May 10, 2016

Dr. Amy Stevens, MD
Family Medicine
University of Tennessee Medical Center
1924 Alcoa Highway
Knoxville, TN 37920

Dear Dr. Stevens:

It is our pleasure to submit our final design qualification and year-long project results to you in this final design report.

At the beginning of the semester, you communicated to us the need for hospitals to have access to patient property storage systems that are capable of being tracked. Over the course of the year, we reviewed the problem to be addressed, considered several conceptual designs, and then moved forward with a final design that we tested and determined to be up to the standards you put forth for us. In this final report, we go into detail about the process we used to conceptualize a feasible design, the final product and how it meets the expectations you communicated to us, and the ways in which we will develop this design in the future.

If you would like any additional information about what is detailed in this report, or would like to provide feedback on our final design, we can be reached at any of the email addresses provided on the next page.

Your continued support of our team is greatly appreciated.

Sincerely,

Nemosyne Design

Final Design Report for the Lost and Found and Dr. Amy Stevens at UTMC

May 10, 2016

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Disclaimer

This research was conducted by myself and my senior design group, Nemosyne Design. The members of this team included myself, Griffin Heise, Michael Totty, and Min Kang. Throughout this project, I was solely responsible for keeping in touch with our stakeholder (who commissioned the project), for keeping the 176-page design file containing our year's work, creating the poster used for the MABE Senior Design Expo, and designing the initial Plexiglas prototype and building it.

As a team, we worked on assignments and presentations and we each ordered parts for the design. Griffin Heise was solely respsonsible for the AutoCad and SolidWorks design files; once Griffin received the final prototype from the 3D Printing lab, he and I attached the lid and lock to the device. Michael Totty was solely responsible for contacting companies concerned with the tracking capability of this design, and Min Kang was solely responsible for contacting ZephyrLock and working with them to secure the RFID lock.

In this research report, I was responsible for the Transmittal Letter, Background, Concept Development, and Design Evaluation sections. Griffin Heise wrote the Product Description, Min Kang was responsible for the Executive Summary and Problem Definition, and Michael Totty was responsible for the Recommendations and Future Works section.

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Executive Summary

The Lost and Found will be a storage system in which patients can store their belongings during their hospital stay. Our goal is to develop the Lost and Found as the first patient property storage system that can be tracked throughout the hospital. Using Bluetooth technology, we will make it possible for hospital staff to easily access the real-time location of the device. The Lost and Found will have an RFID lock equipped that can only be accessed with a user card; this feature will prevent the casual theft of patients' belongings. The device will also be designed to allow fast access to belongings, as well as be lightweight and compact to allow for easy to transport from room to room.

Over the course of the semester, we created a 7" x 8" x 4" box made of acrylonitrile butadiene styrene (ABS); this box is both compact and lightweight. It is equipped with a ZephyrLock RFID lock, which secures patient belongings from casual theft. In testing this device, it was found that while the use of tools could allow someone to break into the device, casual theft without the aid of tools was not possible. The lock itself reliably and consistently engages and disengages with use of the user card. In testing the tracking capabilities of the device, an obstacle was discovered. While the GPS tracking system and software we originally made use of was highly accurate in most buildings, the concrete walls of UTMC made it impossible for the GPS to be located at all, let alone within 5 minutes. In light of this, an alternative Bluetooth tracker was utilized for the final phase of the design. This tracker, the Tile, is effective in helping a user relocate the device within a short range through use of a smartphone app that will cause the device to emit noise (thus making it easy to find) and will allow users to access the last known location of the device on a map. The main challenges going forward, and the focus of next semester's work, will be to gain the vertical GPS location of the device, as well as select the most efficient and inexpensive way to power the device's locking mechanism.

Throughout this year, we developed a compact, lightweight, secure, trackable device that can successfully hold patient valuables such as glasses, jewelry, and watches. This device, with future improvements in manufacturing and minor improvements in design, will be utilized in

keeping patient valuables safe and secure, and it will also be utilized to save UTMC $20,000-$30,000 every year.

