turtle Beach Ear Force Z11 PC Gaming Headset</td>
<td>Amazon</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>USB Mini-B Connector Breakout Board</td>
<td>Pololu</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Acer DA220HQL 21.5&quot; All-in-One Touchscreen Desktop</td>
<td>Amazon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DC Power Adapter Barrel Jack</td>
<td>Pololu</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Wall Power Adapter 12 VDC 5A 5.5x2.1mm Barrel Jack</td>
<td>Pololu</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Manufacturer</td>
<td>Part Number</td>
<td>Quantity</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------------</td>
<td>-------------</td>
<td>----------</td>
</tr>
<tr>
<td>Pololu 5V Step-Up/Down Voltage Regulator S7V8F5</td>
<td>Pololu</td>
<td>2123</td>
<td>1</td>
</tr>
<tr>
<td>Pololu 5V Step-Up/Down Voltage Regulator S10V4F5</td>
<td>Pololu</td>
<td>2121</td>
<td>1</td>
</tr>
<tr>
<td>Twisted Servo Extension Cable 24” Male Female</td>
<td>Pololu</td>
<td>2168</td>
<td>15</td>
</tr>
<tr>
<td>Basic SPDT Relay Carrier 12 VDC Relay</td>
<td>Pololu</td>
<td>2482</td>
<td>2</td>
</tr>
<tr>
<td>Pebble Smart watch</td>
<td>Amazon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Nexus 7 Tablet</td>
<td>Amazon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Metallic Tape</td>
<td>Loft</td>
<td></td>
<td>AR</td>
</tr>
<tr>
<td>Solvent Cement</td>
<td>TAP Plastics</td>
<td></td>
<td>AR</td>
</tr>
<tr>
<td>Elmers All-Purpose Glue</td>
<td>Loft</td>
<td></td>
<td>AR</td>
</tr>
<tr>
<td>Acrylic Cement</td>
<td>Loft</td>
<td></td>
<td>AR</td>
</tr>
</tbody>
</table>

4.1.2 Drawings and Diagrams

4.1.2.1 Mock-up (Mechanical Design)
A CAD model and drawings are shown in Figure 60, Figure 61 and Figure 62. All items in the table in Figure 61 have detail drawings shown in Appendix B. The BOM in section 4.1.1 outlines all additional parts not shown explicitly in the drawings. The mounting of the monitor arm and the monitor is shown in Figure 63.
Figure 60 CAD Model of Mockup Machine

Figure 61 CAD Drawing of Mockup Machine Assembly, Page 1
Figure 62 CAD Drawing of Mockup Machine Assembly, Page 2

Figure 63 Monitor Arm Mounting Position
Figure 64 Monitor Arm Mounting Position and Fixed Camera Position

Figure 65 Fixed Cameras
There were three D-Link cameras used for customer support. Two of these cameras were fixed to the frame, and the other one was used as a wireless movable camera. The positioning of the two fixed cameras is shown in Figure 64 and Figure 65 (just inside each of the top cross bars of the frame). The movable camera had built-in wireless capability, but had to be modified for use with a battery. The battery from the Googo camera was used to power the D-Link camera. The movable camera is shown in Figure 64 and Figure 66.

![Movable Camera in Use](image)

*Figure 66 Movable Camera in Use*

4.1.2.2  Mock-up Wiring Diagram

The power supply design consisted of one 12V (5A) AC-DC power supply and one 5V (3A) AC-DC power supply. The 5V supply needed a linear regulator since the power supply’s voltage was slightly too high for the infrared sensors. Each power source has its own switch and was controlled by a master switch that superseded both switches as shown in Figure 67. This switch was mounted on the outside of the frame for quick access.

Figure 68 illustrates the complete wiring diagram that was used to run the mock-up machine.
Figure 67 Power supply wiring diagram

Figure 68 Complete circuit diagram
4.1.2.3 **Hardware Architecture**

Hardware architecture in system level is shown in Figure 69.

![System Hardware Architecture](image)

*Figure 69 System Hardware Architecture*

4.1.2.4 **Software Architecture**

The software architecture in system level is shown in Figure 70.

![System Software Architecture](image)

*Figure 70 System Software Architecture*
Figure 7.1: State transition diagram

- Start Test
- Machine Ready
- Calibrating
- Move to Reader
- Incubating
- Pipetting
- Detecting
- Exit
- Probe Error
- Temperature Error
- Timeout Error

- Probe Misalignment
- Temperature Too Low
- Temperature in Normal Range
- User Click Restart Button on GUI
- Power On
4.1.2.5  State Transition Diagram
The team applied the state machine framework to write the Arduino code for controlling the machine (Appendix C). Also the machine reports its current state to the cloud data service website [6] to enable interaction with the GUI. The state transition diagram of the machine is shown in Figure 71.

4.1.2.6  GUI User Process
The GUI user process includes the code that was used to develop the GUI in its final form. All of the code can be accessed at Github [7]. The user process for GUI navigation is illustrated in Appendix D.

4.1.2.7  Customer Support Diagram
Our system had two types of errors that could occur: a probe error and a temperature error. The probe error was programed to occur randomly, and the temperature error was based on actual data measuring heat from a light bulb in the device, which we could turn on and off. The steps in each situation are in Figure 72 and Figure 73.

![Probe Error Process Diagram]

*Figure 72 Probe Error Process*
Figure 73 Temperature Error Process
5 Project Planning and Management

In the spring quarter, the Stanford team and the St. Gallen team managed to maintain frequent communication and close cooperation between each other and with the corporate liaisons, well distributed work among the entire team, and successfully kept up with plans that were made during the Stanford visit to St. Gallen. This lead to a successful final product and a satisfying demonstration at EXPE.

5.1 Project Timeline

During the Stanford visit to St. Gallen, the team created a Spring Quarter hunting plan (schedule and milestones) intensively. An excerpt of the hunting plan is shown in Table 7. Red text indicates the task is not pursued. Blue text means the task was completed later than desired time or was under continuous evolution during the whole quarter, with a blue cell in the timeline indicating the actual finish time. The details are mentioned in Figure 74. Other tasks were all implemented and finished within the planned time.

<table>
<thead>
<tr>
<th>Week</th>
<th>Stanford</th>
<th>St. Gallen</th>
<th>Both</th>
<th>Actual Finish date</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 74 Guide for Hunting Plan Terminology

Table 7 Spring Hunting Plan

<table>
<thead>
<tr>
<th></th>
<th>Wee k 13</th>
<th>Wee k 14</th>
<th>Wee k 15</th>
<th>Wee k 16</th>
<th>Wee k 17</th>
<th>Wee k 18</th>
<th>Wee k 19</th>
<th>Wee k 20</th>
<th>Wee k 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milestones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-is Finished PT</td>
<td>GUI Layout</td>
<td>Hardware</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entering Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implemented (HW/SW)</td>
<td>Testing process is implemented (HW/SW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk away is implemented (HW/SW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support for pipette breakdown is implemented (HW/SW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final PT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Design**

**Hardware**

**User Interface**

**User Interface Position**

**User Interface Size / HW**

**Case Design**

**CAD Model of Machine**

**Frame**

**Plastic Frame Cover**

**Front Layout / Doors**

**Fixed Cameras**

**Loading & Unloading**
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors</td>
<td>Maintenance</td>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layout (Mock Ups)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settings &amp; Navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Errors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layout (HTML / Divshot)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settings &amp; Navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Errors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>Icons</td>
<td>Color Scheme &amp; Typo / Styleguide</td>
<td>Logo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------</td>
<td>----------------------------------</td>
<td>---------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software Coding</td>
<td>GUI</td>
<td>Event sensor communication</td>
<td>Support sensor communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera communication</td>
<td>Walk away communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Database</td>
<td>CAD Tutorials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training of ... loading</td>
<td>Troubleshoot of pipette</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk Away</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wearable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feasibility Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log-In</td>
<td>Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tablet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log-In</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charging (Lab Environment)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand (Lab Environment)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Command Center</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Würzburg Lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Munich Lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stephanshorn Lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford Lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Travel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparation EXPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Deliverables

Table 8 shows the plan of Spring Deliverables and the actual deliverables the team delivered this quarter.

<table>
<thead>
<tr>
<th>Date</th>
<th>Deliverable</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 29, 2014</td>
<td>Spring Quarter Project Plan</td>
<td>As the Stanford team and the St. Gallen team spent a week working together, a detailed, comprehensive Spring Quarter plan was made by the whole team during the visit.</td>
<td>Delivered on time. The entire team had thorough discussion about Spring quarter plan, budget, and work distribution. Based on the discussion a detailed project plan was made.</td>
</tr>
<tr>
<td>April 3, 2014</td>
<td>Spring Hunting Plan Hand-out &amp; Presentation</td>
<td>Pitch the plan in five minutes to an audience unfamiliar with our project. Convince people with a clear, compelling solution that can be achieved by EXPE [11]. Get feedback.</td>
<td>Delivered on time.</td>
</tr>
<tr>
<td>April 17, 2014</td>
<td>Finished product Part X and Hand-out</td>
<td>Get one non-trivial part of the design into its final form. Pick the part which the team is set on [12].</td>
<td>Functionally finished on time. Our Part X was the mock-up machine. It experienced several rounds of disassembly and re-assembly and a lot of refinements throughout the whole quarter.</td>
</tr>
</tbody>
</table>

Table 8 Spring Deliverables
### Table 9 Spring Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
<th>Goals</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 29, 2014</td>
<td>Spring Quarter Project Plan</td>
<td>Detailed and comprehensive plan across the whole design team</td>
<td>Finished in time.</td>
</tr>
<tr>
<td>April 24, 2014</td>
<td>Manufacturing Plan</td>
<td>The plan must cover a list of hardware and software that need to be completed for demonstration in EXPE, vendor and human resources for each part, and all design requirements [13].</td>
<td>Delivered on time.</td>
</tr>
<tr>
<td>May 15, 2014</td>
<td>Mostly complete product Briefing package</td>
<td>These are for the Penultimate Design Review before EXPE [14].</td>
<td>Delivered on time.</td>
</tr>
<tr>
<td>May 29, 2014</td>
<td>EXPE Brochure &amp; Poster</td>
<td>Develop final poster and brochure for the EXPE</td>
<td>Delivered on time.</td>
</tr>
<tr>
<td>June 5, 2014</td>
<td>EXPE Presentation</td>
<td>Final presentation for the project</td>
<td>Delivered on time.</td>
</tr>
<tr>
<td>June 12, 2014</td>
<td>Final Documentation</td>
<td>Report due for the entire project</td>
<td>In progress</td>
</tr>
</tbody>
</table>

