

# Interactive Device Design with Kinoma Create

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**MASTER OF ENGINEERING - SPRING 2015**

**EECS**

**Visual Computing and Computer Graphics**

**INTERACTIVE DEVICE DESIGN WITH KINOMA CREATE**

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This **Masters Project Paper** fulfills the Master of Engineering degree requirement.

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## Interactive Device Design with Kinoma Create

### **Abstract**

The goal of our capstone is to develop a new interactive device using the Kinoma Platform by following the product development cycle from user research through to a final, user-tested prototype. After a brainstorming process and consulting with potential users, we uncovered the common problem of forgetting items such as keys or wallets. These are items that are generally needed every day, but are easy to accidentally leave behind. There is also usually a cost associated with forgetting these items, such as being late to work or paying for a locksmith. We determined that an Internet of Things, connected device solution was appropriate for solving this common problem.

In this report we explore the development and technology behind a device called the reMINDER which is our solution to this forgetfulness. It is a consumer product intended to help users remember to take their keys and wallet with them when they leave home. The reMINDER keeps track of these items via Radio Frequency Identification (RFID) tags, detected using RFID readers inside the device. It notifies the user through detecting the user walking to the door with a motion detector and blinking LED lights to attract the user's attention. The user is drawn to the device and is reminded to take their personal items resting on the device. Users interact with the reMINDER through the on-device screen that allows users to pair items with the device, and a smartphone app allows remote monitoring of the status of paired items.

# **Interactive Device Design with Kinoma Create**

## **Master of Engineering Final Report**

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## **1. Problem Statement**

The goal of our capstone is to develop a new interactive device by following the product development cycle from user research through to a final, user-tested prototype. After a brainstorming process and consulting with potential users, we uncovered the common problem of forgetting items such as keys or wallets. These are items that are generally needed every day, but are easy to accidentally leave behind. There is also usually a cost associated with forgetting these items, such as being late to work or paying for a locksmith. We determined that an Internet of Things, connected device solution was appropriate for solving this common problem.

Our solution to this forgetfulness is a device called the reMINDER. It is a consumer product intended to help users remember to take their keys and wallet with them when they leave home. The reMINDER keeps track of these items via Radio Frequency Identification (RFID) tags, detected using RFID readers inside the device. It notifies the user through detecting the user walking to the door with a motion detector and blinking LED lights to attract the user's attention. The user is drawn to the device and is reminded to take their personal items resting on the device. Users interact with the reMINDER through the on-device screen that allows users to pair items with the device, and a smartphone app allows remote monitoring of the status of paired items.

Through following the design cycle, we iterated over multiple device prototypes, testing our device over a pool of six users. The form factor of the reMINDER underwent significant change from the initial bowl concept to the slim rectangular profile of the final prototype, providing a compact enclosure for the internal hardware while also providing sufficient reading area for the RFID readers. Feedback on the experience of using the device in daily life led to improvements on usability and shifting the main point of user interaction from the phone app to

the device itself. The final form of the reMINDER is a product of continual improvements and integration of user feedback over the course of multiple design cycle iterations, as shown in Figure 1.

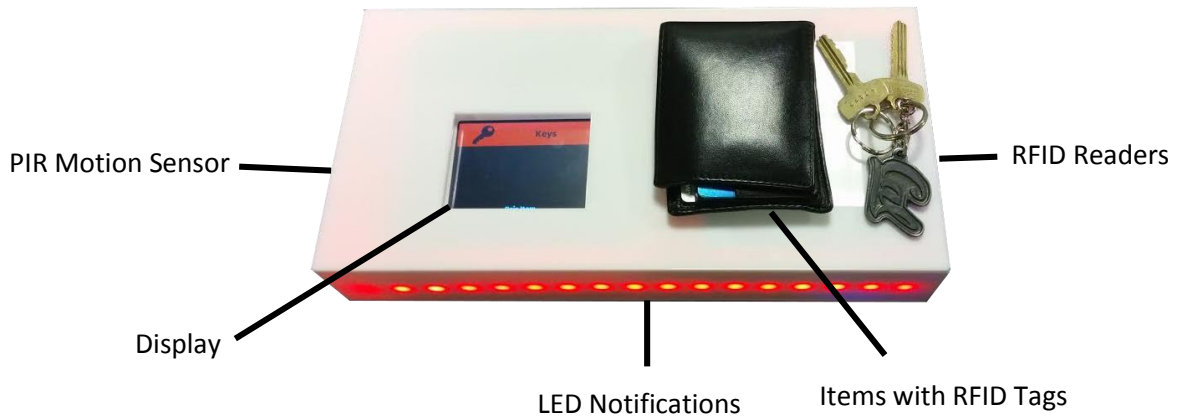


Figure 1: Final prototype of the reMINDER device.

