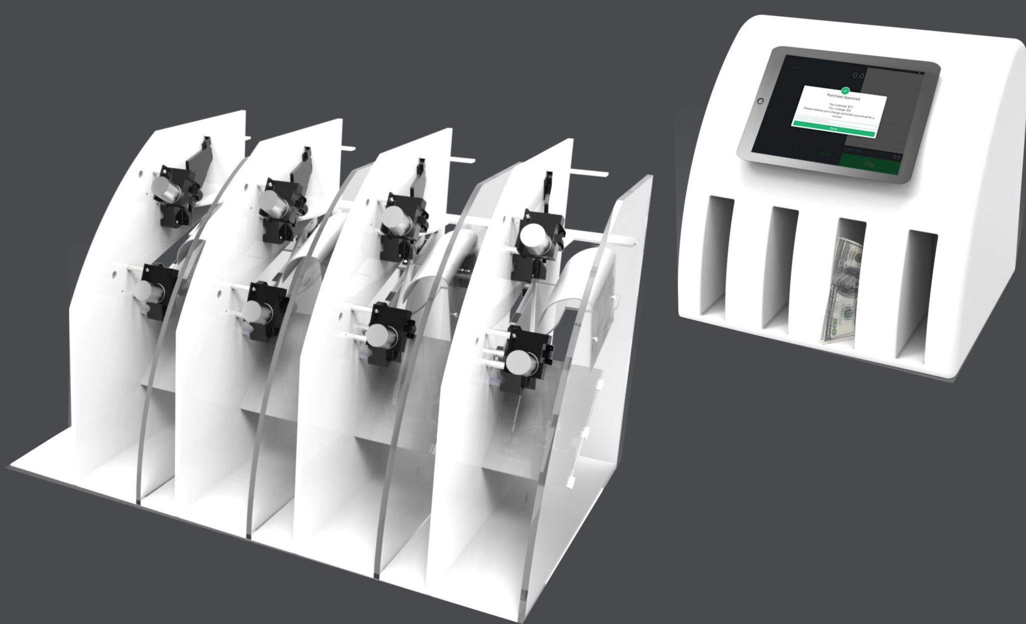
balance

a smart electromechanical cash drawer.

Electrical and Systems Engineering Senior Design 2018



team 20.

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Table of Contents

II. Executive Summary

This report will explore the goal of our project, the technical details of the created product, standards and specifications, as well as a summary of meetings and teamwork. The goal of our project was to redesign the standard cash drawer to ensure accuracy and create a less stressful task for cashiers. After months of user research and electromechanical iteration, we as an interdisciplinary team have developed a device that autonomously counts input cash and dispenses change to the customer without human interference.

III. Overview of Project

The goal of this project was to design a 'smart' cash drawer that can detect the amount of bills input, current balance, and dispense the proper amount of change when necessary while preserving the human-centric role of the cashier. The inspiration for this project came from Evan Inatome, owner of Elixr Coffee in Philadelphia. He told us that he loses $10 to $20 per day from mistakes made from cash transactions--which make up 60% of total transactions. His cashiers/baristas need to provide personalized attention for each customer while fulfilling orders with speed and accuracy. To prevent Evan and business owners like him from continuing to lose money, we wanted to design a product that could replace the current standard cash drawer with one that can prevent cash discrepancies. We designed a three stage cash register with sections A, B, and C: A is for *Acquired* bills that are sorted by the cashier and put in the appropriate slot, B is the *Bank* section to store counted bills, and C is the stage at which *Change* is dispensed to the customer. In addition to the physical component, we provided the manager with an application that allows for monitoring the status of their devices, showing traditional analytics such as cash flow and transaction frequency. We also implemented a simple point of sale application to round out the complete user experience. In industry, we hope for this application to be replaced by a more standard system of the customer's choice such as Square or Clover.

IV. Method of Solution

a. Our target specs chosen such that the user of the final product would be ±1.5x times as fast as the current average transaction time (~7s) and counting/dispensing the correct amount 95% of the time. Other specs were determined by the hardware and software products used and are outlined below:

Timing Specs:

- Counts 600 bills/min
- Timing (aggr. < 10 sec):
    - Manual pt. 1, < 4 secs
    - *Arduino MKR1000, < 2 secs*
    - Electro-mechanical pt. 1, < 1 secs
    - Arduino MEGA, < 200ms
    - Electro-mechanical pt. 2, < 1 secs
    - Manual pt. 2, < 2 secs

Software Specs:

- Database latency - 10,000 concurrent connections
- Chip encrypted data sent with token to the server and verified (RSA encryption)

b. Mechanical Engineering: MEAM 101: Introduction to Mechanical Design (CAD and rapid prototyping), MEAM 211: Dynamics (paper motion and mechanism design), MEAM 508: Materials for Manufacturability (material selection and mechanism design), MEAM 247, 248, 347, 348: Mechanical Design Labs (mechanism design).

Software: For the client and server software, knowledge of web systems, cloud computing, software engineering and application design are necessary. This material was covered by NETS 212 (Cloud Computing), CIS 195 (iOS Development), CIS 350 (Software Engineering), CIS 331 (Networks and Security). Basic programming skills were developed through CIS 120 & 121 (Principles of Programming & Data Structures and Algorithms).

V. **Self-learning**

Mechanical: We researched various types of motors and linear actuators to decide the best way to move the door in stage B. Understanding bill dynamics and paper moving in general were large milestones to overcome in terms of mechanism refinement.

Software: We learned how to use some open-source, graph classes and how to use Firebase's Realtime Database as none of us had used it before.

Embedded: We learned how to combine mechanical and embedded systems; how to use a synchronous embedded system to mimic asynchrony; and how to communicate technical details from the embedded field to technical peers familiar with another discipline.