### 5.3 Milestones

Milestones for the Spring Quarter comments about how each milestone goal was acquired are shown in Table 9.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Details</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 17, 2014</td>
<td>Product Part X Finished</td>
<td>One non-trivial part of the design completed and EXPE ready. (For our team, it was the mockup machine with GUI software)</td>
<td>Part X is to build the mock-up machine for Stanford team, and to decide the layout and user process of the GUI for the St. Gallen team. Both teams achieved their goals for Part X, but as commented in the above section, the parts were refined and improved multiple times and thus cannot be considered as fully completed in Part X.</td>
</tr>
<tr>
<td>April 24, 2014</td>
<td>3D model/software structure of rest of the parts of the product</td>
<td>Finish product designing so that the design can come to the fabrication stage. Detailed and comprehensive manufacturing/software developing plan.</td>
<td>3D model of the machine cannot be finalized until the machine is finalized. Therefore it was actually finished a week before EXPE.</td>
</tr>
<tr>
<td>May 1, 2014</td>
<td>Most Hardware Finished</td>
<td>Finished most parts of the hardware so that the team could assemble the product and conduct some user testing.</td>
<td>Most hardware is functionally finished but the team decided to iterate the product and make it better. Also wiring of the machine was not secured and required further efforts of cleaning-up.</td>
</tr>
<tr>
<td>May 7, 2014</td>
<td>All Software Finished</td>
<td>All the software needed (for GUI, walk-away and customer support) are completely functional.</td>
<td>We definitely underestimated the difficulties of finishing all software. The software for the GUI and communication with the Arduino Yun was not finished until EXPE week.</td>
</tr>
<tr>
<td>May 14, 2014</td>
<td>Penultimate Design Review</td>
<td>Almost completed product.</td>
<td>On penultimate review, the team demonstrated an integrated functional system of the GUI</td>
</tr>
</tbody>
</table>
Polished, compelling, and appealing final product

5.4 Distributed Team Management

Our project management techniques evolved drastically throughout the project. In the Fall, both teams relied on the website Asana for assigning tasks and keeping track of due date. Since Winter Quarter featured fewer missions, we did not have an official project management tool. Google Drive was used much more heavily the final two Quarter to share files between teams and keep both sides up-to-date. Completed files such as handouts for prototypes were posted to our team’s SharePoint site which allowed our corporate sponsor to be able to access our files. The focus in Spring Quarter was much less on finishing one assignment at a time, and more about getting the entire system completed for EXPE.

Tasks were divided based on the strengths and backgrounds of each school and individual. In the final Quarter, the St Gallen management students (Joscha, Carina, and Will) handled the tasks that were related to user testing and researching potential solution methods. Alex utilized his programming background to bring the interface to life. The engineering students at Stanford focused on more physical tasks. These tasks were divided based on personal background experience. Wanxi focused on interface development with Alex and ensuring that it could communicate with the mockup. Sean focused mainly on ensuring the budget was not exceeded and that the mechanical portions of the mockup machine functioned. Yu focused on wiring and soldering the electronic components of the mockup machine. Finally, Harshit contributed in all of these areas offering assistance whenever needed. He also created the initial interface for the customer support command center.

All team members kept their specific administrative roles that were assigned to them at the beginning of the project. Yu was in charge of the communication between teams and with the corporate sponsor for Stanford. On the St Gallen side, Will was responsible for communication solely with Stanford while Joscha kept the corporate sponsor informed. Alex and Harshit were responsible for keeping updated documentation of prototypes. Carina was responsible for project
management and the St Gallen budget. Sean and Wanxi split these responsibilities for Stanford with Sean covering finances and Wanxi taking care of project management.

Stanford, St Gallen, and Merck/EMD Millipore were able to establish strong communication through weekly web chat meetings. These meetings were attended by multiple Stanford and St Gallen students as well as Mahmoud, Jagat, and Beth from EMD. Weekly meetings were also held between Stanford and St Gallen team members. Will and Joscha also made a trip to Boston on February 28 to update Christian Stuppy, the initial sponsor of the project from Merck Germany, of our progress while he was on a business trip to the area.

From March 22nd to the 29th, Harshit, Sean, and Wanxi visited St Gallen to finalize plans for the final Quarter. This trip proved to be extremely valuable in forming the final vision for the project as well as establishing time and budget constraints for the following weeks. It also helped to establish personal connections that had yet to be established.

On May 26th, Carina, Joscha, and Will arrived at Stanford to help with final preparations for EXPE on June 5th. Alex would join as well on June 2nd. These last two weeks were critical to the success of the project, and having all the teammates together to finish the project made the final product a success.

5.5 Project Budget
This section provides a summary of all expenses for the project. The description of all expenses is listed in Appendix E while a general overview is provided in Table 10. Expenses are categorized in Table 11.

<table>
<thead>
<tr>
<th>Table 10 Project Budget Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Budget $ 8000.00</td>
</tr>
<tr>
<td>Fall Spending $ 941.46</td>
</tr>
<tr>
<td>Winter Spending $ 1312.39</td>
</tr>
<tr>
<td>Spring Spending $ 5262.91</td>
</tr>
<tr>
<td>Total Spent $ 7523.50</td>
</tr>
<tr>
<td>Remaining Budget $ 476.50</td>
</tr>
</tbody>
</table>
Table 11 Stanford Catagorized Budget

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Robot</td>
<td>$ 39.35</td>
</tr>
<tr>
<td>Fall Prototypes</td>
<td>$ 224.38</td>
</tr>
<tr>
<td>EMD Temecula Trip</td>
<td>$ 763.18</td>
</tr>
<tr>
<td>SUDS and other foods</td>
<td>$ 956.79</td>
</tr>
<tr>
<td>Dark Horse Prototype</td>
<td>$ 108.85</td>
</tr>
<tr>
<td>FUNKtional Prototype</td>
<td>$ 185.39</td>
</tr>
<tr>
<td>International Travel Preparation</td>
<td>$ 146.41</td>
</tr>
<tr>
<td>Functional Prototype</td>
<td>$ 238.04</td>
</tr>
<tr>
<td>8020 Frame Material</td>
<td>$ 575.44</td>
</tr>
<tr>
<td>Motors and Actuators for Final Prototype</td>
<td>$ 538.38</td>
</tr>
<tr>
<td>Hardware, Electronics and other parts</td>
<td>$ 1229.96</td>
</tr>
<tr>
<td>Cameras for Customer Support</td>
<td>$ 497.70</td>
</tr>
<tr>
<td>EXPE Planning</td>
<td>$ 10.86</td>
</tr>
<tr>
<td>Tablet and Arm for Final Prototype</td>
<td>$ 473.79</td>
</tr>
<tr>
<td>Covers and Floor for Final Prototype</td>
<td>$ 608.16</td>
</tr>
<tr>
<td>EXPE Shirts and Posters</td>
<td>$ 677.86</td>
</tr>
<tr>
<td>Local Travel</td>
<td>$ 248.96</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$ 7523.50</strong></td>
</tr>
</tbody>
</table>

Table 12 shows the St Gallen’s Budget distribution over the project. Some values are approximated as they will continue to travel for the project after the completion of this report.
5.6 Reflections

5.6.1 Yu Hsiao

It has been a challenge-filled year and full of great learning experiences. Though I was not thrilled when we were assigned this project, I was able to still learn many new things and apply design methodology techniques philosophy throughout the course. Most of the things I learned actually more related to working with a team to accomplish goals. I’ve learned to communicate my ideas effectively with teammates as well as taking the time to understand and analyze their ideas. It’s important to consider everyone’s opinions and options and pick the best direction for the project. I also learned that every individual has different ways of communicating and it takes time to build trust and develop smooth/effective teamwork.

I felt very lucky to have had the guidance of our awesome ME310 teaching team. The teaching team encouraged us when we needed motivation and pushed us when we needed to raise the bar higher for ourselves. The small group meetings every week made sure we did something every week and stayed on schedule, and provided us with instant feedback that kept us in the right direction,
I had the pleasure of working with a wonderful group of individuals. I learned new circuit debugging techniques from Wanxi and new knowledge of electronics. From Harshit, I learned to be proactive and not afraid when a new problem arises by understanding the problem and tackling it. From Sean, I learned numerous prototyping techniques/CAD techniques as well as communication skills. I’ve never been involved with a project with so many talented and driven individuals including our international partners. Due to this, we were able to do great things very efficiently but there were naturally disagreements that happen as well. Through this process, I was able to learn how to be a team player and not force what I want on the team. It’s most important to focus on what’s best for the group moving forward. I will surely miss this course and project, but I will take the lessons along with me for my future journeys.

5.6.2 Harshit Jain

A full academic year has come to an end and with it ME310. This was one of the most proactive course I have ever done during my academic career. I still remember the discussion during the fall quarter when we had to fill up the preferences. Nobody in our team wanted to do the project with Merck because it involved blood. I was the only one not because I like hospitals but because it was in collaboration with Switzerland. Although our team gave it 7th preference, we still got it and nobody knows how. Everybody was unhappy and especially Sean because he just hates blood. But the project was allotted and it could not be changed. Then began our roller coaster ride along the next three quarters to ideate solutions for the project.

In the beginning it was tough. With Merck narrowing out focus to just interface, we were extremely disappointed. We wanted to explore so much more, do something different. When we came from our trip to Temecula, everybody was really dispirited. However, talks with our teaching team and coaches really boosted our morale and the dark horse phase helped us to shift our focus just from interface.

After that, consistent talks with Merck and St. Gallen, helped us to broaden our scope and we were not limited to interface by the end of dark horse phase. We had included customer support and walk-away in our scope. Then for the remaining winter quarter while we focused on customer support, St. Gallen focused on interface and walk-away. We developed good prototypes during the winter quarter and were happy with our progress.
Finally during the spring break, we went to Switzerland, the reason for which I gave this project a higher preference in the first place. The trip was basically to finalize the direction for the project. The various elements of the project were decided. Apart from work, we visited Zurich, St. Gallen, Appenzellerland and Munich. It was a fun trip overall (although I did lost my passport on day 1 but was lucky enough to have found it the next day). Once the spring quarter started, all we did was finish what we had finalized during the trip. We collaborated really well with the St. Gallen and successfully completed all the tasks on time. The successful EXPE was direct result of this effective collaboration.

As for the team, I really bonded well with all of them towards the end. They all have become very good friends. I would like to say that my teammates are dedicated, motivated and unselfish. I feel extremely lucky to have worked with Sean, Yu, Wanxi, Will, Joscha, Carina and Alex. I learnt something from everybody whether it was about academics or life in general. Not only that, I made some really good friends among the 310 classmates and the Bonfires were awesome!!

Finally, the teaching team and the coaches were excellent. They helped us all the way along providing useful insights. It was really nice working with them for the three quarters. I still wish the course was not over, I will miss it!!

5.6.3 Wanxi Liu
The year of ME310 design journey finally comes to an end. I am still feeling lucky that I made the choice of enrolling in this class. I’ve got a lot more than I expected, especially in how to team work with people from different countries and different backgrounds. I’ve significantly improve my communication and presentation skills (not only in English!). The whole design process also helped me establish a mindset and even a faith that no matter what the challenge is about, there are always user pain points and then solutions.

I miss the first quarter when all of us felt disappointed of the project assigned to us, but still tried to explore the problem space by going out to talk with relevant people. It was exciting to find myself quickly overcoming the language barrier and learning something that’s totally new to me. The second quarter was also interesting as we explored the solution space based on user needs we identified. Our Dark Horse prototype didn’t turn out to be a real dark horse. But it largely enlarged our design space, provided more fun and thinking method at that confusing phase of the
project, and finally brought us to a successful FUNKtional prototype, functional prototype and all the way to the final product. It was hard to say exactly how our ideas evolved during the process, but the well-designed ME310 design process did work really well on our team.