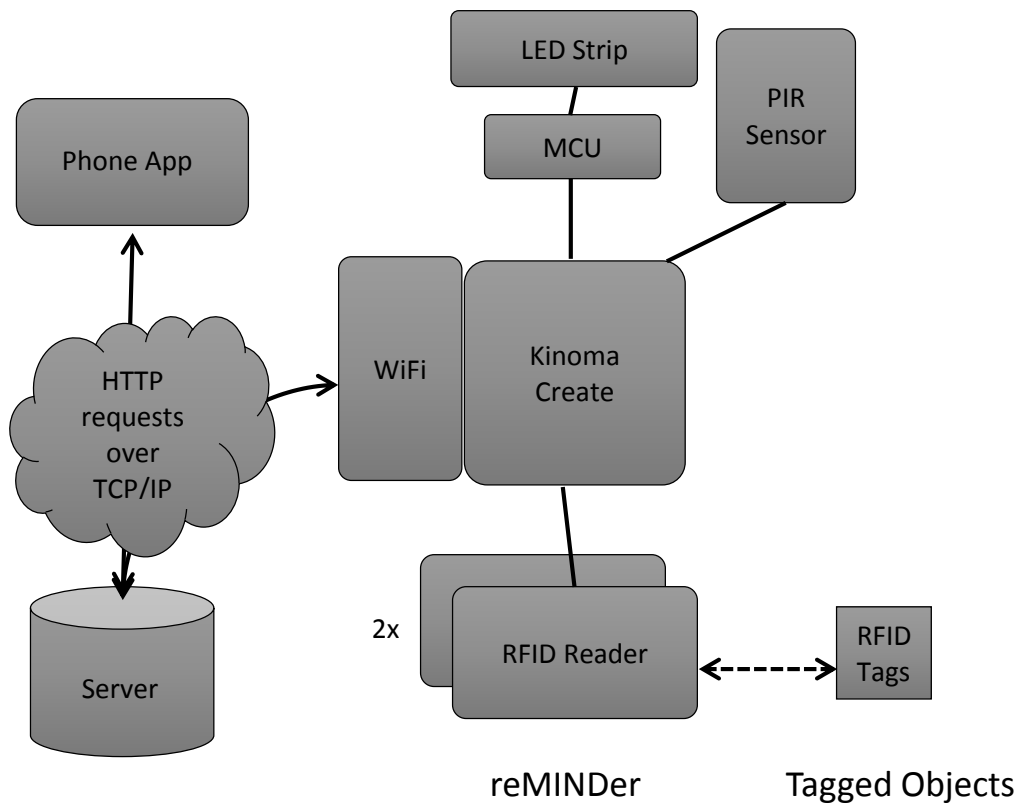


Figure 2: Block Diagram of the reMINDER

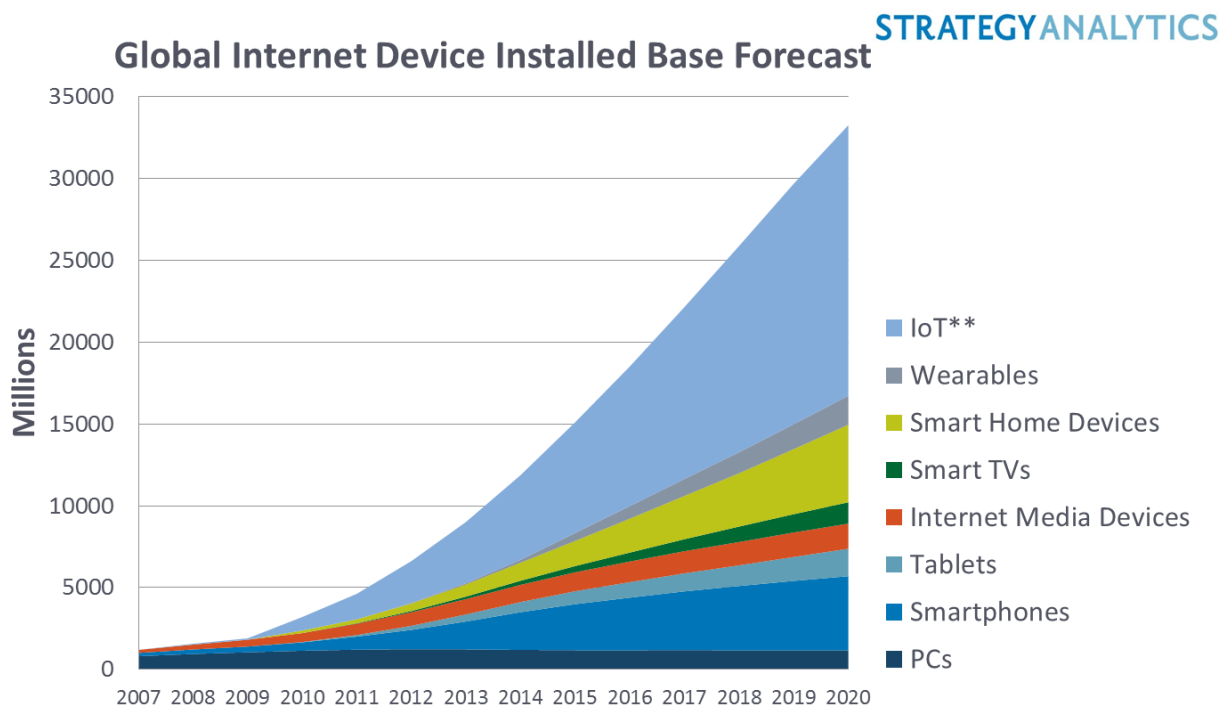
## **2. Industry/Market/Trends**

Although the reMINDER is not intended for commercial release, we investigated the viability of the reMINDER from the perspective of a company seeking to commercialize the reMINDER. This section describes how we, as this hypothetical company, can improve our strategic positioning by focusing on our user experience in order to differentiate our product from competitors. We begin by exploring why the current trends in the broad Internet of Things (IoT) industry make this the right time to enter the industry as a loss-prevention solution. Using the Porter five forces analysis, a common framework used in industry to evaluate the strength of various threats to companies, we determined that the high level of competition and the threat of new entrants are the strongest forces against our strategic positioning (Porter 1979). Given the strength our competition, we find that focusing on creating a unique and seamless user experience will give us the edge we need over our competition. We conclude our industry analysis with a discussion of our marketing plans.

### **Trends Within the Internet of Things**

Our target industry, loss prevention, falls under the umbrella of the Internet of Things industry, but what exactly is the Internet of Things (IoT)? According to a Goldman Sachs research report, the Internet of Things describes devices such as everyday consumer objects that are connected to the network, enabling the use of software to manage new types of services or handle data gathered by such devices (Goldman Sachs 2014). The report suggests that by 2020, as many as 28 billion devices can be connected to the Internet, ranging from items such as bracelets to cars; the chart in Figure 2 (Strategy Analytics 2014) predicts a similar level of growth, particularly in the number of IoT devices connected to networks. Each device can be

customized to provide personal, interactive user experiences and provide new services, and many companies are quickly recognizing the potential of mass personalized devices connected to the Internet. It is reported that thirty percent of device makers today currently develop IoT devices, and about thirty-four percent more plan to develop IoT devices over the next two years (Olavsrud 2015). Predictions for the size of the IoT global market increased from \$1.9 trillion in 2013 to over \$7 trillion by 2020 (Wood 2015).



Source: Strategy Analytics October 2014

Figure 3: Projected growth in number of installed Internet devices, with Internet of Things connected devices experiencing the most growth in the projected time period

The main benefits of participating in the Internet of Things industry are apparent in terms of financial cost and future prospects for our product. The rise of IoT corresponds directly with significant technological changes; these include drastic reductions in the cost of sensors, the