Product: We learned to scope and see a very large scope of the cash drawer industry. In an industry dominated by legacy technology, we learned to see the proliferation of cash drawers across retailers, regardless of size, without a plan to change the status quo anytime soon. We learned about the similarity across different types of retailers and their experiences with POS. Every conversation with a store owner or cashier yielded another perspective on how to build a standard solution that can be enjoyed by all.

VI. Design and Iteration

Mechanical

The main design challenge for the mechanical team is to figure out how to move one bill at a time to be counted when going into stage A and distributed when moving to stage C. In addition to mastering moving bills, we need to move them in such a way that they move through an IR LED and light sensor pair so one will be counted at a time. Our 'gold standard' for the final design was one mechanism that could complete the full A→B→C cycle without human intervention. A 'silver or bronze standard' for the final design was one in which bills were counted at A and stored in a section called B1. Then, there would also be a separate, preloaded B2 from which change would be dispensed. However, a cashier would need to empty B1 when full and refill B2 when empty--posing as an inconvenience and a potential security risk.

Early designs from the Fall semester had the bills stacked horizontally, similar to how they are in the current standard cash register (Figure 1). There was a cam wheel located below the bills that pushed the bill at the bottom of the stack out through a slot. This design failed to meet our standards because it was very slow and imprecise. The bottom bill in the stack had to be completely removed before the next bill could begin to be dispensed. Then, ensuring only one bill is dispensed is nearly impossible given the extreme variance of the condition of bills and the full length of a bill needs to pass through the sensors with a small gap following it before the next bill can begin to move.

The next stage of design iteration was inspired by a purchased compact bill counter (Figure 2) where bills were stacked on their side and passed through light sensors by a tapered wheel. Early versions of this design resulted in chaotic bill motion (Figure 3) as paper notes were tossed upwards. Their trajectory was nearly impossible to model due to the non-rigid nature of the bills and variance from bill to bill dependent on creases, age, stiffness, etc. Without being able to map the bills and predict where they would land, we couldn't feasibly design a system any bill could reliably go through from A to B to C.

While not wanting to scrap this whole system because it counted bills one at a time with high reliability, we experimented with ways to confine the path of the bill. It turned out, rotating the full system 180° solved many of our issues (Figure 4). The tapered wheel now directs bills downward and the counting mechanism itself works just as consistently as in its original orientation.

From this point, the design was refined so bills were caught after being counted from A to B in such a way that they would land in position to be counted for a second time when going from B to C. Another bill counter was mounted, creating a mechanism that could seamlessly count received bills, store them, then distribute change to the customer (Figure 5).

The final design includes a geometrically elastic, thin, rigid deflector that assists bills when moving from A to B while preventing the bills from falling through the system (Figure 6). The deflector is shaped such that bills descending from A to B fall along it. However, when it is time to dispense bills from B to C, there is space for bills to pass under it.

There is also a servo actuated door at stage B (Figure 7). This was necessary because the door can pull back when bills are entering the bank, and swing forward to provide the necessary pressure on the bills against the wheel. The servo switches between two pre-programmed positions we calibrated on the prototype.

The final design is also very modular as we are combining four of these A to B to C devices, one for $1, $5, $10, and $20 (Figure 8). This is advantageous from a design for manufacturability and assembly standpoint as there is one mechanism that needs to be built several times for one product. It is also designed with concern for future product servicing, for if one denomination section malfunctions, it can be replaced without affecting the others. Cash is placed at the top on the cashier-facing side, and change is dispensed out of the slots. The screen on the customer facing side is used to sign receipts and complete transactions.

Hardware

Overview

The hardware design both constrained and was constrained by the mechanical design and software design. At every step of the mechanical iteration process described above, the hardware team was in charge of asking “electrically, will this work?” and making sure that if it created an infeasible or impractical solution that this was brought to the mechanical team’s attention. On the other side of the spectrum, this system needed to interface with the software described below. Some of the questions that we needed to ask were “How does data get to and from this system?”, “What are the power considerations?”, “What kind of electronics does the team need?”, “Which embedded system allows for the most flexibility and ease of prototyping?”, and “Is this both practical and possible?”. From these questions spawned the four different tasks of the embedded electromechanical system: sense, drive, communicate, and control.

Sense

The sensor system is made of multiple infrared LED, phototransistor pairs. This creates a non-contact object detector: as the object passes between the LED and phototransistor, the IR signal is obstructed and the channel of the phototransistor closes, causing a voltage drop in a sense pin that is connected to an arduino. This voltage drop is compared to a calibrated average that is taken over one thousand samples in the first second of system operation. If the voltage drop is below a certain threshold, then the object is “detected”. We used two of these object detectors to sense when a bill was passing between the wall of the system and the motor. The two detectors created an inherent redundancy and allowed for a state machine that was more complex and reliable than a single detecting LED could have been.

Drive

The motors for the rotating, tapered wheel were driven by a TI SN754410NE tristate buffer H-Bridge. The H-Bridge allowed the embedded system to rotate the motor both clockwise, pushing the bills through the system, and counterclockwise, pulling them back into place. This was vital to the correct operation of compartment B. For the bill dispensing, the motors were activated clockwise, pulling the bills through and counting them until the correct number (which we will call n) was reached. Because the $n + 1^{th}$ bill was already in the tapered wheel by the time the n^{th} bill had been dispensed, we needed to place that $n + 1^{th}$ bill back into compartment B. To do this, we rotated the tapered wheel counterclockwise until it was no longer obstructing the IR sensors.