The final quarter was all about realizing and showcasing our ideas. Before that the Stanford team paid a one week visit to St. Gallen, which turned out to be extremely valuable. The team spent several hours a day discussing to reach consensus on what solutions we were going to implement and make a detailed and comprehensive plan for the following quarter. Also during the visit we established friendship in person, which ensured close cooperation during the spring quarter.

In spring quarter I worked closely with Alex from University of Zurich for a successful integration of the GUI and the machine. During the process I also got to know about how AngularJS framework works, and learnt to implement some of the webpages using html5 and JavaScript. I also gained experience of designing and implementing a relatively complicated mechatronic system with Arduino Yun. If I could do it again, I would design the electronic part with more consideration of physical implementation, and chose a more convenient and secure way to wire the circuits at the very beginning (rather than cleaning it up again and again). These are precious experience for any future project.

There are still plenty of lessons that I learnt in ME310 that cannot be covered by this reflection. In all, I highly appreciate the work of the Stanford teaching team, all of my awesome teammates, and strong support and attention paid by our corporate liaisons. I will miss this ME310 year of my life. I wish I could someday introduce the ME310 journey to my undergraduate university in China.

5.6.4 Sean Poluha

I was not thrilled when our team was assigned this project. I really do not like biomedical engineering or software, which was what I expected this project to exclusively consist of. In addition, it was very disheartening to be told that EMD simply wanted an interface to control a bio-testing machine. This seemed like a very limited scope that did not go with the design innovation theme of ME310.

The needfinding and benchmarking stages were difficult for me as it put the team in contact with hospitals and in view of blood being drawn. As we moved on to prototyping, I realized that the
path we chose to follow was very generic in that it could be applied to any measuring device. I actually enjoyed building these prototypes and feel like our vision could actually make a difference for EMD and the field. Honestly, I would have preferred to work on a product as opposed to a platform, I feel that I learned a lot about areas that I was previously not familiar with.

I was really happy when our teaching team approved us building the mockup machine. This allowed me to learn what it takes to build a relatively complex mechanical system and experience the challenges associated with the building process.

Our experience in this course has proven that this design process can lead to an understanding of any field, even one that you are not familiar with. While I am not going to jump at the next opportunity to work for a bio-engineering company, I am happy to know that I can handle whatever project is presented to me.

I found that the greatest benefit from the project was the weekly small group meetings with our teaching team. Being able to pitch your ideas and justify your work is crucial in almost any engineering job and something that I believe a lot of engineers struggle with. This experience will undoubtedly help me in the future when I need to communicate with upper management.

Overall, I would definitely consider our project a success. There were times when we were so caught up in the process, that it was hard to remember exactly why we were adding certain features or if they would be beneficial, but our final user testing and EXPE feedback was very uplifting. The big challenge for our presentation was to accurately describe the working environment around these automated machines. Based on the positive feedback that we received after our presentation and at EXPE, I believe that we succeeded in conveying our message.

Finally, I greatly appreciated the social elements of this course. Weekly SUDS gave us a chance to forget about our projects for a couple of hours and bond with our classmates. ME310X also helped to establish this bond (not to mention the BONDfires).

This course has been a part of my entire Stanford experience to date. I am not sure how it will feel once I no longer have access to the loft. It is a very bittersweet ending, but I know that I am better off now than when I arrived. I know that I may never see some of my classmates again, but I also know that I have established lifelong friendships with people from around the globe.
5.6.5 Joscha Held

After nine months of intensive work on our design challenge, we finally came to the point where to reveal our solution in its full “beauty” to our corporate partner. This point was very exciting for both our design team as well as our liaison. Let me reflect my own experience of this project using the three dimensions: people, content, method.

People
In the beginning of the project I was very curious about becoming part of a global team and working together with smart and dynamic people around the globe. When our Swiss team was told that we are going to work with a team from Stanford, our professor shared two more facts: First, it is a great opportunity and second, it might become a pain working together around the globe in a diverse team in addition to the nine-hours time shift. Due to the situation that we did not had the chance to get known to our counterparts from Stanford on a personal level although we went to Stanford for the kick-off, the first month of the project gave me the feeling that it is more the second fact which is dominating our global collaboration. After the Stanford team came over to St. Gallen in March this feeling abruptly turned into positive since from then on our global not only had the same vision for finalizing the project but we also became a team on a personal level. The peak of that great experience was our stay in Stanford prior to the final presentation in June. For future projects my key take away will be to really build a team spirit in the very beginning of a project, especially if you have to mainly work on a virtual basis afterwards.

Further, the project was very challenging in terms of managing discussions and conflicts with team mates having other opinions and abilities. Although this was not the most enjoyable part of the project, I could learn a lot about teamwork and myself.

Content
Neither me nor any other team mate had specific knowledge in the domain our design challenge was set up. While in the first place that situation created an unsettling feeling, it was amazing to find myself constantly gaining knowledge in a totally new area and becoming a serious discussion partner for users and experts. Thus, I am already looking forward in finding a new
challenge which requires extensive acquisition of knowledge and provides a steep learning curve similar to this project.

**Method**

Although being a bit sceptical when the design thinking method was introduced to me for the first time, after going through the whole design thinking journey, I generally regard this approach as a very powerful way to foster innovation. However, I believe that it is more the mindset (putting the focus on the needs of the user, getting fast feedback on ideas using prototypes and allowing for crazy ideas) which drives the success of design thinking rather than rigidly reeling the different prototyping phases off. For future projects I definitely can benefit a lot from this course and project from a methodical point of view.

5.6.6 Will Kölbener

Working in a cross-cultural and an interdisciplinary team has made our project more challenging but definitely also much more rewarding. Looking back onto the last few months I believe that the visit of our Stanford team to Switzerland and the last visit of ourselves to Stanford have been the best three weeks of the project.

Being able to collaborate together more closely did not only help us to proceed faster in the construction of our final prototype but also gave us the opportunity to build a strong bond on the personal level. Looking back I believe we would have needed more time together as an international team during our SUGAR kick-off in Stanford. Due to bad communication our Stanford team learned too late about our coming and we couldn’t use our first days in Stanford to build a strong personal bond, which would have enabled us to achieve more during the first weeks.

Overall the last few month have been an interesting and challenging journey. Not only was I able to learn a lot about the medical industry and the Design Thinking method, but also about myself. Additionally the course did not only challenge my academic and professional competencies, but also my interpersonal and intercultural skills.

At the beginning I struggled a lot with the seemingly chaotic approach of the Design Thinking methodology. I'm used to work very structured and goal orientated. Over the time I realized the
value of longer discussions and brainstorming sessions. Even though many of our ideas and efforts turned out as "failures" we could learn valuable lessons that we could use for our final prototype.

The extensive user testing was another challenge and great learning opportunity. Furthermore the testing of our final prototype was one the most rewarding experiences. Until then I wasn’t sure how good our solution was, as we were operating under many assumptions. The extreme positive and encouraging feedback of the end-users was a great conformation of our hard work.

In conclusion I am very happy that I was able of being part of this international team and this course. The end-user feedback was an acknowledgement for our hard work and all the long hours we poured into the final prototype. Additionally I was able to win new friends from other countries that I wouldn’t have been able to meet otherwise.

As a last note I would like to thank our corporate sponsors. Their constant encouragement, feedback and interest really let us feel, that we actually worked on something that had the potential to make a difference and that our work was appreciated. Looking at other teams I don’t think this close collaboration can be taken for granted. Our sponsors took much time in order to guide and support us in various ways. Without their extensive involvement I don’t think we would have managed to achieve as much.

5.6.7 Alex Mulli

Looking back to the beginning of the project last autumn when we visited Stanford for the first time it feels much more further in the past as we have come a long way since then.

At the beginning of this course the Merck Challenge clearly would not have been my first choice. The area of medical devices in lab environments was something I didn’t have any interest in before. However when exploring the the topic in the first few weeks I quickly got excited about the design space we were in as it combined many different aspects, from communication and supply processes between labs and hospitals to the human-machine interaction in the lab.

Working on a internationally collaborative project over the period of nearly 8 month was an immensely valuable experience for me.
The second visit to Stanford towards the end of the project was much more intense and we were able to work much more closely together as one team.

5.6.8 Carina Them
First of all I am glad to be part of the ME310 network and that I had the opportunity to attend this course. The ME310 project has been both challenging and rewarding. Firstly, the topic of the problem statement was fairly new and seemed to be insoluble as I never had before something to do with healthcare and diagnostic instruments. Second, the fact that our group consists of three universities each with a different field of study, located in two countries comprising eight students with eight nationalities looked like a thrilling starting point. Additionally to that the different and unique characteristics of the team members lead sometimes to energy-sapping discussions. Thirdly, to work with the design thinking approach was new and impalpable. However these fears changed quickly after starting to work on the project. The fact that the scope of the project was within the healthcare system turned out to handle more on the interaction of the user with an automated device and the communication between several stakeholders. Therefore I could applying my existing skills and in addition deepen my knowledge in new areas. Furthermore the interdisciplinary and global team composition was very inspiring and lead to a significant learning curve in my social skill settings. Lastly the design thinking method turned out to be very facile to understand and to apply. To sum it up, the experience made and the skills i learned were unique and a phenomenal enrichment.
6 References

[2]. http://www.ematic.us/tablets/10-single-core-egs102, Ematic’s Tablet
[4]. https://angularjs.org/
[6]. http://www.firebaseio.com
[7]. https://github.com/amuelli/tucuxi
[12]. http://wikibox.stanford.edu/12-13/index.php/Assignments/PartXIsFinished
7 Appendix A

Additional Benchmarking & Needfinding

7.1 Analogous Experiences

The team wanted to explore how other devices communicate errors to the user. We also brainstormed experiences that are similar to the process that the bio-sample devices produce. Finally, we explored new technologies in touch screen interfaces.

7.1.1 TI-83+ Calculator

The TI-83+ Graphing Calculator (shown in Figure 75) is a standard graphing calculator that has the ability to display error messages. It has a 1.5 by 2.5 inch screen.

![TI-83 Error Display](image)

*Figure 75 TI-83 Error Display*

7.1.1.1 Findings

- Has a lot of screen space, but does not utilize it when displaying error messages.
- Points you to the issue when it switches back to input screen.
- Changes the screen to display just the error, instead of showing error and input on the same page.
• Displays short, nondescript error messages.

7.1.1.2 Conclusions
We discovered that the size of the screen does not necessarily matter if you don't utilize all the space. Also, it is beneficial to not only be told which error has occurred, but to also be shown where the error is. It would have been better if it displayed the error message on the screen along with the input.

7.1.2 MATLAB
Working off of our findings from the TI-83 calculator, we decided to look at how a more complex computing program handles error messages. Figure 76 and Figure 77 shows the error windows in MATLAB.

![Figure 76 Error Display at the Input](image1)

![Figure 77 Error Display in the Function](image2)

7.1.2.1 Findings
• Displays descriptive error messages that tell you exactly where the error occurred along with a potential solution for the problem.
• Displays the error in both the function and the prompt time, which is analogous to the interface and the machine for physical devices.
• Distinguishes between errors and potential problems.