popularity and widespread use of smartphones, nearly universal wireless coverage, and inexpensive processing that allows devices to both connect to networks and manage an inflow of data (Goldman Sachs 2014). The widespread availability of these resources means that we have less financial burden in creating our product. This allows us to develop our reMINDER technology, conduct user tests, and refine based on user feedback, all without being constrained by parts and development costs. Additionally, high profile acquisitions such as Google's acquisition of Nest, a startup that produces smart thermostats for the home, illustrate corporate opinion that connected devices are the future of hardware (Forbes 2015). Research showing that companies spent \$14 billion to acquire IoT-related companies in 2014 (451 Research 2015) indicates that many companies share this belief in IoT as the future of hardware. With companies willing and eager to invest in the potential of IoT startups, this is the right time to bring our ideas to market and gather attention to ourselves with our device and unique user experience.

## **Competitors**

Within the Internet of Things category there are several companies attempting to address the problem of losing small personal items, such as wallets and keys. These companies all belong to what we call the industry of loss prevention. Most competitors' products within the industry of loss prevention require affixing a large tag to each item a user desires to track, increasing the profile of the object and making it awkward and unwieldy to carry around (Cohen 2014). Most of these alternative solutions assist users with finding items once they are lost, in contrast with the reMINDER, which attempts to prevent loss of items in the first place. The reMINDER is plugged in to a regular power outlet and comes with Radio Frequency Identification (RFID) tags that are very slim (almost the thickness of a sheet of paper) and do not require

replacing. We will analyze three of the main competitors to the reMINDER: the traditional bowl, the Tile, and Trackr.

### The Traditional Bowl

The traditional bowl provides an inexpensive solution to the problem of forgetting personal items. It is also commonly available, as many people own spare bowls. To use the traditional bowl, you place the items in your bowl when you come home and take them out as you leave. The items are consolidated in one location. Not forgetting these items, however, still entirely relies on memory as there is no interactive experience. The bowl cannot catch a user's attention as he walks to the door. This is where the reMINDER is different. The reMINDER adds interactions to the traditional bowl in an attempt to remove the dependency on memory so that the users are reminded when to remove and replace items. This solution is simpler for users and more likely to prevent forgetting items since the recall has been replaced with recognition (Budiu 2014).