Communicate

Originally, we aimed for WiFi communication. However, after working with the iOS devices, we realized that we could capitalize on the BLE technology available to both the embedded community and iOS devices. To that end, the embedded system used an adafruit bluefruit SPI friend to communicate with the iOS device. After initialization, the SPI friend broadcasts UART enabled communication, which is detected by the iOS device. The iOS device sends the cost of the item to the embedded controller with a single integer. It is then the embedded system's job to handle the data, perform detection and dispensing, and respond to the device with the number of each denomination that was input, dispensed, and to re-send the original cost for redundancy. This information is used to update the database with information on the ongoing status of the drawer.

Control

We were in search of a board with enough analog pins to place two sensors on every motor and enough digital pins to drive the bi-directional H-Bridges in our design. The original embedded system control design was to two separate microcontrollers. The first, the Arduino MKR1000, would act as the control and communicate with the database, iPad, and communicate over SPI to the second, an Arduino MEGA, which would control the sensors and motors. However, when we examined the real estate offered by the Arduino MEGA board, we realized that we could use the SPI pins on the MEGA to perform the communication directory to the adafruit bluefruit SPI friend. As a result, by consolidating two pieces of electronics, we reduced the code surface area, physical surface area, power consumption, complexity, and source of errors.

The control flow of the Arduino MEGA follows: first, the device receives transaction data over BLE--the total amount of money that the customer owes (an integer); next, this signals the device to start the counting process for all slots from compartment A to compartmen B, driving the motors and detecting with the sensors as described above; after that, the device calculates the correct change as an integer, calculates the number of which denomination should be dispensed, and dispenses that number of bills from B to C using the pull-back mechanism described in the Drive section above; finally, the embedded controller communicates the final status back to the iOS device over BLE to indicate either an error or the final state of the drawer. This is repeated for each customer throughout the business day.

Software

Overview

The design of the client application started as a brainstorming session that was driven by the question: 'What information is relevant to business owners with regards to their cash registers and cash flows'. This led to the core issues: cash status, management, and analytics. We decided that a client application can help a consumer (business owner in these regards). We decided to make our client application for iOS devices due to its cross-platform availability.

The first series of iterations of the client application involved testing compatibility with cloud and server services. We mocked up a test project to see how an iOS application would interact with Google's Firebase platform, Amazon AWS and Microsoft Azure.

After researching these features, we decided to mock up views for the user experience using the client application. We then created a prototype client application where all the data was hosted locally so that we could prototype what the user experience should look like. It consisted of screens for the drawer status and analytics for cash flow and transaction frequency.

As the project progressed, we realized that we would not be able to integrate a traditional 3rd party application like Square or Clover with our product because of it's academic nature. Therefore, we decided to implement our own point of sale application that would act as a temporary module. This application would be replaced with whatever existing point of sale technology that was installed by the customer.

Our next iteration of the client application had intended to query a Firebase Realtime Database. However, the security protocols of Firebase were not compatible with the Arduino components of our product. We then decided to switch to an Azure SQL database that the Arduino would use standard HTTPS procedures to post the data to the database and the client application would query for changes in the data set. With the implementation of the temporary point of sale application, we decided to have the point of sale application post the data to a Firebase (reverted to a Firebase application since it was easier to integrate with both of our applications and due to its cost effectiveness).

Client Application (Figures 9 - 11)

Our final client application provides the user with a simple login and signup flow requesting their username and password. The input data is sanitized and then checked against a User database (stored on Firebase). On input of validated credentials, the application segues to the transaction history chart. Otherwise, it prompts the user that their credentials are incorrect.

The logged in user is then presented with the transaction frequency, cash drawer status, and cash flow analytics for their cash register.

Point of Sale Application (Figures 12 - 13)

Our point of sale application provides the user with a traditional numerical input and a button to add an item to the bill. On the right, they are provided with a scrollable list of the items that they have inputted and the subtotal at the bottom. Upon hitting the 'Pay' button, the application triggers the Arduino component of the project via Bluetooth. The application implements the standard Swift Bluetooth Delegate in accordance with the standards. After the mechanical components have processed the transaction, it returns to the application the relevant information such as the amount of money received and the client application provides the cashier with confirmation of the transaction.

Standards

Both of our applications subscribe to the MVC design pattern standard as dictated by the programming language, Swift. We maintained the view controllers separately from the model, which handled the data, which were both separate from the controller which handled the interaction between both components.

An expected standard with an application with important information such as this would be to make sure that the data was encrypted, particularly from the embedded system. Traditionally, one would use SHA-256 hashing to maintain the privacy of the consumers. However, for the demonstrative purposes, we left our information as plain text so that it could be human readable for the demonstrations.

VII. Societal, global and/or economic impact.

Local context

We interviewed and held user observation sessions at Wawa, Fresh Grocer, Green Eggs, Elixr, Double Knot in Philadelphia, PA and Espresso Vivace, Whole Foods, and Safeway in Seattle, WA to record cash transaction rates and times as well as asked for the establishment's willingness to update/pay for our solution. Through these user studies, we were able to define some logistical standards to guide our design (See Section XIII: Standards for more detail). By adhering to these standards, we grounded our design realistically, with our target market and potential users just a short distance away. We were inspired to capture this market segment as our initial market in our business plan.

Economic Context

Our team conducted multiple marketing sizing exercises, before finally adopting a conservative top-down model. This model is being continuously fitted again newly collected data points from user interviews and user observation sessions. From our research, we believe that the majority players that would adopt our solution include restaurants, coffee shops, small retail stores, and eventually large supermarkets.