7.1.2.2 Conclusions
MATLAB was more effective at displaying error messages than the calculator because you could see both the function and the input at the same time. The error messages were displayed with the original text which meant that you did not have to switch between views to solve the problem.

7.1.3 Large Xerox Printer
We evaluated the error messages and troubleshooting for the large Xerox printer located in the ME310 loft. Figure 78 shows the Xerox printer that was being studied.

Figure 78 Xerox Printer

7.1.3.1 Findings
• The large screen displayed detailed pictures of potential issues along with step-by-step solutions to the problem.
• Breaks down solution one step at a time as opposed to displaying entire solution at once.
• All the assistance was on the screen, there was no guidance on the machine itself.

7.1.3.2 Conclusions
The animations and broken-down steps on the screen were very helpful. It would have been beneficial to also have lights or some other indication on the machine itself to help point you to
the problem area. This would help to avoid constant cross-referencing and make it much easier to locate the issue.

7.1.4 Small Personal Printer

We evaluated a Canon C4400 color printer to compare to the large Xerox printer. The screen is one square inch and is controlled by buttons surrounding the screen as shown in Figure 79.

7.1.4.1 Findings

- Extremely small screen, but the space is well used.
- Small simple device meant that it was easier to locate issue purely based on screen’s description of the problem.
- Featured generically shaped buttons that changed function based on what was displayed on the screen. The buttons with a predetermined shape such as “X” and “OK” never changed function.

7.1.4.2 Conclusions

The main difference between the small and large printer was the screen size. Even though there was a large difference in size, the way errors were displayed was very similar and equally effective. Due to the simplicity of the device, error messages were not as critical.

![Cannon C4400 Interface](image)

*Figure 79 Cannon C4400 Interface*
7.1.5 HunterLab Colorflex EZ
This device is used to measure the color of a small sample of material and display a numerical result representing that color. The insights are from a previous internship of one of our team members. The device is as shown in Figure 80.

![HunterLab ColorFlex EZ](image)

Figure 80 HunterLab ColorFlex EZ

7.1.5.1 Findings
- Non-customizable interface, testing method had to be adjusted to match the machine.
- By making the current model “EZ” certain features were removed that were beneficial in the past.
- All functions are hidden in multiple menus.
- Buttons were arrow shaped, yet changed functionality based on the screen.

7.1.5.2 Conclusions
There needs to be a balance between menus and having everything displayed on the screen at once. In this case, to accomplish any task, multiple screens had to be navigated. Also, if buttons are a permanent shape such as an arrow, it is confusion for them to change function. The small printer did a good job in making buttons with changing functions a generic shape.

7.1.6 Installing Large Programs on a Computer
This can be a very time-consuming and stressful process. The team decided to investigate this event as we found similarities to waiting the machine to finish a sample.
7.1.6.1 Findings
- May take hours, but you need to monitor the computer to see if you need to input.
- Would be nice to be sent a text message if there is an error as opposed to hanging around.
- Time remaining rarely accurate.
- Find way to complete all inputs at beginning (i.e.: create desktop shortcut) to let process happen without monitoring.

7.1.6.2 Conclusions
In a lab, the technicians need to be able to work on other procedures while the test is running. We will need to find a way for them to do so, but not have the finished samples waiting for too long as to increase throughput. The time remaining is also important, as they may like to know when to return to the machine.

7.1.7 Best Buy Trip
We decided to go to Best Buy to explore what technologies current laptops are using to make the interface more intuitive.

7.1.7.1 Findings
- All new PCs on display have both touch screen and keyboard.
- It is annoying to have arm constantly elevated, we found that we just ended up using touchpad on the devices that didn't have an adjustable screen.
- Having all the info right in front of you is overwhelming, it would have been beneficial to be able to hide functions that were not used as often.
- When typing, we had no desire to reach out to touch the screen. In this case, we found that we were just using the touchpad near the keyboard.
- Being able to choose between using the touch screen or a mouse was helpful.

7.1.7.2 Conclusions
It was nice to use devices with an adjustable screen as it is not comfortable to have our arms elevated constantly. We also found that we were playing with the touch screen initially because it was a new experience, but as we got more used to the feature, we resorted to the mouse or touchpad. Still, it was nice to have the option to use one or the other.
7.2 Needfinding

7.2.1 World Usability Day

On the 14th of November, 2013 “World Usability Day” [WUD] took place. In 32 countries 107 events were held on the topic of “Healthcare: Collaborating for better System.” The St. Gallen team decided to visit two events in order to get a good impression of usability in the medical environment. The event in Geneva, Switzerland had three guest speakers. The first was Rolf Wiplfi, PhD, who is working at the Geneva University Hospitals and who talked on the topic of “Usability in the Hospital”. The second speaker was Virginia Lang, PhD and founder of HirLan, talking about “User Centered Participatory Design and Medical Devices: The Good, the Bad, and the Ugly”. And the last speaker Florian Egger, PhD spoke on the topic of “Mapping the User Experience of Smart Blood Pressure Monitors”. At the same time he was the organizer of the event.

7.2.1.1 Findings

- Human Factor Testing is required by regulators in America (FDA) and Europe, meaning that the usability of a new device must be tested before getting approval. HirLan is an example of a company which offers services to test the usability before applying for approval.

- Paper is often still preferred over electronic devices for communication in Europe. One reason for this fact is that the HIS are not yet developed very well and the second reason was that electronics do not yet add big value over paper. Hospitals often work with several different systems offered by a big number of smaller vendors. Virginia Lang mentioned that this causes problems and can affect patient's safety and therefore is becoming a higher priority by regulators. Changes are expected to happen in the coming years.

- According to studies, most alerts are ignored by the users, especially when they the alerts are shown routinely. It is therefore important to decide which alerts are really important to the user and how to present them in order to avoid overseeing them in a case of emergency.

- A further interesting learning was the integration of new technologies in the medical field. We were presented examples where new technologies such as Google Glass or
motion control are adopted in hospitals. Both technologies are being tested for use during operations. In some cases these examples are even being applied during procedures.

- A further interesting insight was the conflicting priorities between safety and innovation. Safety usually is valued more strongly than innovation. Accordingly functionality is at the moment the main decision criteria, when it comes to investment decisions. However, usability is gaining importance. It is getting more and more important to offer both aspects.
- The aspects of support and troubleshooting were one last important insight from our visit of the WUD event in Stuttgart. These valuable services are being requested by users increasingly. New offers such as remote access are being deployed and help to reduce downtime for the user. Vendors are able to differentiate their product though offering such additional services.

7.2.1.2 Conclusions
It will be important that any system that we develop will be flexible enough to adapt to different hospital systems. It will also have to be intuitive enough to merit the hospital switching from paper to electronic. We need to also make sure that we only show alerts that need to be attended to as others may be ignored. We will have to be aware of which technologies are simply fads as opposed to those that will have a long lasting impact.

7.2.2 MEDICA
The St. Gallen team also visited MEDICA, the world's largest exhibition for the medical sector. On the 21st and 22nd of November two the team members visited several vendors in order to be inspired by different designs, ideas and new developments.

7.2.2.1 Findings
- The development of laboratory testing machines in most cases is initiated by reagent companies that need a platform for selling their reagents. The technical planning and development is done by other specialized companies that are interested in producing such machines in a large scale.
- When looking at diagnostics devices and their user interface in all different fields of application we quickly realized that they are far behind consumer electronics in terms of usability. Although we know that investment cycles for diagnostic devices are much
longer (5-20 years) than for consumer devices, we were surprised how little influence the trend of usability brought by the evolution of smart phones and tablets had on latest diagnostic devices so far.

- We assume that most vendors are not spending much effort in the development of a user interface; they mainly focus on hardware functionality.

- One of the few companies which seem to think about using the positive user experience of consumer tablets for their diagnostics solution is Orphe Group (Geneva). *Figure 81* shows one of their prototypes which uses an Android based tablet as user interface which can be easily detached in order to control the device remotely. The fact that they are obviously successful in trying to implement consumer electronics for improving user experience shows us that there is a potential which we should not forget about.

- A further insight we gained is that there are obviously very high regulation standards that need to be complied with when developing a new application in the medical field. Therefore time to market is rather high.
Figure 81 Orphe Group Prototype
8 Appendix B

Detailed drawings
9 Appendix C

Arduino Code

9.1 Operating the Machine

```c
/*--------------------- Includes ---------------------*/
#include <Timers.h>
#include <Bridge.h>
#include <YunServer.h>
#include <YunClient.h>

bool flagProbeError = true;       //for probe error
YunClient client;
YunServer server;

/*------------------Module Defines------------------*/
int TempCircuitPin = 12;
float Temperature = 0;
float prevTemp = 0;

#define TEMP_MIN 25
#define TEMP_MAX 34
#define TEMP_ABNORMAL 21

int IR0_Value = 0;
int IR1_Value = 0;
int IR2_Value = 0;
int IR3_Value = 0;

/* ----------------pin definition---------------------------*/
#define GoodCircuitPin 12

#define LEDRedPin A0
```
#define LEDGreenPin A1
#define LEDProbePin 13
#define LEDFusePin 7
#define TempPin A4
#define StMotorStep 6   // Stepper motor step pin
#define LAProbeDir 8    // Linear Actuator direction pin for moving the probe
#define LAProbeSpeed 9  // Linear Actuator pin for controlling speed of the probe
#define LAPlateDir 10   // Linear Actuator direction pin for moving the plate
#define LAPlateSpeed 11 // Linear Actuator pin for controlling speed of the plate
#define IR0Signal 2
#define IR1Signal 3
#define IR2Signal 4
#define IR3Signal 5

/* ---------------------- define different timers ----------------------*/
#define Calibration 0
#define IntervalCalibration 5000
int TimerCalibration = 0;
#define StateStart 1
#define IntervalStateStart 10000
int TimerStateStart = 0;
#define ProbeFwd 2
#define IntervalProbeFwd 6500
#define ProbeBck 3
#define IntervalProbeBck 13000
int TimerProbe = 0;
#define Incubation 4
#define IntervalIncubation 4000
int TimerIncubation = 0;

#define Print 5
#define IntervalPrint 4000
int TimerPrint = 0;

#define RemovePlate 6
#define IntervalRemovePlate 4000
int TimerRemovePlate = 0;

#define Timeout 7
#define IntervalTimeout 15000
int TimerTimeout = 0;

/*the max frequency the sensor can be sampled is about once per 3 seconds*/
#define TempSensing 8
#define IntervalTempSensing 500
int TimerTempSensing = 0;

unsigned int state;
unsigned int prevState;

typedef enum
{
    CalibrateMachine = 0,
    TestStart = 1,
    MoveToReagents = 2,
    MoveProbes = 3,
    MoveToIncubator = 4,
Incubating = 5,
MoveToPrinter = 6,
Printing = 7,
Exit = 8,
TimeoutError = 9,
ProbeError = 10,
TempError = 11,
CustomerSupport = 12,
MachineReadyState = 13,
};