Background

The need of this project came from the constant misplacement of patient's belongings in the hospital. The reason of misplacement of patient belongings comes from the frequent transportation of patients that occurs in the hospital. Whether they are admitted to the hospital via the emergency room or through their primary care physician, patients have to remove all personal items for the doctors to complete their inspection. The clients that are affected by this project would be hospitals that are looking for a more efficient method to store patient's belongings. With this device, the hospital should be able to locate and retrieve the belongings stored in the device via Bluetooth. It is known that some hospitals are required to pay for the misplacement of patient's belongings; with this device, this would not be a problem. Previous designs that were patented to fix this problem were just plain bags that were made to hold the patient's belongings. For example, the SMARTSafe™ is a Ziploc bag type design that had a unique way of connecting the bag to the patient. On the bag there would be five barcode stickers that would be available for use in connecting the patient to the bag. The problem with these past works were that they were not able to locate the bag when the bag was lost. Without some kind of real time tracking capability incorporated into the design, the SMARTSafe™ cannot be located in the event that it becomes lost.

Problem Definition

The goal of the Lost and Found patient property storage system is to provide a hospital's staff with a relocatable, secure, easy to use method of storing patient belongings during their stay in the hospital. This device will be primarily designed for hospital staff use, specifically the nurses attending to the patients. While the hospital staff are considered to be our main clients, the patients whose property is being stored will be our secondary clients. With this device, we have a list of objectives we want to fulfill for both of the parties who will be utilizing it. For the hospital staff, we want to make sure the storage system is relocatable in the event that it becomes lost; we also want to ensure that staff members can easily transport the device whenever a patient

must be moved. For the patients, we want to give them the ability to access their belongings whenever they would like, as well as give them the peace of mind that their belongings are securely locked up when the device is not being accessed.

In order to ensure that these objectives are met, we will assemble several prototypes and test them in the hospital setting. To test the relocatability of the Lost and Found, we will ask a third party to move the box to an unknown location in the hospital and then use the Bluetooth tracking software to locate it. If the device can be accurately located and recovered within 5 minutes, we will consider this test to be a success.

To test the security of the device, we will attempt to gain access to the RFID lock with the user card. If we can successfully access the device multiple times, we will consider the "secure" objective fulfilled.

To test the durability of the device, we will attempt to break into it with tools and without tools. If we are unable to gain access to the inside contents of the device and the device remains intact after the burglary attempts are made, then we will consider the "durability" test a success.

Our final design of the Lost and Found was largely decided upon via feedback from the stakeholder who has experience with both patients and staff members, so with her help we have been able to find a balance in our design between stakeholder needs and client expectations, all while keeping manufacturing costs as low as possible.

Concept Development

The main function of the product is to provide a more convenient way for the hospital staff to locate the patient's belongings. The design for our product originally consisted of a GPS system that would theoretically allow the user to locate any belonging placed in the product within a certain radius of the hospital. The locking mechanism would be controlled by an ID scanner, so doctors and nurses would be the only ones to have access to the belongings. The initial product

design also consisted of internal components for small items such as jewelry or smaller medical devices that the patient brings to the hospital. The initial design can be seen in **Figure 1.**

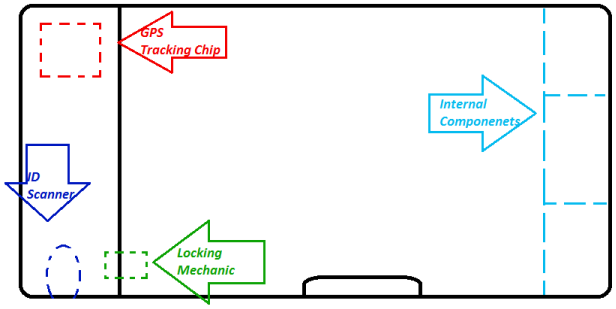

Figure 1. Aerial view of the first design concept.

After further consideration and more stakeholder and supervisor feedback, we felt that the ID scanner would be too expensive to incorporate into the device, and it would not make sense for a doctor or nurse to have to be present every time the patient wanted access to their belongings.