### Tile/TrackR

Tile is a product designed to be tethered to a key chain or affixed to an item a user wants to track in order to find it if lost, as shown in Figure 3 (Nzama 2014). Each Tile holds a Bluetooth Low Energy (BLE) beacon making it quite bulky, and often the largest object on a keychain, as some users have pointed out (Bonnington 2014). Tile users must replace their Tiles every year or more frequently depending on usage, at \$20 per Tile (Bonnington 2014), since Tile's battery is non-replaceable. To assist users in finding their lost item, the Tile device is capable of emitting sound. However, this capability alone may be insufficient to locate the lost

item. One user described his inability to hear the sound emitted from the Tile due to ambient noise even when it was placed in his pocket (Cohen 2014).

The most novel feature of Tile is the ability to find objects with the help of other users of its phone application or through “crowd finding”. Assuming there are many millions of Tile users, the phone applications can assist with finding other users’ objects securely over the network. However, the most obvious flaw with this idea is that all these users would have to have their Tile application open. Even if this issue were circumvented, the service would only be useful once Tile has gained mass adoption, which is currently not the case.

TrackR is another company that offers an interactive solution to loss prevention, using a small, coin-sized device that attaches to valuables such as keys, wallets, and cell phones and pairs with a smartphone app; the device and app interface are pictured in Figure 4 (TrackR 2015). TrackR utilizes Bluetooth technology to track items that have the tracking device attached. A smartphone app provides information on proximity of the item and allows the user to ring the device so users can find their items via sound. Like Tile, TrackR also provides support for tracking items when they are outside Bluetooth range in the form of Crowd GPS, in which users who also have the TrackR app installed on their smartphone can provide a user’s phone with updates if they are in range of the user’s lost item.



Figure 4: The Tile device (Nzama 2014)

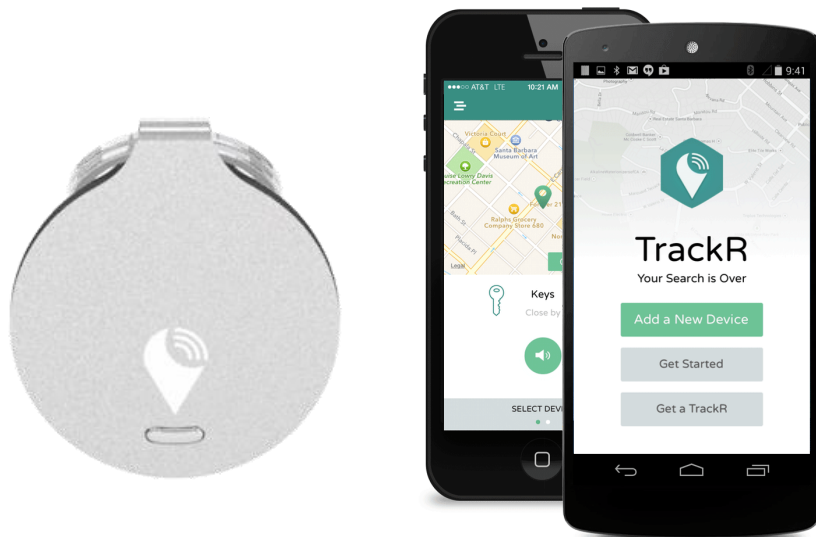


Figure 5: The TrackR device and associated smartphone app (TrackR 2015)

We aim to differentiate ourselves from competitors like Tile and TrackR in such aspects as technology used and approach to loss prevention. In contrast to the battery-powered Bluetooth beacons both Tile and TrackR use, RFID tags are powered wirelessly from the reMINDER via electromagnetic induction, removing the need to ever replace the tags. More importantly, though, Tile and TrackR seek to prevent loss by enabling users to locate their personal items when they are lost. Our device aims to address the issue even earlier by preventing users from forgetting their items in the first place. The need that we see exists at the moment of remembering or forgetting to take personal items along. One can use tracking technology to locate missing items, but the problem of items going missing will continue to persist with such a solution. By addressing the moment of forgetfulness before it occurs and notifying users to take their items, our reMINDER solves the same problem as TrackR but at a point in time farther upstream. We expect that young, busy working professionals will find our solution attractive; our device is designed to slip seamlessly into their daily routines: get up in the morning, shower, brush teeth, get dressed for work, grab keys and wallet from reMINDER, walk out the door.

In addition to these competitors within our industry, there are also the threats of new entrants as well as substitutes from other industries. Through our own user studies and experiments we have come to understand existing substitutes that our target users currently use. Users typically have a designated region or area in their home where they keep items when they leave or enter their home, for example a regular bowl or a key hanger. However, these substitutes provide poor interactive interfaces. The reMINDER helps its users by providing visual feedback as they step out and into the door, reinforcing the habits that will prevent losing the items. In addition, a service feeds information about the contents of the reMINDER to a smartphone

application that can be useful for book keeping and sharing items amongst several members in a household.