/*------------------- Module Function Prototypes -------------------*/
void Calibrating();
void Starting();
void MovingToReagents();
void MovingProbes();
void MovingToIncubator();
void IncubationStay();
void MovingToPrinter();
void PrinterStay();
void ExitPlate();
void ShowingTimeoutError();
void MeasureTemp();
void IncubatorTempControl();
void ShowingProbeError();
void ShowingTempError();
void Support();

void setup()
{
    //pinMode(StMotorDir, OUTPUT);
pinMode(StMotorStep, OUTPUT);
pinMode(LAProbeDir, OUTPUT);
pinMode(LAProbeSpeed, OUTPUT);
pinMode(LAPlateDir, OUTPUT);
pinMode(LAPlateSpeed, OUTPUT);
pinMode(GoodCircuitPin, OUTPUT);
pinMode(IR0Signal, INPUT_PULLUP);
pinMode(IR1Signal, INPUT_PULLUP);
pinMode(IR2Signal, INPUT_PULLUP);
pinMode(IR3Signal, INPUT_PULLUP);
pinMode(TempPin, INPUT);
pinMode(LEDRedPin, OUTPUT);
pinMode(LEDGreenPin, OUTPUT);
pinMode(LEDProbePin, OUTPUT);
pinMode(LEDFusePin, OUTPUT);

analogWrite(LAPlateSpeed, 0);  //Speed while coming back
analogWrite(LAProbeSpeed, 0);  //Speed while coming back
analogWrite(StMotorStep, 0);

state = CalibrateMachine;
prevState = state;
setState(state);

digitalWrite(LEDRedPin, LOW);
digitalWrite(LEDGreenPin, LOW);
digitalWrite(LEDProbePin, LOW);
digitalWrite(GoodCircuitPin, HIGH);
digitalWrite(LEDFusePin, LOW);

Bridge.begin();
server.begin();
void loop()
{
    if (state != CalibrateMachine) {
        MeasureTemp();
        IncubatorTempControl();
    }

    switch (state)
    {
    case (CalibrateMachine):        Calibrating();
            break;
    case (MachineReadyState):       MachineReady();
            break;
    case (TestStart):               Starting();
            break;
    case (MoveToReagents):          MovingToReagents();
            break;
    case (MoveProbes):              MovingProbes();
            break;
    case (MoveToIncubator):         MovingToIncubator();
            break;
    case (Incubating):              IncubationStay();
            break;
    }
case (MoveToPrinter): MovingToPrinter();
    break;

case (Printing): PrinterStay();
    break;

case (Exit): ExitPlate();
    break;

case (TimeoutError): ShowingTimeoutError();
    break;

case (ProbeError): ShowingProbeError();
    break;

case (TempError): ShowingTempError();
    break;

case (CustomerSupport): Support();
    break;
}

// Check communication
client = server.accept();
if (client) {
    // Process request
    process(client);
    client.stop();
}

// Push new state and temperature to firebase
if (state != prevState) {
setState(state);
prevState = state;
if (state == ProbeError) {
    sendNotification("error", "Probe Error", "touch for instructions");
}
if (state == TempError) {
    sendNotification("error", "Temperature Error", "touch for instructions");
}
)

if (abs(Temperature - prevTemp) > 0.5) {
    Temperature = 0.6 * Temperature + 0.4 * prevTemp;
    setTemperature(Temperature);
    prevTemp = Temperature;
}
}

/*---------- Defining all the functions -----------*/

void Calibrating()
{
    if (TimerCalibration == 0 && TimerTimeout == 0)
    {
        TMRArd_InitTimer(Calibration, IntervalCalibration);
        TMRArd_InitTimer(Timeout, IntervalTimeout);
        TimerCalibration = 1;
        TimerTimeout = 1;
        TimerStateStart = 0;
        TimerProbe = 0;
TimerIncubation = 0;
TimerPrint = 0;
TimerRemovePlate = 0;

analogWrite(LAPlateSpeed, 0);
analogWrite(LAProbeSpeed, 0);
digitalWrite(LEDRedPin, LOW);
digitalWrite(LEDDGreenPin, LOW);
digitalWrite(LEDProbePin, LOW);
digitalWrite(LEDFusePin, LOW);
}

if (TMR_Ard_IsTimerExpired(Timeout))
{
  TimerCalibration = 0;
  TimerTimeout = 0;
  state = TempError;
}

else
{
  analogWrite(StMotorStep, 122);

digitalWrite(LAPlateDir, HIGH); //bring the LA to original position
analogWrite(LAPlateSpeed, 255); //Speed while coming back

digitalWrite(LAProbeDir, LOW);  //bring back to original position
analogWrite(LAProbeSpeed, 255); //Speed while coming back

MeasureTemp();
setTemperature(Temperature);
if (Temperature > TEMP_MIN && TMR_Ard_IsTimerExpired(Calibration)) {
    TimerCalibration = 0;
    TimerTimeout = 0;
    state = MachineReadyState;
}

void Starting()
{
    if (TimerStateStart == 0)
    {
        TMR_Ard_InitTimer(StateStart, IntervalStateStart);
        TimerStateStart = 1;
    }

    IR0_Value = digitalRead(IR0Signal);

    if (TMR_Ard_IsTimerExpired(StateStart) || IR0_Value == LOW)
    {
        analogWrite(LA_PlateSpeed, 0);
        digitalWrite(LA_PlateDir, HIGH);  //Move back to original position
        analogWrite(LA_PlateSpeed, 255);  //Speed of movement
        state = MoveToReagents;
        TimerStateStart = 0;

        if (TMR_Ard_IsTimerExpired(StateStart))
        {
            TimerStateStart = 0;
        }
    }
state = TimeoutError;

}

}

else
{
    analogWrite(LAPlateSpeed, 0);
digitalWrite(LAPlateDir, LOW); //Move the plate to the belt
analogWrite(LAPlateSpeed, 255); //Speed of movement
}

}

}

void MovingToReagents()
{
{
    if (TimerTimeout == 0)
    {
        TMRArd_InitTimer(Timeout, IntervalTimeout);
        TimerTimeout = 1;
    }

    if (TMRArd_IsTimerExpired(Timeout))
    {
        state = TimeoutError;
        TimerTimeout = 0;
    }
}

IR1_Value = digitalRead(IR1Signal);

if (IR1_Value == LOW)
{

}
analogWrite(StMotorStep, 0);
state = MoveProbes;
TimerTimeout = 0;
}

else
{
analogWrite(StMotorStep, 122); // Run the stepper motor
}

void MovingProbes()
{
if (TimerTimeout == 0)
{
    TMRArd_InitTimer(Timeout, IntervalTimeout);
    TimerTimeout = 1;
}

if (TMRArd_IsTimerExpired(Timeout))
{
    state = TimeoutError;
    TimerTimeout = 0;
}

if (TimerProbe == 0)
{
    TMRArd_InitTimer(ProbeFwd, IntervalProbeFwd);
    TMRArd_InitTimer(ProbeBck, IntervalProbeBck);
    TimerProbe = 1;
if (flagProbeError)
{
    state = ProbeError;
    flagProbeError = false;    //Probe error only shows once
    TimerProbe = 0;
    TimerTimeout = 0;
}

if (TMR Ard_IsTimerExpired(ProbeBck))
{
    state = MoveToIncubator;
    TimerTimeout = 0;
    TimerProbe = 0;
}

else
{
    if (TMR Ard_IsTimerExpired(ProbeFwd))
    {
        analogWrite(LAProbeSpeed, 0);
        digitalWrite(LAProbeDir, LOW);  //Move the probe back
        analogWrite(LAProbeSpeed, 255);
    }

    else
    {
        analogWrite(LAProbeSpeed, 0);
        digitalWrite(LAProbeDir, HIGH);  //Move the probe forward
        analogWrite(LAProbeSpeed, 255);
    }
void MovingToIncubator()
{
    if (TimerTimeout == 0)
    {
        TMRArd_InitTimer(Timeout, IntervalTimeout);
        TimerTimeout = 1;
    }

    if (TMRArd_IsTimerExpired(Timeout))
    {
        state = TimeoutError;
        TimerTimeout = 0;
    }

    IR2_Value = digitalRead(IR2Signal);

    if (IR2_Value == LOW)
    {
        analogWrite(StMotorStep, 0);
        state = Incubating;
        TimerTimeout = 0;
    }

    else
    {
        analogWrite(StMotorStep, 122);
    }
void IncubationStay()
{
    if (TimerIncubation == 0)
    {
        TMRArd_InitTimer(Incubation, IntervalIncubation);
        TimerIncubation = 1;
    }

    if (TMRArd_IsTimerExpired(Incubation))
    {
        state = MoveToPrinter;
        TimerTimeout = 0;
        TimerIncubation = 0;
    }
}

void MovingToPrinter()
{
    if (TimerTimeout == 0)
    {
        TMRArd_InitTimer(Timeout, IntervalTimeout);
        TimerTimeout = 1;
    }

    if (TMRArd_IsTimerExpired(Timeout))
    {

    }
state = TimeoutError;
TimerTimeout = 0;
}

IR3_Value = digitalRead(IR3Signal);

if (IR3_Value == LOW)
{
    analogWrite(StMotorStep, 0);
    state = Printing;
    TimerTimeout = 0;
}

else
{
    analogWrite(StMotorStep, 122);
}

void PrinterStay()
{
    if (TimerPrint == 0)
    {
        TMRArd_InitTimer(Print, IntervalPrint);
        TimerPrint = 1;
    }

    if (TMRArd_IsTimerExpired(Print))
    {
        state = Exit;
    }
TimerPrint = 0;

void ExitPlate()
{
    flagProbeError = true;

    if (TimerRemovePlate == 0)
    {
        TMRard_InitTimer(RemovePlate, IntervalRemovePlate);
        TimerRemovePlate = 1;
    }

    if (TMRard_IsTimerExpired(RemovePlate))
    {
        TimerCalibration = 0;
        TimerStateStart = 0;
        TimerProbe = 0;
        TimerIncubation = 0;
        TimerPrint = 0;
        TimerRemovePlate = 0;
        TimerTimeout = 0;
        analogWrite(StMotorStep, 0);
        state = CalibrateMachine;
        analogWrite(LAPlateSpeed, 0);  // Speed while coming back
        analogWrite(LAProbeSpeed, 0);  // Speed while coming back
    }

    else
void ShowingTimeoutError()
{
    analogWrite(StMotorStep, 0);
}

void MeasureTemp()
{
    /* to measure the temperature every 3 seconds*/
    if (TimerTempSensing == 0)
    {
        TMRArd_InitTimer(TempSensing, IntervalTempSensing);
        TimerTempSensing = 1;
        int t = analogRead(TempPin);
        Temperature = t * (5000. / 1024.);
        Temperature = (Temperature - 500) / 10;
    }
    else if (TMRArd_IsTimerExpired(TempSensing))
    {
        TimerTempSensing = 0;
    }
}

void IncubatorTempControl()
{

if (Temperature > TEMP_MAX)
{
    if (state == CustomerSupport || state == TempError)
    {
        state = CalibrateMachine;
    }
    digitalWrite(GoodCircuitPin, LOW);
}

else if (Temperature < TEMP_MIN)
{
    digitalWrite(GoodCircuitPin, HIGH);
}

if (Temperature < TEMP_ABNORMAL)
{
    //Glow red light
    //Print Error
    //Display --- Error in the machine. check light bulb connection

    digitalWrite(GoodCircuitPin, HIGH);  //so that there is no current in the circuit while changing the fuse.
    state = TempError;
}

void ShowingProbeError()
{
    analogWrite(StMotorStep, 0);
    analogWrite(LAProbeSpeed, 0);
    TimerTimeout = 0;
/glow red led in the probe
digitalWrite(LEDProbePin, HIGH);
digitalWrite(LEDRedPin, HIGH);
digitalWrite(LEDGreenPin, LOW);
}

void ShowingTempError()
{
analogWrite(StMotorStep, 0);
TimerTimeout = 0;

//glow red led
digitalWrite(LEDRedPin, HIGH);
digitalWrite(LEDGreenPin, LOW);
}

void MachineReady()
{
//grow green light
digitalWrite(LEDRedPin, LOW);
digitalWrite(LEDGreenPin, HIGH);
//wait for the GUI to start
analogWrite(StMotorStep, 0);

TimerTimeout = 0;
}

void Support()
{
//while error -- display error
// Have to decide when to turn on the TempCircuitPin again, to light the bulb back so that the temperature can rise again.