In the next phase of the design, phase 2, we considered barcode scanners, QR code locks, and electromagnetic locks to solve the problem of how we would best increase the security of the box. We wanted to restrict the accessibility of the device without raising the cost dramatically or preventing patients from accessing their own belongings. We also narrowed our choice of GPS chip and software down to the Xexun TK 102-2 chip and accompanying smartphone app. The actual, physical design of the box was rendered in AutoCad for this phase and can be seen in **Figure 2.**

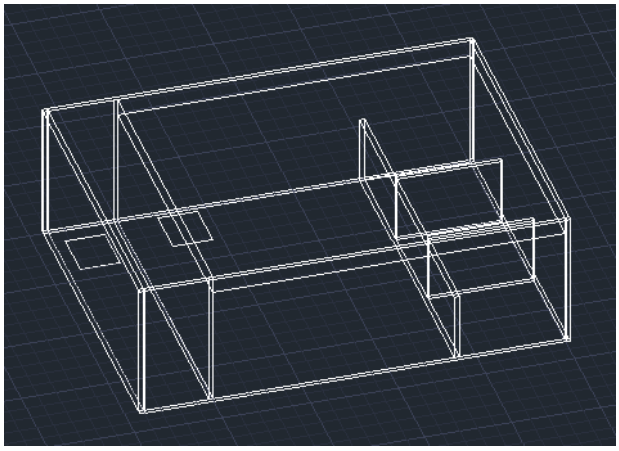

Figure 2. AutoCad rendering of the Lost and Found. Left: Internal compartment for GPS chip. Middle: Space for large items. Right: 3 compartments for small items.

In Phase 3, we narrowed down our search for locks to two choices: electromagnetic locks or RFID locks. We quickly ruled out the electromagnetic lock after we discovered that the lock must be connected to a constant source of power for it to work properly; the ease of transport of the device would be compromised if it must always be connect to some sort of power supply. The ZephyrLock RFID device, on the other hand, was compact and used batteries as its power source; the batteries last up to 20,000 uses of the lock, so power would not be an issue.

In Phase 4, we created two prototypes. Our initial thought was to 3D print the box using ABS, as that is the material we wanted our final product to be made of (lightweight, cheap). Our professor, however, suggested we make the prototype out of clear material so the internal components we wanted to add could be easily seen. We chose Plexiglas as the material. The first prototype we constructed from Plexiglas was 16.5” x 10.5” x 5.25”, with 0.5” thick walls and a lid that was 0.25” thick; we eliminated the internal compartment for the GPS in order to allow for more space for patient belongings. It quickly became evident that this was much too large to easily transport, so we downscaled the box to 10” x 9” x 6”. This prototype was a much easier to handle size. Because we eliminated the internal compartment for the GPS, we decided to mount the GPS to the side of an internal wall with adhesive. This prototype can be seen below in **Figure 3.**

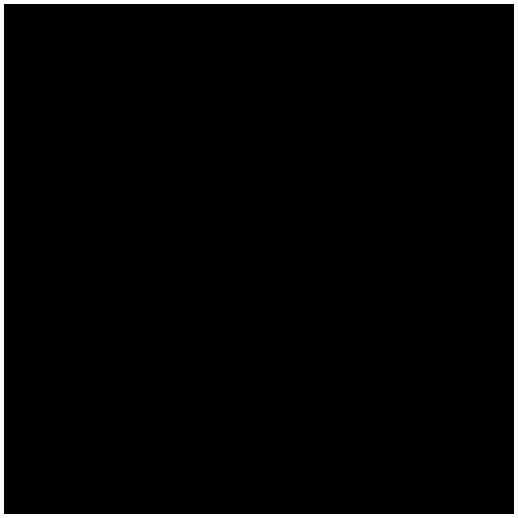

Figure 3. The 10” x 9” x 6” Plexiglas prototype. The ZephyrLock RFID lock is mounted on the lid, with the internal compartments for small valuables underneath. A strip of adhesive where the GPS chip was mounted can be seen at the front right corner of the device.