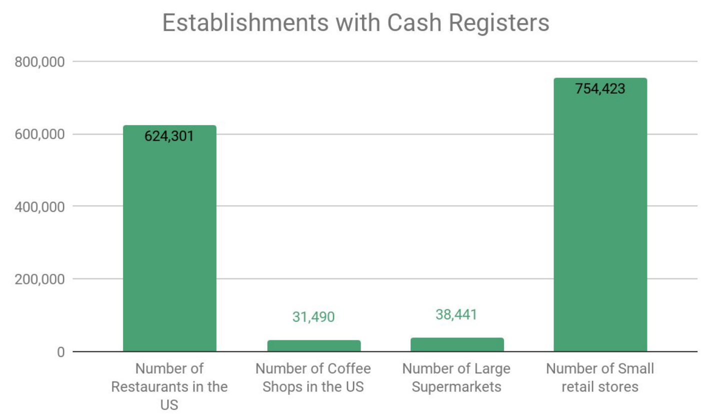


Figure 2: Potential partner establishments for Balance

Currently, we estimated that there are over 6 million cash registers in operation without our target markets. Based on user interviews and surveys, there is a ~60% willingness to update to a better solution. Using research data and and estimations of the cost savings our solution would bring (weighed against the cost of using the solution), we extrapolates that, we could demand $70. As a result, we believe this is a capturable $53M opportunity every 7 years. Discounted by a weighted cost of capital of 8.8% (WACC of close competitors), we see that the value of such technology presents an $119M opportunity.

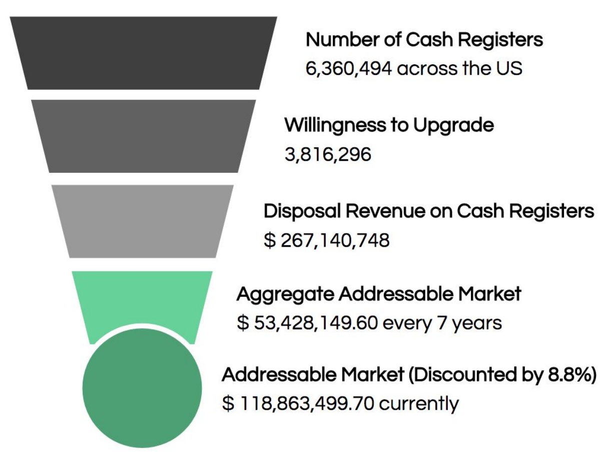


Figure 3: Funnel Analysis on Industry size

For all these figures, see our model for our assumptions, user questions, and analysis.

Global Considerations

Looking at the 2016 10-K report for NCR Corporation, 54% of revenue was generated from outside the US. A further investigation into this revenue source reveals plans for expansion of traditional cash registers in emerging economies. Though this is not a focus of our team right now, we can consider this as a possibility after Balance becomes an accepted solution in the US. Point of Sale technology is growing very rapidly around the world. Even though we see entities like M-Peso, AliPay, QR codes, and many more POS systems of those likes, the manufacturing and usage of traditional cash registers hasn't been slowed. When legacy technology does not slow down, it becomes easier to justify creating peripheral technologies around, such as our solution.

Ethical Considerations

There are two societal considerations for our product: 1) the environmental implications during manufacturing and 2) the power implications when as our tool operates. Due to short term projects, we are only considering certified manufacturers in the US and Australia to manufacture our product using an aluminum alloy material that does minimal harm to the environment during manufacturing. Though energy consumption is a scalable problem, we extrapolate that even if we achieve our target of 3 million units deployed, this would equate to 391.97kW. See Calculations here.

One additional ethical consideration is who would take responsibility for machine failure. In our case, we prioritize a running record of all the transactions that would be retrievable in the case of any electronic or network failures for manual reconciliation. These considerations leverage the tradeoffs between consistency and availability.

Lastly, in our deployed solutions, we seek to have our Arduino MEGA controller and iOS applications run encryption libraries so that financially sensitive information cannot be accessed outside of trusted parties.

VIII. Summary of Meetings

In the Fall semester, the team met every Friday from 3:00-4:00 pm to discuss the big picture ideas of the project. We also had meetings with the teaching staff, our mentors and TAs to stay on track. In the Spring semester, most meetings were among subgroups of the team in order to efficiently get work done in each of the three disciplines' domains. Between small group meetings, the whole group came together to ensure all of our work would be able to integrate. We continued to have meetings with the teach staff and mentors.

Fall:

09/05/17 Meeting with Nick

Phillip, Enrique, Alison, Nick McGill

Brainstorming problems to solve and whether our door lock idea was valuable

09/08/17 Team Meeting with Elixr Evan

Alison, Phillip, Bill, Rhianna

Met with Evan, the owner of Elixr to talk about potential projects

09/08/17 Team Meeting with Sid

Enrique, Bill, Rhianna, Phillip, Alison

Updated Sid on new project direction

09/15/17 Team Meeting

Enrique, Bill, Rhianna, Alison, Phillip

Started brainstorming mechanisms for the cash drawer interface

09/29/17 Team Meeting

Rhianna, Bill, Alison, Enrique, Phillip

First iteration of purchasing list

10/04/17 Meeting with TAs and instructors

Alison, Phillip

Updated TAs and instructors on things that we plan to purchase and direction for the team

10/11/17 Meeting with Mark Yim

Rhianna, Alison, Mark Yim

Met about dispensing mechanism (leveraging his experience with Xerox)

10/15/17 Team Meeting

Rhianna, Alison, Bill, Enrique, Phillip

Brainstorming different sensors for the input and output

10/17/17 Meeting with Nick

Alison, Phillip, Rhianna, Nick McGill

Brainstorming mechanisms and sensor designs, using his experience

10/20/17 Team Meeting with TAs and instructors

Alison, Bill, Enrique, Phillip, Rhianna

Updated course instructors and TAs on directions and gathered feedback

10/25/17 Meeting with Leroy

Alison, Rhianna

Met to talk about deconstructing a printer as an example for paper handling

10/27/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Discussed vision for the project and updated team members on progress