// else if Temp back to normal.
// change to State = Calibrating
TimerTimeout = 0;
}

// process command from the GUI
void process(YunClient client) {
    // read the command
    String command = client.readStringUntil('/');

    if (command == "state") {
        stateCommand(client);
    } else if (command == "digital") {
        digitalCommand(client);
    } else {
        client.println("Wrong Command!");
    }
}

void stateCommand(YunClient client) {
    int value;

    value = client.parseInt();
    state = value;
    client.println("Change machine state to state No." + String(state));
void digitalCommand(YunClient client) {
    int pin, value;

    // Read pin number
    pin = client.parseInt();

    // If the next character is a '/' it means we have an URL
    // with a value like: "/digital/13/1"
    if (client.read() == '/') {
        value = client.parseInt();
        digitalWrite(pin, value);
    } else {
        value = digitalRead(pin);
    }

    // Send feedback to client
    client.println("HTTP/1.1 200 OK");
    client.println("Access-Control-Allow-Origin: *");
    client.println("Content-Type: text/html");
    client.print(F("Pin D");
    client.print(pin);
    client.print(F(" set to ");
    client.println(value);
}

void setState(int s) {
    Process p;
    p.runShellCommand("curl -X PUT -k -d " + String(s) + "
        https://tucuxi.firebaseio.com/machine/state.json");
}
void setTemperature(float t) {
    Process p;
}

void sendNotification(String type, String title, String text) {
    Process p;
    p.runShellCommand("curl -X POST -k -d '{"type": "" + type + "," + "title": "" + title + "," + "text": "" + text + "}' https://tucuxi.firebaseapp.com/notifications.json");
}

### 9.2 Servo Motor Control Code

```
#include <Servo.h>
Servo servo[2];
char val = 0;
char signal[2];
int pos[2];
int bytesread;

void setup()
{
    servo[0].attach(9); // attaches the servo on pin 9 to the servo object
    servo[1].attach(11);
    //Initialize Servo Position
    pos[0] = 90;
    pos[1] = 90;
    servo[0].write(pos[0]);
    servo[1].write(pos[1]);
```
Serial.begin(9600);
}
void loop()
{
  while (Serial.available() == 0){}

  if((val = Serial.read()) == 's')
  {   // check for header
    bytesread = 0;
    while(bytesread<2)
    {
      if( Serial.available() > 0)
      {
        val = Serial.read();
        if(val == 's' || val == 'e') // if header or stop bytes before the 10 digit reading
          signal[0] = 'n';
        signal[1] = 'n';
        break;                      // stop reading
      }
      signal[bytesread] = val;    // add the digit
      bytesread++;               // ready to read next digit
    }
  }
  for (int i=0; i<2; i++){
    if (signal[i] == 'u' && pos[i] < 180)
    {
      pos[i] += 2;
      servo[i].write(pos[i]);
    }
    else
    {
      if (signal[i] == 'd' && pos[i] > 0)
{  
    pos[i] -= 2;
    servo[i].write(pos[i]);
}
if (signal[i] == 'r')
{
    pos[i] = 90;
    servo[i].write(pos[i]);
}
}

9.3  Keyboard Control Code (part of a typical MFC Application Project)

BOOL CFunkyCommandCenterDlg::PreTranslateMessage(MSG *msg)
{
    DWORD dwWritten;
    if (msg->message == WM_KEYDOWN)
    {
        if (msg->wParam == VK_DOWN)
        {
            if (!WriteFile(m_hComm, LPCVOID("snue"), 4, &dwWritten, NULL))
            {
                AfxMessageBox(LPCTSTR("error sending message"));
            }
            return true;
        }
        if (msg->wParam == VK_UP)
        {
            if (!WriteFile(m_hComm, LPCVOID("snde"), 4, &dwWritten, NULL))
if (msg->wParam == VK_LEFT) {
    if (!WriteFile(m_hComm, LPCVOID("sdne"), 4, &dwWritten, NULL)) {
        AfxMessageBox(LPCTSTR("error sending message"));
    }
}
if (msg->wParam == VK_RIGHT) {
    if (!WriteFile(m_hComm, LPCVOID("sune"), 4, &dwWritten, NULL)) {
        AfxMessageBox(LPCTSTR("error sending message"));
    }
    return true;
}
if (msg->wParam == VK_SHIFT) {
    if (!WriteFile(m_hComm, LPCVOID("srre"), 4, &dwWritten, NULL)) {
        AfxMessageBox(LPCTSTR("error sending message"));
    }
    return true;
}
return false;
9.4 Functional Prototype Code

/*
Motor Definition:
Shield 1:
  11 - Robotics Arm X axis Left - A=1, +x
  12 - Probe - A=1, -y
  14 - Incubator - A=1, out
Shield 2:
  21 - Robotics Arm X axis Right - A=1, +x
  22 - Robotics Arm Y axis - A=1, -y
  23 - Robotics Arm Z axis - A=1, up
  24 - Robotics Arm Electromagnetic - A=1, on
*/

#define Data1_MotorControl 10
#define Data1_Clk 12
#define Data1_En 11
#define Data1_Latch 9

#define Data2_MotorControl 7
#define Data2_Clk 5
#define Data2_En 6
#define Data2_Latch 8

#define M11_speed 2
#define M12_speed 13
#define M21_speed A1
#define M23_speed 3

#define SwitchZ0 4
#define SwitchX0 A2
#define SwitchY0 A3
#define SwitchXi A4
#define SwitchYi A5

// M3B, M4B, M3A, M2B, M1B, M1A, M2A, M4A
byte MotorState1 = B0;
byte MotorState2 = B0;
int time_now;

void setup(){
    pinMode(Data1_MotorControl, OUTPUT);
    pinMode(Data1_Clk, OUTPUT);
    pinMode(Data1_En, OUTPUT);
    pinMode(Data1_Latch, OUTPUT);
    pinMode(Data2_MotorControl, OUTPUT);
    pinMode(Data2_Clk, OUTPUT);
    pinMode(Data2_En, OUTPUT);
    pinMode(Data2_Latch, OUTPUT);
    digitalWrite(Data1_En, HIGH);
    digitalWrite(Data2_En, HIGH);
    pinMode(M11_speed, OUTPUT);
    pinMode(M12_speed, OUTPUT);
    pinMode(M21_speed, OUTPUT);
    pinMode(M23_speed, OUTPUT);
    pinMode(SwitchZ0, INPUT_PULLUP);
    pinMode(SwitchX0, INPUT_PULLUP);
    pinMode(SwitchY0, INPUT_PULLUP);
    pinMode(SwitchXi, INPUT_PULLUP);
    pinMode(SwitchYi, INPUT_PULLUP);
}

void loop(){

//digitalWrite(Data1_En, LOW);
//digitalWrite(Data2_En, LOW);
//MoveRoboticsArmXaxis(false);
//MoveRoboticsArmYaxis(true, 0);
//MotorState2 = B10;  //M22(A=1)
//SendData2MotorShield2(MotorState2);
//TurnOnMagnetic();
//LiftArm(10000);
//DropArm(20000);
//LiftArm(4000);
//MoveRoboticsArmYaxis(false, 8000);
    //MotorState2 = B10 | (B1000000 & MotorState2);  //M22(A=1)
    //SendData2MotorShield2(MotorState2);
//MoveRoboticsArmYaxis(true, 20000);
//TurnOnMagnetic();

// lift arm
//LiftArm(6000);
Initialize();
runThrough();
while(true){
    //runError();
}

boolean Initialize(){
    //Initialize all motor component position
    //Probe arm & Incubator plate
    analogWrite(M12_speed, 140);
    MotorState1 = B10;  //M12(A=1)
    digitalWrite(Data1_En, LOW);
    ChangeMotorShield1State(800);
    MotorState1 = B1;
    ChangeMotorShield1State(4000);
MoveRoboticsArmYaxis(false, 5000);
//Robotics arm X axis
digitalWrite(Data2_En, LOW);
MoveRoboticsArmXaxis(true);
//Robotics arm Y axis
MoveRoboticsArmYaxis(true, 0);
// Initialize Robotics Arm Z axis position with switch
DropArm(0);
}

void runThrough(){
//robotics arm: from initial to tray hotel
LiftArm(16500);
MoveRoboticsArmYaxis(false, 8000);
//move to tray hotel
MoveRoboticsArmXaxis(false);
MoveRoboticsArmYaxis(true, 0);
DropArm(6000);
TurnOnMagnetic();
delay(500);
LiftArm(6000);
//robotics arm: from tray hotel to probe
MoveRoboticsArmYaxis(false, 8000);
MoveRoboticsArmXaxis(true);
//move to the probe
DropArm(17000);
TurnOffMagnetic();
//move probe
analogWrite(M12_speed, 140);
MotorState1 = B10000;
ChangeMotorShield1State(1000);
MotorState1 = B10;
ChangeMotorShield1State(1000);

// robotics arm: from probe to incubator
TurnOnMagnetic();
LiftArm(5000);
MoveRoboticsArmXaxis(false);
MoveRoboticsArmYaxis(false, 0);
DropArm(3000);
TurnOffMagnetic();
LiftArm(3000);

// move plate into incubator
MotorState1 = B1000000;
ChangeMotorShield1State(3500);
delay(500);

// move plate out of incubator
MotorState1 = B1;
ChangeMotorShield1State(3500);