We previously described trends that make entering the IoT industry with reMINDER attractive, but these trends also make entrance into the IoT space attractive for other new entrants as well. As described earlier our goal is to differentiate our product significantly through an exemplary user experience. Through multiple prototype iterations we have accumulated valuable user feedback for creating a user experience in line with user expectations, and new entrants would need to spend valuable time performing user tests to refine their own devices and user experience before going to market. In addition, our access to the Kinoma team at Marvell will give us an advantage in the manufacturing of hardware products, one of the biggest barriers for most hardware startups.

In order to differentiate ourselves from this strong competition, we must create a unique user experience. Whereas many of our competitors rely purely on their effectiveness at finding an item you have lost with no regular interaction with the user, the reMINDER relies on daily interactions that build habits. This is our major differentiator and we must continue to innovate and emphasize this point in order to maintain an advantage. Since the user interacts so often with the reMINDER, these interactions must be seamless and unparalleled in order to compete. By staying ahead of the curve with this user experience we can greatly reduce the strength of the force from competition.

## **Market**

We will sell directly to our end-users via our website, making our users our customers as well. We have segmented our market, and our initial target users are young professionals. We are

targeting this group because our interviews have shown that they are the most likely to forget items at home due to the fact that they most frequently leave their homes to go to work and social events. In preliminary user interviews, three out of five interviewees said that they regularly forgot to bring their wallet, keys, and other personal items with them. Since they forget their items so frequently, they have the most to gain by using the reMINDER. In addition, ninety percent of those aged eighteen through thirty-four own a smartphone, the highest percentage of any age group (Harland 2015). Given that a smartphone is a requirement to use the reMINDER, this cements the case for young professionals.

The Porter five forces market analysis model lists customers as a potential threat, defining buyer power as the ability to put a company under pressure. There are four main reasons why customers have low buyer power over our product. First, the reMINDER does not represent a large portion of their income. These are young professionals with stable jobs, an Internet of Things device for under \$100, our target price point, is not a large portion of their income in the way that an item like a car would be, which would drive up their buying power. Second, as was mentioned when discussing suppliers, the reMINDER is a complex product that cannot be reproduced easily by the average customer. It is far more convenient for customers to purchase a reMINDER device, compared to creating their own interactive solutions. Third, the industry is non-standardized. Customers will be attracted to devices that have unique features and styling, such as the reMINDER, which offers a unique user experience unlike that of other competitors. Finally, the possibility of future upside from our product makes it so that our customers will be less price sensitive. For instance, paying a visit to the locksmith after locking oneself out of the house can cost anywhere from \$35 to \$100. These potential future savings

push buyers to be willing to pay more for our product. With these four reasons in mind, the strategic position for our customers is weak.

Our marketing will serve to further improve our strategic position by pushing on this last point. We aim to emphasize the future savings which can be either financial (from reducing costs from lost items or using services like locksmiths) or in terms of stress (by removing the need to worry about forgetting something for years to come). This plan will show our customers the true value they are getting from our product, putting the strategic power firmly on our side.

### **3. IP Strategy**

In this section, we will analyze intellectual property protections applicable to our project and what we can do to protect our competitive advantage using IP protections. As patents are the primary method of protecting intellectual properties of invented devices, we first examine the patentability of our device from different angles. Our analysis shows that a design patent on product's physical enclosure will be our initial best bet at protecting our competitive advantage. We then look at the impacts of having a design patent on our enclosure, whether it is worth pursuing, and the risks involved should we choose not to apply for a patent at all.

As we concluded above in our discussion on strategy, the path to standing out in the loss prevention industry and in the broader scheme of the Internet of Things is to differentiate the reMINDER based on a unique and seamless user experience. There are three core components that make up the user experience of the reMINDER. These are the hardware configuration that directly provides the functionality for storing items and issuing notifications to the user, the software running on the device's hardware and in the mobile app that control user-device interactions, and the physical enclosure that dictates how users are to use their personal items in conjunction with the reMINDER. Intellectual property protections for any of these components will provide protection for the way in which we achieve our user experience. An examination of the patentability of these components reveals that our most promising prospects for intellectual property protections lie in patenting the enclosure with a design patent.

On the hardware side, patents provide strong, broad protections but are costly in terms of wait time. To protect intellectual property concerning our hardware configuration, we would need to have a utility patent, which protects the functional aspects of our device. This would provide broader protection for our product, since competitors would not be able to copy the way

the reMINDER operates to provide the unique user experience. However, utility patents take a long time to obtain; Eric Waltmire of Erikson Law Group, PC estimates the wait time to be thirty-two months on average (Waltmire). This is certainly an option to consider but not our most promising bet for the near future.