11/01/17 Meeting with Peter Bressler

Alison, Rhianna

Talked about Peter Bressler's past projects moving paper

11/03/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Discussed updates from bressler meeting and prepared for presentations

11/10/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Updated project vision and solidified milestones for the rest of the semester

11/16/17 Meeting with Leroy

Alison, Rhianna, Leroy

Discussed motor selection

11/17/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Met to show mechanisms and present test results for rudimentary prototypes

11/24/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Iterated on previous prototypes and started preparing for presentation

12/01/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Started on poster and finalized presentation

12/03/17 Team Meeting

Alison, Bill, Enrique, Phillip, Rhianna

Finished poster and finished polishing demo

Spring:

1/19 Brainstorming meeting

Alison, Phillip, Rhianna

Brainstorming mechanism redesign post-Fall demo

1/23/18 Team meeting with teaching staff

Alison, Bill, Enrique, Phillip, Rhianna

Check in after Fall demo

1/26/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Prototyping vertical bill orientation with foam core, made CAD model of foam core prototype. Electromagnet prototyping

1/27/18 Software Team Meeting

Enrique, Phillip

Planning database integration with arduino

2/7/18 Mechanical Team Meeting

Alison, Rhianna

Deconstruct compact bill counters to gain better understanding of mechanism and harvest spare parts

2/13/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Laser cutting mount for bill counter, characterized PCB connected to the motor

2/13/18 Software Team Meeting

Implementation of database and attempts to connect to Arduino

Phillip and Enrique

2/16/18 Meeting with Teaching Staff

Alison, Bill, Phillip, Rhianna, Enrique

Checking in

2/16/18 Mechanical Team Meeting

Alison, Rhianna

Laser cutting, refining bill counter

2/17/18 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

Product integration, laser cutting

2/16/18 Mechanical Team Meeting

Alison, Rhianna

Adjustments before the demo

2/19 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

CADing and laser cutting final mid-semester demo product

2/20/18 Software Meeting

Phillip and Enrique

Verified demo database set up for the mid semester dem

2/21/18 MID SEMESTER DEMO

3/14/18 Mechanical Team Meeting

Alison, Rhianna

Semester planning

3/17/18 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

Optimized orientation of bill counting device

3/19/18 Mechanical Team Meeting

Alison, Rhianna

Experiment will bill catching angles

3/20/18 Mechanical Team Meeting

Alison, Rhianna

Re-laser cut bill counter with new angles, testing

3/26/18 Software Meeting

Attempts at HTTP Posting from Arduino to DB

3/28/18 Mechanical Team Meeting with Leroy

Alison, Rhianna

Brainstorming session for seamless A → B → C

3/30/18 Mechanical Team Meeting

Alison, Rhianna

Continued brainstorming from meeting with Leroy, begin prototyping

Software Team Meeting

Enrique, Phillip

Implementation of POS application

4/1/18 Mechanical Team Meeting

Alison, Rhianna

Re-addressing how bills are caught in section B (decide to catch bills oriented vertically rather than flat). Began to CAD ‘bronze standard’ A → B1 → B2 → C

4/4/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Laser cut A → B1 → B2 → C model, installed hardware, testing

4/5/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Recut A → B1 → B2 → C model to experiment with bill orientation angles

Software Team Meeting

Completing client application and integration

4/6/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Further electromechanical integration, more mechanical iteration (CAD-ing, laser cutting)

4/7/18 Mechanical + Hardware Team Meeting

Alison, Rhianna, Phillip

Revisited upward orientation for bill counter briefly, developed new guiders from A → B1 → B2 → C model, electromechanical integration improved for distributing change

4/8/18 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

Install servo to get B → C working. Experiment with servo orientation

4/9/18 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

Develop guider at stage B to enable seamless A → B → C integration

4/10/18 Mechanical + Hardware Team Meeting

Alison, Phillip, Rhianna

Assembled final prototype for demo

4/11/18 FINAL DEMO DAY

IX. Final schedule with milestones

Task	Who?	Date
Disassemble bill counters for parts	Alison, Rhianna	2/7/18
Have working prototype of A→B and B→C	Alison, Rhianna	2/21/18
Communication between embedded controller and cloud	Phillip, Enrique	3/26/18
Implementation of POS application	Phillip, Enrique	3/30/18

A→B1→B2→C (bronze standard)	Alison, Rhianna, Phillip	4/4/18
Integrated POS and client application with mechanism	Phillip, Enrique	4/6/18
Seamless A→B→C (gold standard)	Alison, Rhianna, Phillip	4/9/18
Protoboard Housing for the embedded components	Bill	4/9/18

X. **Discussion of teamwork.**

The team communicates using Slack and Trello. We have a main Slack channel to coordinate deadlines for presentations and organize weekly meetings. We also maintain Slack channels to discuss research, meeting notes, and connected Slack to our Trello board. On Trello, we break down tasks into the three disciplines of our team members, and how much progress has been made on the task so far.

Work was subdivided by discipline. Rhianna and Alison (MEAM) worked together on the mechanism design. They both collaborated equally on ideation, CADing, prototyping, and testing. Bill (M&T) focused on the business side, and helped with the electrical systems. Phillip (CMPE) worked on the embedded systems and sensors. Enrique (CIS) contributed to cloud architecture, POS application and our client application.

XI. **Budget**

The budget is broken up into 4 sections: mechanical, software, hardware, and experimental (items needed for ideas we tried but didn't use in the final project).