// robotics arm: from incubator to tray hotel
DropArm(3000);
TurnOnMagnetic();
LiftArm(14000);
MoveRoboticsArmYaxis(true, 0);
DropArm(6000);
TurnOffMagnetic();
LiftArm(6000);
}

void LiftArm(int time){
digitalWrite(Data1_En, HIGH);
analogWrite(M23_speed, 250);
MotorState2 = B100000 | (B1000000 & MotorState2);
void DropArm(int time){
    digitalWrite(Data1_En, HIGH);
    analogWrite(M23_speed, 250);
    MotorState2 = B10000000 | (B1000000 & MotorState2);   //M23(B=1)
    time_now = millis();
    SendData2MotorShield2(MotorState2);
    if (time == 0){
        while(1){
            if (digitalRead(SwitchZ0) == false) break;
        }
    } else{
        delay(time);
    }
    MotorState2 = B0 | (B1000000 & MotorState2);
    SendData2MotorShield2(MotorState2);
}

void TurnOnMagnetic(){
    MotorState2 = B1000000;        //M24(A=1)
    SendData2MotorShield2(MotorState2);
}

void TurnOffMagnetic(){
    MotorState2 = B0;
    SendData2MotorShield2(MotorState2);
}

void ChangeMotorShield1State(int time){
}
digitalWrite(Data1_En, LOW);
SendData2MotorShield1(MotorState1);
delay(time);
MotorState1 = B0;
SendData2MotorShield1(MotorState1);
digitalWrite(Data1_En, HIGH);
}

void ChangeMotorShield2State(int time){
SendData2MotorShield2(MotorState2);
delay(time);
MotorState2 = B1000000 & MotorState2;
SendData2MotorShield2(MotorState2);
}

void MoveRoboticsArmXaxis(boolean dire){
digitalWrite(Data1_En, LOW);
//digitalWrite(Data2_En, LOW);
if (dire == false){
analogWrite(M11_speed, 255);
analogWrite(M21_speed, 254);
MotorState1 = B1000; //M11(B=1)
MotorState2 = B100 | (B1000000 & MotorState2); //M21(B=1)
SendData2MotorShield2(MotorState2);
SendData2MotorShield1(MotorState1);

while (1) {
if (digitalRead(SwitchXi) == false) break;
}
MotorState2 = B1000000 & MotorState2;
SendData2MotorShield2(MotorState2);
MotorState1 = B0;
SendData2MotorShield1(MotorState1);
digitalWrite(Data1_En, HIGH);
return;
}
if (dire == true){
analogWrite(M11_speed, 254);
MotorState1 = B100;  //M11(A=1)
analogWrite(M21_speed, 255);
MotorState2 = B1000 | (B1000000 & MotorState2);    //M21(A=1)
int time_now = millis();
SendData2MotorShield1(MotorState1);
SendData2MotorShield2(MotorState2);
while (1) {
    if (digitalRead(SwitchX0) == false) break;
}
MotorState2 = B1000000 & MotorState2;
SendData2MotorShield2(MotorState2);
MotorState1 = B0;
SendData2MotorShield1(MotorState1);
digitalWrite(Data1_En, HIGH);
return;
}

void MoveRoboticsArmYaxis(boolean dire, int time){
digitalWrite(Data1_En, HIGH);
digitalWrite(Data2_En, LOW);
if (dire == true){
    MotorState2 = B10 | (B1000000 & MotorState2);    //M22(A=1)
    SendData2MotorShield2(MotorState2);
    if (time == 0){
        while(1){
            }
if (digitalRead(SwitchY0) == false) break;
}
}
else{
delay(time);
}
}
if (dire == false){
    MotorState2 = B10000 | (B1000000 & MotorState2);  //M22(A=1)
   SendData2MotorShield2(MotorState2);
    if (time == 0){
        while(1){
            if (digitalRead(SwitchYi) == false) break;
        }
    }
    else{
delay(time);
    }
}
}
if (dire == false){
    MotorState2 = B1000000 & MotorState2;
    SendData2MotorShield2(MotorState2);
    
    MotorState1 = B0;
    SendData2MotorShield1(MotorState1);
}

void SendData2MotorShield1(byte MotorState) {
    // turn off the output so the pins don't light up
    // while you're shifting bits:
    digitalWrite(Data1_Latch, LOW);

    // shift the bits out:
shiftOut(Data1_MotorControl, Data1_Clk, MSBFIRST, MotorState);

  // turn on the output so the LEDs can light up:
  digitalWrite(Data1_Latch, HIGH);
}

void SendData2MotorShield2(byte MotorState) {
  // turn off the output so the pins don't light up
  // while you're shifting bits:
  digitalWrite(Data2_Latch, LOW);

  // shift the bits out:
  shiftOut(Data2_MotorControl, Data2_Clk, MSBFIRST, MotorState);

  // turn on the output so the LEDs can light up:
  digitalWrite(Data2_Latch, HIGH);
}
10 Appendix D

Graphical User Interface: It includes all the screenshots of the interface developed.

10.1 Final Interface: Tucuxi
### Scheduled QC

<table>
<thead>
<tr>
<th>ID</th>
<th>Date / Time</th>
<th>Scheduled By</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>30.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>202</td>
<td>30.05.14, 1:15 AM</td>
<td>Gerda Hilbert</td>
<td>![icon]</td>
</tr>
<tr>
<td>203</td>
<td>29.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>204</td>
<td>28.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>205</td>
<td>29.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>206</td>
<td>25.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>207</td>
<td>28.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
<tr>
<td>208</td>
<td>25.05.14, 1:15 AM</td>
<td>Pera Welker</td>
<td>![icon]</td>
</tr>
</tbody>
</table>

### Machine State: Timeout Error

*0.46h*

### PEG

**Status:** OK

Test regent environment set up correctly.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot 1: Regent A</td>
<td>Slot 5: Regent E</td>
<td>Slot 9: Regent J</td>
</tr>
<tr>
<td>[details]</td>
<td>[details]</td>
<td>[details]</td>
</tr>
<tr>
<td>Slot 2: Regent B</td>
<td>Slot 6: Regent F</td>
<td>Slot 10: Regent J</td>
</tr>
<tr>
<td>[details]</td>
<td>[details]</td>
<td>[details]</td>
</tr>
<tr>
<td>Slot 3: Regent C</td>
<td>Slot 7: Regent G</td>
<td>Slot 11: Regent J</td>
</tr>
<tr>
<td>[details]</td>
<td>[details]</td>
<td>[details]</td>
</tr>
<tr>
<td>Slot 4: Regent D</td>
<td>Slot 8: Regent H</td>
<td>Slot 12: Regent J</td>
</tr>
<tr>
<td>[details]</td>
<td>[details]</td>
<td>[details]</td>
</tr>
</tbody>
</table>
How to Fix Probe Error

Step 1: Remove Probe

Instructions

1. Unscrew right probe and remove from holder.
2. Open holder and place broken probe in the left container.
3. Remove new probe from the right container.
4. Align new probe with the holder and slide into place.

Step 2: Remove Probe
How to Fix Probe Error

Step 3: Remove Pipette

Instructions
1. Unscrew right probe and remove from holder.
2. Open back-end plate of main probe in the left container.
3. Remove new probe from the right container.
4. Align new probe with the holder and screw into place.
10.2 Winter Quarter Interface
<table>
<thead>
<tr>
<th>Purchaser</th>
<th>Date</th>
<th>Category</th>
<th>Vendor Name</th>
<th>Description of Expense</th>
<th>Pre-tax Amount</th>
<th>Shipping &amp; Handling (if any)</th>
<th>Amount Incl Sales Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harshit Jain</td>
<td>10/18/2013</td>
<td>Prototype</td>
<td>Room 36</td>
<td>Materials for Paper Robot</td>
<td>$39.35</td>
<td>$0.00</td>
<td>$39.35</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>11/5/2013</td>
<td>Prototype</td>
<td>CVS Pharmacy</td>
<td>Cholesterol and Glucose Meters</td>
<td>$30.98</td>
<td>$0.00</td>
<td>$33.69</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>11/20/2013</td>
<td>Prototype</td>
<td>Radio Shack</td>
<td>3 Vibrating Motors</td>
<td>$11.97</td>
<td>$0.00</td>
<td>$13.02</td>
</tr>
<tr>
<td>Manny</td>
<td>11/25/2013</td>
<td>NA</td>
<td>Southwest</td>
<td>Plane to EMD (Sean, Yu, Harshit)</td>
<td>$461.40</td>
<td>$0.00</td>
<td>$461.40</td>
</tr>
<tr>
<td>Manny</td>
<td>11/26/2013</td>
<td>NA</td>
<td>Southwest</td>
<td>Plane to EMD (Wanxi)</td>
<td>$157.80</td>
<td>$0.00</td>
<td>$157.80</td>
</tr>
<tr>
<td>Yu Hsiao</td>
<td>November</td>
<td>Travel</td>
<td>Mileage Reimbursement</td>
<td>See Mileage sheet</td>
<td>$36.73</td>
<td>$0.00</td>
<td>$36.73</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>November</td>
<td>Travel</td>
<td>Mileage Reimbursement</td>
<td>See Mileage sheet</td>
<td>$16.72</td>
<td>$0.00</td>
<td>$16.72</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>December</td>
<td>Travel</td>
<td>Mileage Reimbursement</td>
<td>See Mileage sheet</td>
<td>$5.08</td>
<td>$0.00</td>
<td>$5.08</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>12/1/2013</td>
<td>Prototype</td>
<td>Best Buy</td>
<td>Leap Motion</td>
<td>$79.99</td>
<td>$0.00</td>
<td>$86.99</td>
</tr>
<tr>
<td>Sean Poluha</td>
<td>12/1/2013</td>
<td>Prototype</td>
<td>Michaels</td>
<td>Velcro</td>
<td>$3.79</td>
<td>$0.00</td>
<td>$4.12</td>
</tr>
<tr>
<td>Wanxi Liu</td>
<td>12/1/2013</td>
<td>Prototype</td>
<td>Jameco</td>
<td>Arduino and RFID materials</td>
<td>$79.40</td>
<td>$0.00</td>
<td>$86.56</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$941.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fall Allocation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Available Balance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$58.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Amount</td>
<td>Description of Expense</td>
<td>Vendor Name</td>
<td>Category</td>
<td>Due Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>------------------------</td>
<td>-------------</td>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Food for 2nd Quarter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Travel for 2nd Quarter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stationery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cleaning Supplies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Office Supplies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internet &amp; Phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conference Attendance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Business Calls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equipment Repair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Travel for 3rd Quarter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stationery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cleaning Supplies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Office Supplies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internet &amp; Phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conference Attendance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Business Calls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equipment Repair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total:**

Amount: $123,456.78

**Balance:**

$98,765.43
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Category</th>
<th>Description of Expense</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>$50.00</td>
<td>Food</td>
<td>Lunch at the cafe</td>
<td>5/31/2014</td>
</tr>
<tr>
<td>Item 2</td>
<td>$75.00</td>
<td>Entertainment</td>
<td>Movie tickets</td>
<td>5/10/2014</td>
</tr>
<tr>
<td>Item 3</td>
<td>$25.00</td>
<td>Travel</td>
<td>Airfare</td>
<td>6/20/2014</td>
</tr>
</tbody>
</table>

**Spring Quarter Budget**

Team Name: Marketing and Sales

Purchase Order: 12345678

Vendor Name: Acme Corp.