Looking at the software side of things, we find that the software patent landscape is uncertain and unlikely to provide adequate IP protections. As defined by the Foundation for a Free Information Infrastructure, a software patent is a patent on any performance of a computer realized by means of a computer program (Josefesson 2005). In a recent 2013 case, *Alice Corp vs. CLS Bank*, the Supreme Court ruled that the software patent disputed in the case was invalid due to the software simply being a series of basic computer functions implementing an abstract idea (Robertson 2014). Since the *Alice* case, however, what exactly constitutes an abstract idea in the legal sense has not been established (Casey et. al 2015). With the legality of software patents being questioned in Supreme Court itself, it is unlikely that we will find much hope for solid protections in software patents.

This leaves us with the applying for a design patent on the enclosure. Design patents protect the ornamental features of a product and so do not protect the product's functions from being copied. However, the wait time is shorter for a design patent at an estimated one to two years compared to the wait time for a utility patent (Neustel Law Offices). The success rate is higher as well when compared to utility patents; Patent Info.Net reports an eighty percent conversion rate for design patent applications into actual design patents, compared to twenty-five for utility patents (Patent Info.Net). Additionally, a design patent gives us protection on the overall user experience, as companies that copy our functionality will have to apply it to a unique design that may not be optimal for supporting such functionality. Design patents can be used

effectively to defend against infringement, as in the case of Apple and its D'087 patent on the iPhone's design. Based on this patent alone, Samsung was found to have infringed upon Apple's design patent with the Samsung Galaxy S 4G and two other phone models, and the total damages in this case totalled \$163,018,625 (Nowotarski 2013). From this analysis it is clear that, while a utility patent is a form of protection we should investigate and strive for, in the short term a design patent is our best bet at protecting our user experience.

A design patent would help establish the reMINDer team as user experience experts. However, applying for a patent of any kind is an expensive and time consuming process. A UC Berkeley law survey of 1300 high tech entrepreneurs claims that the average cost of filing a patent is \$30,000, a high cost for resource poor entrepreneurs (Stuart et al. 2009). Patents are viewed to be less useful in our industry than in other like like biotechnology and medical devices (Stuart et al. 2009). Even if we were to obtain patents, we are unlikely to be in a position to afford the cost of using them to protect ourselves in the near future.

However, a design patent would provide some advantages. The Berkeley Law survey revealed that although patents are viewed less useful in some industries, startups with venture backing tend to hold more patents regardless of industry (Stuart et al. 2009). This is in line with the generally accepted view that investors value patents, but may also suggest that venture capitalists encourage the pursuit of patents once they invest in a startup. In addition, patents are valued by larger corporations who are far more capable of protection with their use. As a result companies are sometimes primarily for their intellectual property as demonstrated by Google's acquisition of Motorola (Roberts 2014). For the reMINDer team however we may consider a design patent primarily to establish credibility of our unique design. It is unlikely to hinder copy cats but it may bolster support for original design.

Forgoing a design patent is potentially risky for the reMINDER due to the low barrier to entry in our industry. While the technology may be difficult for a customer to replicate on their own, a competitor such as Sony could very quickly design and go to market with a similar device. This would decrease our market share, and given the number of such possible competitors we could be pushed out of the market altogether due to our lack of resources to compete. A patent would hinder these competitors from simply replicating our product, allowing us a stronger hold on the market.

To further improve our position we can pursue measures in addition to a design patent. In particular, we intend to focus on innovation over protection (Ferrill et al. 2013). This is a technique which the fashion industry has used for many years, relying on changing their designs before they can be copied in order to maintain their competitive advantage. By constantly improving and altering the design of the reMINDER we can stay ahead of our competitors. They can choose to copy our designs, but they will always be a step behind if they do so. This strategy adds a second layer of protection beyond a design patent in order to address the strong threat of new entrants.

## **4. Technical Contribution**

### **Overview**

The goal of our capstone project is to follow the product development cycle in order to build an interactive product using the Kinoma platform. This development cycle includes ideation, user research, prototype development, user testing, and can even be extended to marketing or business plans. Given this inherently interdisciplinary goal, in combination with all of the members of our team having a background in computer science, we elected to work together on all of the different elements of the project. Product designers and developers must have a knowledge of the business, technical, manufacturing, and marketing sides (Rogers 2011:11), and by working together on everything we are all able to be exposed to each of these. This approach allowed us all to gain experience with the different components such as user research, embedded systems, and rapid prototyping so that we could all get a sense of the entire development cycle rather than being limited to a specific niche. It also allowed us to apply our previous experience and to all help in the areas where we were less familiar. However, given that I have had previous experience working with embedded systems and hardware in the past, I took the lead on the tasks related to sensors and the hardware in general.