Mechanical:

RPL supplies (acrylic)	free
GM Lab supplies (fasteners, standoffs, servo motor, etc)	free
9 bill counters	$400

Tool kits	$50
Total Mechanical	$450

Software:

Xcode and Apple Developer Toolkit	free
Cloud database services (Firebase)	free
Total Software	$0

Hardware:

Detkin supplies (wires, motor driver, breadboard, protoboard, shrink wrap, resistors, capacitors, IR LEDs, IR transistors, adafruit bluefruit)	$44
Arduino mega	$20
Total Hardware	$64

Experimental:

Cash drawer	$150
Receipt printer	$45
Electromagnets	$12
Permanent magnets	$19
Linear actuators	$39
Compact motors (10)	$90
Total Experimental	$355

Total:

Total Budget	$869

XII. Work for Second Semester

Mechanical

At the end of the fall semester, we had a working prototype for moving one bill at a time. However, it did not meet the needs of the desired product. During the spring semester we iterated through dozens of mechanism ideas (see section VI) using laser cutting as our means of rapid prototyping. The major change made from Fall to Spring was shifting the orientation of the bills into a vertical stack and settling on passing the corner of the bill past an IR LED and sensor pair as the means of counting bills. Along the way, the mechanical system was tested with the electrical components.

Software

At the end of the fall semester, we had a test client application that did not have a working backend. This semester, we integrated Firebase and completed the application. We also implemented a POS application that communicated with the device (via bluetooth) and the cloud database.

Hardware

We worked integrally with the mechanical team to make sure the design that was implemented could accurately disrupt an object detection sensor. We also worked with the software team to ensure correct dataflow. Practically, this was writing C embedded code, soldering, breadboarding, and designing both data collection and sensory-motor systems.

XIII Standards and compliance

Our development of the electromagnetic and iOS application was continuously inspired by UnifiedPOS v1.14, an set of pen standards that vendors and retailers worldwide seek compliance. However, even though the standard claims to support up to 36 different types of devices, this is not true in practice, and many retailers are not able to take advantage of this set of standards. Instead, most device manufacturers resolve to using their own device drivers for devices. While there are many obscure function calls, such as CapStatisticsReporting and DeviceServiceDescription, that we decided to leave alone, there were many properties that our

MEGA control did adheres to, such as register state, and bill count. This makes not only physical integration simple, but also embedded and component integration. For the applications that we are envisions, we do not need the interface to be all implemented in a comprehensive manner.

Since we are using many peripheral technologies such as Bluetooth (IEEE_802.15) or SPI (IEEE 1687), we were fortunate enough that our devices comes with physical drivers or leveraged libraries that exposed these objects in a manner that was easy to use but also compliant with IEEE.

APG Drawers (the brand of our cash drawer) offers a closed set of standards for communicating between POS systems. However, our team was unable to leverage the cable and communication that occurs between POS peripheral devices. This gave inspiration for the iOS application that runs as a frontend user interface.

Next, our team considered UL 962: The Standard for Safety for Household and Commercial Furnishings. However, after some consideration, we determined that because of the small size and narrow use cases, our module need not fully comply with UL 96.

In the follow few data points are external standards that we gathered during our user study sessions. By questioning and analyze these characteristics, we were able to make the appropriate tradeoffs when constructing our project:

- Maintain entire workflow under 7 seconds
- Ease of integration with existing POS system
- Space constraints: 3.1 in x 11in x 5in (W x L x Depth) ea.
- Power supply: 100-240V - 50/60Hz AC/DC adaptor
- Size of countable bill: 130mm x 50mm or 180mm x 100mm, 0.075-0.15mm thick
- Variable bill conditions

XIV. **Conclusion**

Together, we created a working prototype for a section of our ‘gold standard’ cash register. Bills could be input by a cashier, counted, stored, and dispensed directly to the customer. All of this is controlled by embedded electronics and sensors, which then also communicate with a client application. Moving forward, we need to assemble a full prototype of our mechanical design so we can bring it back to Evan at Elixr for product testing.

Along the way, we certainly ran into challenges. Creating a successful, integrated system requires constant communication. Logistically, coordinating the schedules of five team members across the disciplines is nearly impossible. However, with our determination to see through a final product, we were able to find a way.

XV. Appendices

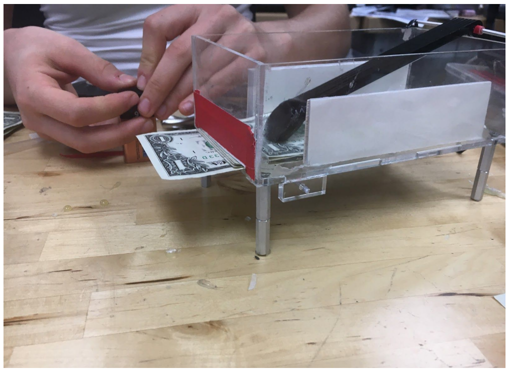


Figure 1: Fall Semester Prototype

Bills are in a horizontal stack and bottom bill is dispensed by a cam wheel under the box.

Figure 2: Compact Bill Counter

Purchased on amazon and studied to understand paper moving mechanism. Motor and spring were recycled for our project.

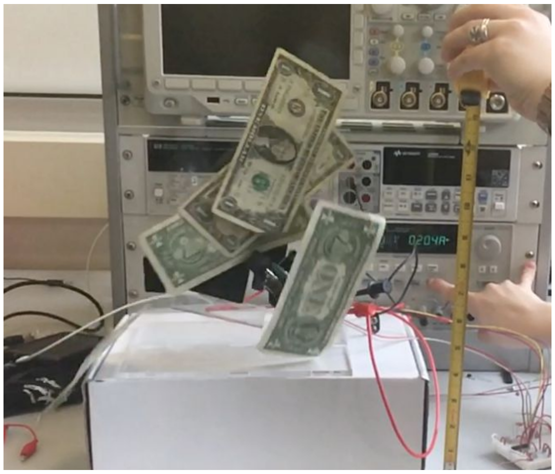


Figure 3: Early Spring Semester Prototype
Bills are thrown upward through the IR LEDs and sensors, resulting in accurate counting but chaotic motion.