Customer: XYZ Company

Address: 123 Main St, Anytown USA

Contact Person: John Doe

Phone: 555-1234

Email: johndoe@acme.com

Budget Monitor: Marketing and Sales

Signature: Jane Smith, President

Date: 5/15/2014
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Mileage</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/4/2022</td>
<td>12:00 PM</td>
<td>443.7</td>
<td>Home to Office</td>
<td>Commuting to work</td>
</tr>
<tr>
<td>11/4/2022</td>
<td>3:00 PM</td>
<td>450.3</td>
<td>Office to Client Meeting</td>
<td>Business meeting</td>
</tr>
</tbody>
</table>
How can we improve the user experience in clinical laboratories?
The interface is an afterthought and not aligned to clinical testing processes

The need to constantly monitor testing devices interferes with user's workflow
The smallest issues require complicated maintenance procedures.
User-friendly
Flexible
Great support

User-friendly
Customize information to your needs
User-friendly
Easily access your information

Flexible
Subtle and effective notification
Flexible
Monitor from your workstation

Great support
Independent troubleshooting
Great support
Direct support access

Great support
Enhance remote communication
Great support
Enhance remote communication
1. Gain freedom in your daily work
2. Take full advantage of automated testing solutions
3. Great customer support collaboration
4. Fall in love with our user-friendly interface
5. A platform for the entire testing process
6. Troubleshoot with built-in video tutorials
13 Appendix G: Dark Horse Prototype Specifications

The Dark Horse Prototype consisted of a simple wall with frame made out of PVC pipes and wall covering made out of cardboard. In addition, there were two HD720P webcam installed to monitor the arm as well as monitor the facial expressions of the user during the experience for analysis. All of these features can be seen in Figure 12 through Figure 15. The stream of the arm from the webcam is broadcasted using simple PC webcam set up, with external monitors hooked to the PCs. The wall is to have a slot for the monitor as well as a slot for the arm itself.

13.1.1 Hardware

- Webcam

We used V7 Professional HD Webcam 720p [8] as shown in Figure 82 in our prototype. A selection of its specifications [8] is mentioned in Table 13.

![V7 Professional HD Webcam 720P](image)

**Figure 82 V7 Professional HD Webcam 720P**

**Table 13 Webcam Specifications**

<table>
<thead>
<tr>
<th>Model Number</th>
<th>CS 720A0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>60 x 25 x 102 mm</td>
</tr>
</tbody>
</table>
| Photo Shooting | Hardware: 1280 x 720 pixels / 1 mega pixel  
                 Software enhanced: 4000 x 3000 pixels / 12 mega pixel |
| Video Recording | Hardware: 1280 x 720 pixels / 1 mega pixel  
                 Software enhanced: 2560 x 1920 pixels / 5 mega pixel |

- Generic Windows 7 or 8 for webcam broadcast system (x2).
- Generic Computer Monitor (x2).

196
- Generic Packaging Cardboard material found in recycling.
- Blue colored cloth for a soothing environment.
- PVC Pipe (O.D. 1 inch) 8x(60 inches)
- PVC Pipe (O.D. 1 inch) 4x(30 inches)
- PVC Pipe Minimal 2-way Orthogonal Joints (O.D. 1 inch), 4x.
- Duct tape for securing components.
- Generic Chair.
14 Appendix H: FUNKtional Prototype Specifications

The FUNKtional Prototype consisted of a frame that represented the machine, an RC car rail system and a two-servo laser pointer system. One webcam was mounted to the RC car and another webcam was mounted high on top of the frame.

14.1.1 Hardware

- Webcam
  Same as described in section 13.1.1. Also refer [8] for details.

- RC (Remote Control) Car
  The RC car we used is manufactured by World Tech Toys (Figure 83). Product description can be found on the product page [9]. The dimension of the RC car is 7.5 inches long by 3.5 inches wide by 2 inches high.

  In order to control two RC cars at the same time, communication frequency of the two transmitters should be different. The two RC cars we were using communicated at 49MHz and at 27MHz.

- Servo
  We used two micro servos from RadioShack [10]. Product specifications are shown in Table 14.
Table 14 Micro Servo product specifications

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>0.91 x 0.45 x 0.94 in</td>
</tr>
<tr>
<td>Voltage</td>
<td>4.8 ~ 6.0 V</td>
</tr>
<tr>
<td>Torque</td>
<td>1.5 Kg-cm @ 4.8 V; 1.8 Kg-cm @ 6.0 V</td>
</tr>
</tbody>
</table>

14.1.2 Frame with Overhead Webcam

The frame was built according to the actual size of the machine. It was basically a box shape that was 33 inch in length, 51 inch in width, and 30 inches in height. The overhead webcam aims at an entire view of the machine. With a field of view (FOV) of about 70 degrees, the height of the webcam was 37 inches above the frame top (Figure 84).
14.1.3 RC Car Rail System and Command Center

The RC car rail system was located on top of the frame, with two rails in X direction that was fixed on the frame, and one rail in Y direction that was movable (Figure 85). There were two RC cars in total, one moved along the Y axis with a webcam attached to it, and the other one moved along the X axis, pulling another car on the other side.
In order to control the two RC cars and move the webcam in both X and Y directions, we made a command center that integrated the two transmitters and arranged them in designated direction so that user can control the webcam to move in each direction intuitively (Figure 86).
14.1.4 Servo–laser Pointer System

We attached one servo to the other, and the laser pointer to one of the servos to create a 2 DOF laser pointer system (Figure 87).

*Figure 87 2 DOF laser pointer system (each curve show the servo’s moving range, the arrow shows its initial position as shown in the figure)*
The laser pointer was controlled using the arrow keys on laptop keyboard. This was completed by a small program receiving keyboard command and sending corresponding char through serial port. The program code can be found in Appendix C.

14.1.5 Testing Blocks Specifications

We designed six color cubes to assist in user testing. The colors we used were white, black, red, blue, yellow, and orange. Each block was a cube with 2.5 inches sides. We created proportional top view images that showed goal layouts of user testing. One example of these images is shown in Figure 88. All dimension of the goal layouts are provided in Table 15.

Table 15 All block layouts dimensions

<table>
<thead>
<tr>
<th>Block</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>27.8</td>
<td>37.3</td>
<td>10.4</td>
<td>43.6</td>
<td>19.3</td>
<td>16.9</td>
</tr>
<tr>
<td>Y</td>
<td>10.9</td>
<td>17.7</td>
<td>15.7</td>
<td>27.7</td>
<td>25.3</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>43.4</td>
<td>6.5</td>
<td>18.2</td>
<td>19.1</td>
<td>11.7</td>
<td>32.1</td>
</tr>
<tr>
<td>Y</td>
<td>28.0</td>
<td>27.3</td>
<td>21.6</td>
<td>25.8</td>
<td>7.0</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>21.5</td>
<td>18.0</td>
<td>43.4</td>
<td>10.0</td>
<td>36.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Y</td>
<td>18.1</td>
<td>4.8</td>
<td>14.9</td>
<td>27.3</td>
<td>25.6</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>40</td>
<td>10.5</td>
<td>36.5</td>
<td>22.0</td>
<td>20.5</td>
<td>28.0</td>
</tr>
<tr>
<td>Y</td>
<td>8.0</td>
<td>22.5</td>
<td>26.5</td>
<td>25.5</td>
<td>7.0</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>34.8</td>
<td>6.5</td>
<td>46.5</td>
<td>44.5</td>
<td>22.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Y</td>
<td>15.5</td>
<td>5.0</td>
<td>29.0</td>
<td>11.0</td>
<td>20.5</td>
<td>33.5</td>
</tr>
</tbody>
</table>
15 Appendix I: Functional Prototype Specifications

There were four elements to our Functional Prototype, each of which will be detailed in this section.

15.1.1 Machine Mockup

The machine mockup was the most intricate part of our Functional Prototype. The exact dimensions and materials used are not essential, as this is only meant to act as a workspace and is not a final product that can be used by Merck. The frame was constructed from PVC pipe and appropriate corner pieces. The overall box dimensions were 30 inches tall by 33 inches deep by 51 inches long. Within this space, we placed four stationary parts; a test tube rack, tray holder, incubator, and a box representing the portion of the machine where tests are performed (while will be referred to as “the box”). The dimensions of each components as well as their position in the frame are shown in Figure 89 through Figure 92 in CAD-form. “The box’s” dimensions were 17.75 inches by 10 inches by 14 inches. All of these parts were made using 0.25 inch thick sheets of wood.

![Incubator Dimensions](image)

*Figure 89 Incubator Dimensions*
Figure 90 Test Tube Rack Dimensions

Figure 91 Tray Holder Dimensions
The assembly and simplified CAD model is shown in Figure 93 and Figure 94. Robotic arm lateral motion was achieved using the same rail system that was used for our FUNKtional prototype, except the cars’ motors were connected to an Arduino for this prototype. A third car was added to move the probes back and forth. This ran on a ledge that was 24 inches long and was connected to the side wall 23.5 inches above the floor of the machine. Two 19.5 inch long square sticks (0.25 inch sides) connected the probes to the car. The four probes were 0.125 inch diameter by 3 inch long wood rods. The robotic arm consisted of a 0.5 inch diameter PVC pipe telescoping into a 1 inch diameter PVC pipe. At the bottom of the 0.5 inch diameter pipe was an electromagnet that picked up the tray. The pipe was raised by a motor-pulley system attached to the bottom of the RC car. The tray was a plastic shell with outside dimensions of 3 inches by 3.75 inches by 0.875 inches tall. The depressed section was 2.875 inches by 2.5 inches wide and went the depth of the part. We attached a 2 inch by 2 inch piece of sheet metal to the bottom of the tray with tape so the electromagnet would pick it up. Finally, there was a feeder to put the trays in and out of the incubator. This consisted of a 6.5 inch by 9.5 inch by 1.25 inch tall box.
that sat on a motor which fed the box in and out. All motors were controlled by an Arduino and motor drivers. The Arduino code can be referred in Appendix C.

### 15.1.2 Graphical User Interface

The Graphical User Interface was developed by St Gallen using InVision software. The entirety of screen views currently developed is shown in Appendix D and the basic flow of screens is shown in Figure 95. The program uses buttons placed on the screen to navigate to the appropriate window. The main functions achieved so far include a simulated login, QC run, process summary, maintenance log, blood ordering system, and test results. It is also possible to simulate the customer support feature.
15.1.3 Walk-away

The supplies used to construct our walk-away device were a tablet, a portfolio clipboard, 0.25 inch thick foam board, and electrical tape. The construction was quite simple. First, the tablet was placed on the corner of the clipboard. We then covered the remaining surface with the foam board. Finally, we taped all of the parts together. The tablet being attached to the clipboard is not necessary for complete function, but we wanted to integrate the two as scientists commonly carry clipboards around the lab. The final assembly is shown in Figure 96.

The control of the interface was performed using Team Viewer 9 [3] software. The software allows any device (computer, tablet, phone, etc.) to view and control the screen of another device using an internet connection. We set up our interface on a laptop to simulate the screen that would control the machine. We then used the software to control it remotely (Figure 96).
Figure 95 Simplified Flow Diagram for Graphical User Interface

Figure 96 Walk-away Device
15.1.4 First-Person Perspective Glasses

Our prototype for the first-person perspective glasses (Figure 97) was very primitive and just meant to demonstrate functionality.

![First-person Perspective Glasses](image)

Figure 97  First-person Perspective Glasses

We started with a pair of safety goggles. We used tape to attach a webcam to the bridge of the goggles (same as used for Dark Horse and FUNKtional). Finally we attached a laser pointer to the right side of the goggles. The laser pointer was turned on and off by a wing nut and bolt that were taped to the frame. As the nut was tightened, it depressed the “on” switch of the laser. As it was loosened, it lost contact with the switch turning off the laser.