Once this design was evaluated, it was found that the lid was not cut correctly to fit the hinge, so the box would not open all the way. Also, the stakeholder noted that the size of the box could still be drastically cut down to even further improve the ease of transportation of the device. Unfortunately, during this phase, we tested our GPS device in UTMC to see if it was relocatable within 5 minutes; to our disappointment, the GPS could not function in the hospital. The alternative we then chose was a Bluetooth tracker, the Tile. The Tile, while not an efficient long range tracker, can be affixed to the device and tracked in a short range (30-100 ft). This device was found to be effective in the basement of Perkins, which simulates the thick, windowless concrete found at UTMC.

In phase 5, we 3D printed our device with ABS at the new dimensions of 7” x 8” x 4”; the device had walls that were 0.5” thick and a lid that was 0.25” thick. We believed we had fixed the placement of the hinge, but while the device easily opens all the way now, part of the hinge is exposed, which means a thief could break the hinge easily. We also decided at this point that we would sacrifice one of the internal pockets for small valuables storage and turn it into the storage container for the Bluetooth device. The final product (SolidWorks design and finished product) are shown in **Figure 4**.

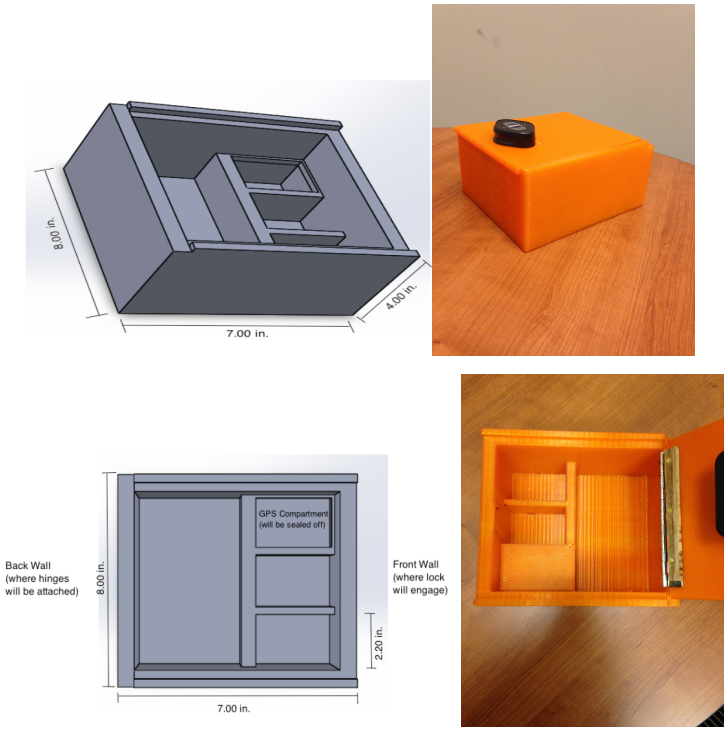

Figure 4. The final product. Top Left: SolidWorks rendering of the device. Bottom Left: Aerial view of the SolidWorks design. Top Right: The finished product, lid closed. Bottom Right: The finished product aerial view, lid open.

We faced many obstacles in getting this design ready, but we have been able to come up with alternatives and solutions for every problem. We plan to further develop this prototype beyond phase 5 and explore a long range tracking option that would work in a hospital setting.

Product Description

Lost and Found is a easy to use, trackable safe-box for patient use within hospitals. At 7” x 8” x 4”, it is small enough and light enough (made of lightweight ABS material) to be carried with one hand, yet still has enough storage space to hold essential valuables such as jewelry and hearing-aids. Lost and Found uses an RFID lock which can be uniquely activated by RFID user cards provided to each patient, meaning that only those in possession of a user card (the patient) and a master card (the hospital staff) can gain access to the contents of the device.