In this section I will discuss the team's work on our embedded systems, which deal with how the reMINDER device interacts with the physical world around it. The primary task of these systems is to identify which objects are currently located in the reMINDER. This information can be used to keep track of the status of the items which the user has paired. Additionally, there are also the tasks of identifying when users are entering or leaving their home, as well as notifying the users at this time of their need to either take or leave their items. The goal of the reMINDER is to help users develop habits by giving them well timed reminders about their items' statuses. It

is these embedded systems which allow the bowl to know which reminders to give and at what time to give them in order to build these habits. These systems integrate with the software systems on the Kinoma Create and accompanying smartphone app in order to provide this core functionality of the product. Codanda Appachu will discuss these software components, including the network communication between different devices, the user interface, and our chosen technique for connecting the reMINDER to a Wi-Fi network. Steven Hong will provide a complementary discussion on our methodologies for making design decisions about the user experience, which led to many of the choices we made in our software and hardware.

## **Object Identification Background**

There are five methods which we considered for identifying the objects which are placed in the reMINDER. These are load sensors, RFID (Radio-frequency identification) tags, Bluetooth beacons, and color sensors. Each of these technologies has been used in different applications in order to identify objects. I will provide a background on how each of these methods work, the positives and negatives of the methods, and how they would fit with the reMINDER in order to allow us to identify which of the users items are present.

### Load Sensors

Load sensors are used to determine the weight of objects. They work by translating the force applied to them by the weight of an object to a change in resistance. This change in resistance will result in a change in voltage which a microcontroller can interpret as weight after calibration. The surface of the reMINDER could be connected to a load sensor in a similar manner to digital scales. Whenever a new item is paired with the bowl its weight could then be measured and recorded. Combinations of items can then be recognized by solving for the

combination of item weights which sum to the currently recorded weight. An advantage of this method is that any number of items can be paired, and the user doesn't need to do anything special to these items as they would in the RFID or Bluetooth cases below.

There are three issues that can arise by using this method to recognize objects. The first is the accuracy of the sensor itself. Despite careful calibration, other factors can affect the accuracy of the reading, most notably hysteresis and temperature (Vishay Precision Group 2011:2). Hysteresis is the difference in readings based upon the history of force applied to the sensor. Different readings can occur based upon whether objects are placed on or taken off to get to the current weight. Temperature can also cause fluctuations in readings, even within the operating zone of the sensor. The second issue is different combinations of items can lead to the same or very similar weights. This is especially true since the reMINDER targets a specific subset of items such as keys and wallets. The last issue is that the weight of these objects can and will change over time. A set of keys can have individual keys or accessories added and removed, and wallets contents may vary from day to day. Any of these issues could cause the incorrect classification of which items are and are not present.

### RFID Tags

RFID, or Radio-frequency Identification, is the use of electromagnetic fields to wirelessly transfer data from passive tags to active readers. These passive tags are unpowered, but store a small amount of data on them, most notably a unique identifier. Tags are small, available in form factors that range from the size of a quarter to the size of a credit card. The reader is powered, and creates an alternating current in its antenna which in turn creates an electromagnetic field. This field induces a current in any nearby tags, providing them with the

power to generate their own field to send their data back to the reader. These tags can then be attached to any item, and that item can be recognized by the reader via a mapping between tags and items. This is the technology that is used in key cards in order to identify whether a person can unlock a given door. RFID comes in three different categories, Low Frequency (125 kHz), High Frequency (13.56 MHz), and Ultra High Frequency (900 MHz). Ultra High Frequency is able to detect many tags at a time (Roy Want 2004:58) at a larger distance than either of the lower frequencies.

RFID allows for very accurate object recognition since each tag will have a unique identifier, making it a one-to-one mapping between the values read by the reader and objects. By placing a tag on each item which we wish to track, and a reader inside of the reMINDER, we can detect which items are placed on top. However, there is a trade-off between cost and the systems range and ability to read multiple tags. Low frequencies are inexpensive, but can only identify one tag at a range of about one inch. High frequencies can detect many tags at a range of one to one hundred meters, however both the tags and the readers are much less economical. There is the potential to miss some of the items which are present with a system which is financially feasible to use in the reMINDER.

### Bluetooth Beacons

Bluetooth Beacons are similar to RFID in that they wirelessly communicate their identity, however this communication is over Bluetooth. Standard beacons are able to communicate at a range of up to 75 meters. Rather than being powered by the reader, beacons are active and have a battery on board. Most beacons available today have an estimated battery life of about 1 year. Since the beacons themselves are active, each additional beacon is a substantial additional cost.

With RFID, most of the cost is in the reader, with each additional tag being negligible. Beacons have the potential to be much more powerful than RFID since they can be used to detect location, and can also have other onboard sensors. Many of our competitors use different versions of Bluetooth technologies so that they can detect when you have gotten too far away from your tagged items, and then be able to locate them.

Beacons could be attached to any items that the user wants to track, and they would transmit to the reMINDER when within range. Since Bluetooth is longer range than RFID, there is the potential of identifying the object as being within the bowl, when potentially it is only nearby, perhaps still on the user. Whereas a reading from RFID guarantees the tag is next to the reader, with a beacon it can be anywhere within range. By analyzing the signal strength, a position can be calculated which has been shown to have an average error of 0.53 meters (Martin et al. 2014:190).