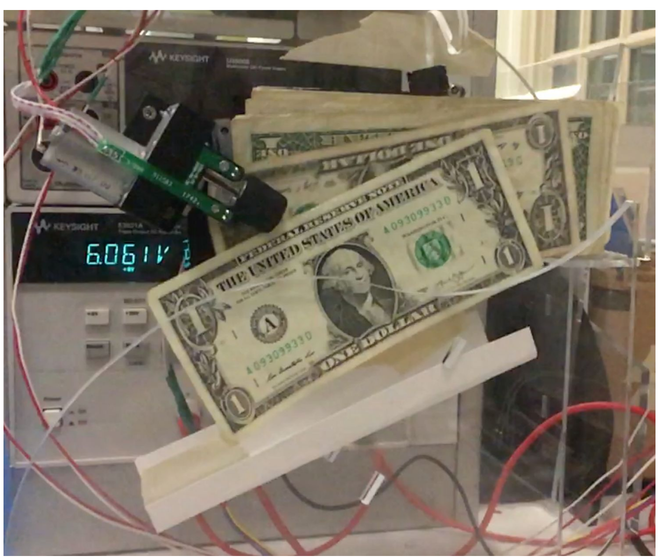


Figure 4: Mechanism Flipped
Bills now move downward through the sensors.

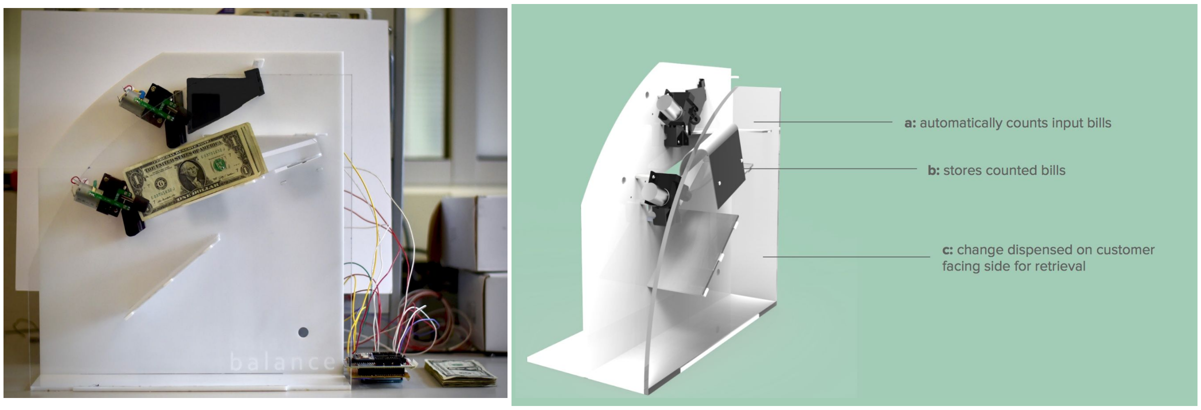


Figure 5: Seamless A→B→C (Product and Rendering)

Two bill counters in sequence to count input and dispense change

Figure 6: Deflector (Product and Rendering)

Thin deflector keeps bills upright at B, but also allows bills to move past it when going to C.

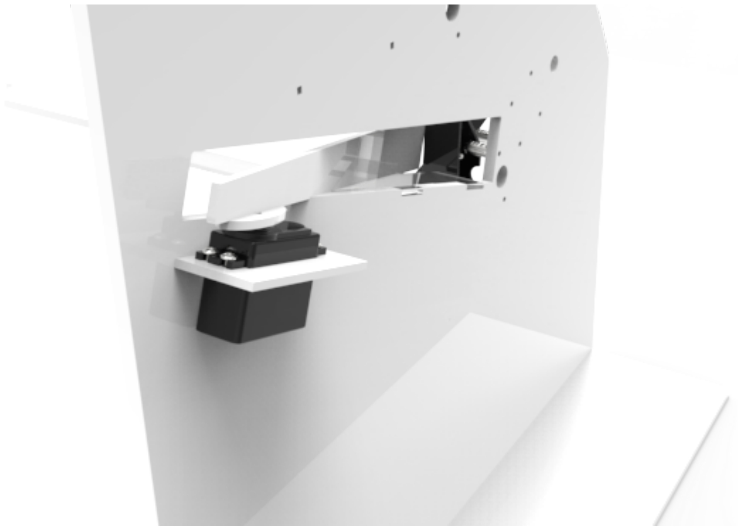


Figure 7: Servo-Actuated Door

A servo at stage B pushes bills against the tapered wheel of the motor to initiate change dispensing.