Upon misplacing the safe-box, it can be quickly relocated by accessing the Tile via the Tile app. Unlike the GPS chip we explored earlier in the course of the project, the Tile will make noise if the user activates that aspect via the app, and it's last known location can be viewed on a map. Also, if all staff members in the hospital install the Tile app on their smartphones, users can access the community feature to locate a box that is lost within the hospital. In the community feature, the user who is trying to locate their Tile (which is affixed to the device) can receive information from all the smartphones in the hospital with the app. Once the Tile comes within range of someone's smartphone, that phone will automatically send the location of the user's Tile to them.

Design Evaluation

Three tests were used to evaluate the performance of our device against the stakeholder's established design requirements. The tests are outlined below.

Test 1: Hide and Seek

Trial 1: GPS

In this test, the goal was to hide the GPS chip within UTMC and then relocate it; if the chip was relocated within 5 minutes, the test would be considered a success. When the GPS was located next to a window, it was able to communicate with the GPS phone app and report back the location. When it was taken away from the windows, however, the GPS was unable to communicate with the phone and the location was unrecoverable, therefore this test was a failure.

Trial 2: Bluetooth

After it became apparent that the GPS would not function in the hospital, an alternative was chosen. The alternative, the Tile, is a Bluetooth based tracker. If it's within a 30-100 ft radius of the phone with the Tile app, the user can use the app to make the Tile emit noise, which can be used to locate the Tile and the device it's attached to. Also, the location of the Tile can be accessed using Google Maps. We tested the Tile in the basement of Perkins,

which simulates the concrete walls of UTMC. We were able to locate the Tile with noise. Then the Tile was taken outside of the building to a location the user was unaware of, and the map feature was used to relocate it. While this tracker is not ideal for use in long range situations, it can be used to relocate the device in under 5 minutes when in the proper range, even in an area with thick, concrete walls, so this test was a success.

Test 2: Anger Management

Trial 1: With Tools

To evaluate the device's ability to resist theft, users first attempted to break into it with tools such as a hammer and a screwdriver. The plastic of the box walls, because it is sparse (contains hollow portions), shattered under the force of the hammer. The hinge is exposed and made of weak material (nickel) so it also broke under the force of a hammer and was able to be pried away with a screwdriver. This test was a failure, but it must be remembered that the device is only meant to prevent casual theft, which is better displayed by the next test.

Trial 2: Without Tools

Without the aid of tools, the user could not gain access to the box while it was locked. The spaces left by the hinge were too small to get fingers or hands through, the walls could not be warped or broken using manual compression, and the lid could not be forced open using bare hands while the lock was engaged. This test was a success and proved that the device is resistant to casual theft.

Test 3: Pop, Unlock, and Drop It

In this test, users made sure that only a user card or manager card could be used to engage and disengage the RFID lock. This test was a resounding success, as the user card could be used to engage and disengage the lock.

These tests indicate some need for improvement, which is outlined in the section below. It would cost $353.12 ($237 for 3D printed ABS, $84.14 for ZephyrLock, $24.99 for the Tile, $6.99 for hinge) to replicate this prototype.

Recommendations and Future Work

The most important aspect of the box is the ability of it to be tracked. With the problem of the GPS being ineffective inside the hospital, we would have to find another efficient way to track patient belongings in the hospital. The best option in our opinion would be the use of RFID tracking that could be used within the hospital, unlike the previously tested GPS chip. These systems use RFID sensors placed along the walls of a floor of a hospital to triangulate the position of an RFID chip on that floor; if we incorporated that chip into our device, we could easily detect which floor and where on the floor the device is.

We think the overall size of the final prototype would be our ideal size of our final product. The thing that we would have to improve on would be the placement of the hinges and the fitting of the lid. Due to the irregular fitting of the hinges, the lid comes forward over the edge of the box by about 0.25". One way around this is to eliminate the hinges altogether. If we create slots all around the box, we can slide the lid of the box into these slots and then engage the lock, which would still secure patient belongings. We plan on pursuing this project through some parts of the summer, and our first step is to talk to a company that sells RFID sensors for tracking purposes and inquire if they would like to help us.