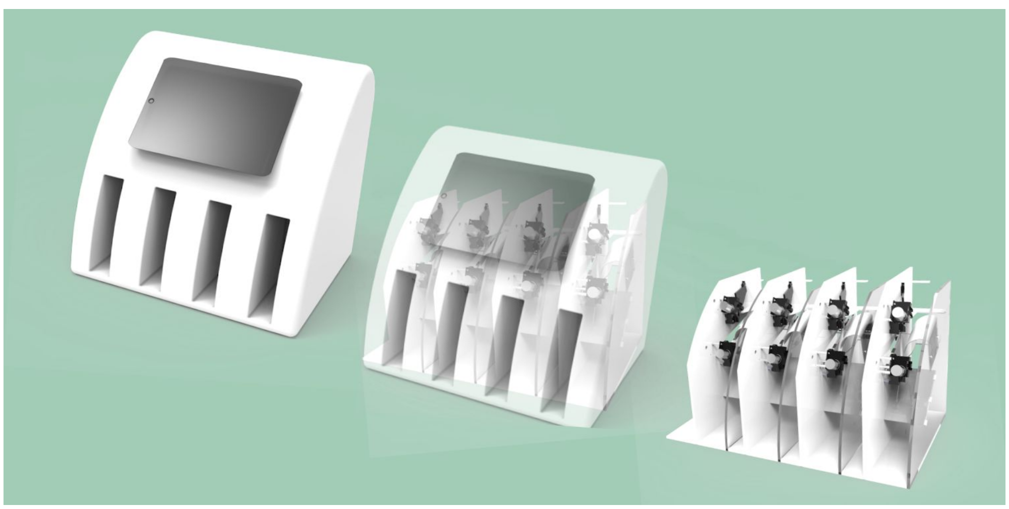
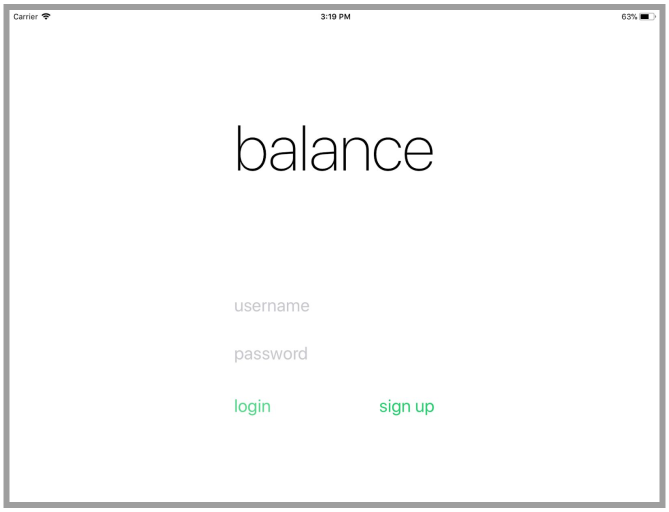
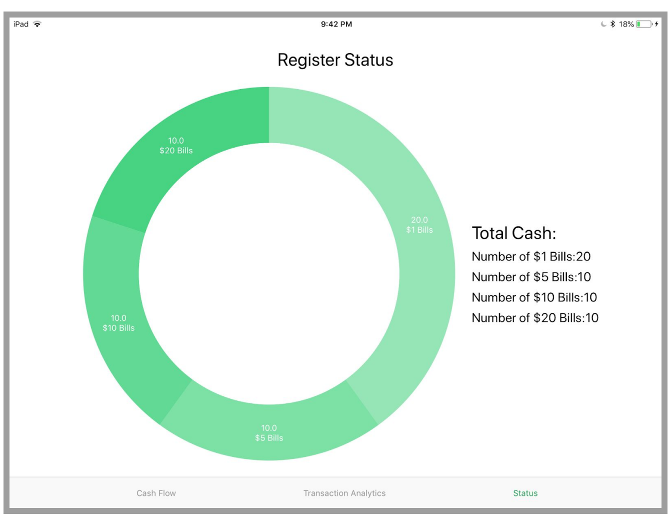


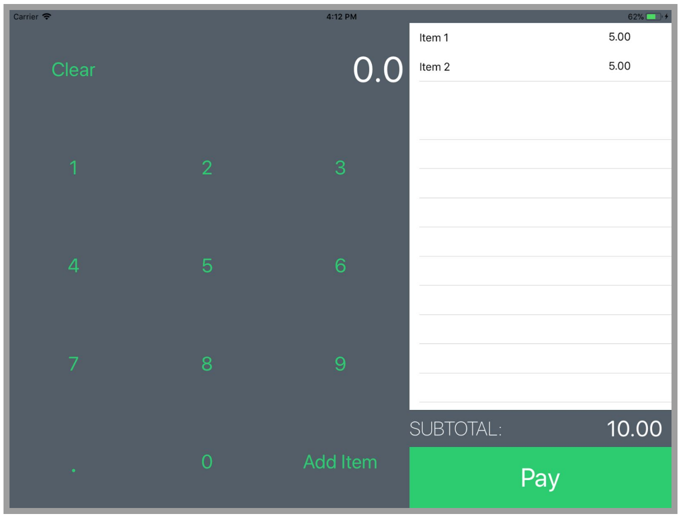
Figure 8: Final Product Rendering

View from customer-facing side of the register where change is collected and receipt is signed on iPad.





Figures 9 -11: Screenshots of client application



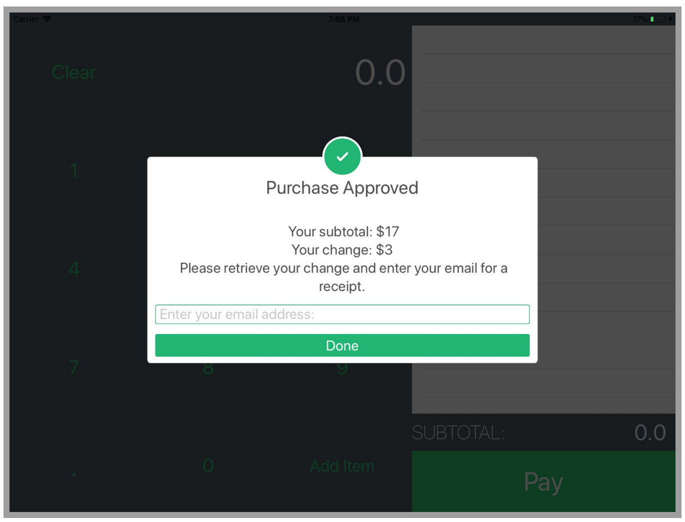


Figure 12 - 13: POS application screenshots