### Color Sensors

Color sensors are capable of identifying the color of nearby objects. They do so by illuminating the object with red, green, and blue LEDs and then measuring how the light is reflected with a photocell. The response to each color is combined and the color of the object is derived. By measuring the colors of any items placed on the reMINDER, we can infer which objects are present. This technique is prone to error since it would require many sensors to detect multiple objects, different objects could have similar colors, and stacked or close together objects could give misleading readings.

## **Object Identification Tests and Results**

In order to determine which technology would be best for the reMINDer, we began by researching the limitations of each and then found our specific needs through the user research methodologies detailed in Steven's paper. We found that our users wanted to use multiple items with the reMINDer which are sometimes very similar, such as two different sets of keys. They also wanted to be able to add additional items, but minimize any sort of upkeep after initial setup. The reMINDer is a product that should integrate in to their lives seamlessly in order to help develop habits.

We evaluated these requirements against each of the different object identification methods. Color sensors can be dismissed due to the use case of items like wallets and keys which can vary in color depending on how they are placed down, and which can have many colors in common between items. Since these items are also of similar weights, which can potentially vary over time, we can also dismiss using a load sensor. This leaves Bluetooth beacons and RFID tags, both of which provide the high degree of accuracy at correctly identifying items. The beacons come with three major downsides given our interviews with users. First, their high cost means that users would need to purchase additional beacons for about \$20 to add a new item to their bowl, which goes against their desire to be able to track many different items. Second, beacons would need to be replaced or have battery changes about once a year which both adds cost and maintenance time. Finally, the size of the beacons themselves is less convenient than an RFID tag. This is improving, but current generation

beacons don't fit within a wallet like an RFID tag, and make for a large keychain. Given these downsides to beacons, we settled on using RFID as our object identification method.

RFID is generally used to identify one tag at a time in consumer settings, such as with access control via key cards, or to identify many tags (hundreds or thousands) in a commercial setting, such as in a warehouse (Zhang et al. 2012:999). Our application is within a consumer product, so we need to maintain lower costs, however the reMINDER must be able to identify several objects at a time. For this reason we chose to use High Frequency RFID, which is available at a price point similar to low frequency, but can read several different tags in quick succession at low range. The RFID reader we are using is the PN532, a popular chip which operates at 13.56 MHz. An accompanying breakout board can be found through Adafruit, which has a built-in antenna. The antenna can play a large role in both the range of the reader, as well as the area which it can read. These are two important variables for us to maximize since we need to be able to read tags on items which can be stacked in the bowl, or placed beside each other.

In order to maximize our read range and area, we performed several tests on antennas of our own construction which we connected to the breakout board, as well as the standard built-in antenna as well. We tested each antenna design for range and reliability with two different tags, the MiFare Classic Card (Figure 1) and the MiFare Classic White Tag (Figure 2). Their sizes can be seen relative to a quarter below. The card form factor works well to tag a wallet, and the white tag can be attached to keys. Antennas varied in both number of turns (number of loops of wire) and diameter of the wire ring. A tag is considered to be readable within the antenna if it can be held anywhere over the area surround by the antenna ring and be read. It is considered to

be readable inside the antenna if it must additionally be on the plan of the ring, within the loops of the antenna itself.



Figure 6: MiFare Classic Card



Figure 7: MiFare Classic White Tag

Antenna	Card Results	Tag Results
Standard Adafruit Breakout,	Range: ~8cm Reads reliably when any part of card is over antenna	Range: ~4cm Reads reliably when any part of tag is over or within antenna
2 turns, Copper tape, 15 cm diameter	Unable to read	Unable to read
3 turns, copper wire, 8cm diameter ring	Range: ~4cm Reads reliably when card is within antenna	Range: ~0cm Reads reliably when tags are physically inside the antenna
2 turns, copper wire, 15cm diameter ring	Range: ~4cm Reads reliably when card is within antenna	Unable to read
3 turns, copper wire, 15cm diameter ring	Range: ~7cm Reads reliably when card is within antenna	Range: ~0cm Only able to read when directly over wire
4 turns, copper wire, 15cm diameter ring	Range: ~7cm Reads reliably when card is within antenna	Range: ~0cm Only able to read when directly over wire
9 turns, copper wire, 15cm diameter ring	Range: ~2cm Reads reliably when card is within antenna	Range: ~0cm Only able to read when directly over wire

Table 1: Results of Antenna Tests with PN532 RFID Reader

## Final Prototype RFID Configuration

After these tests with different antennas, the results of which can be found in Table 1 above, we found that the standard antenna on the break-out board provided the best range to area ratio for our application. We could cover more area, but would lose both range and then ability to reliably read the smaller tags. Our final design toggles reading between two PN532's which can accurately recognize any tagged items that are placed within range, and then communicates those tags to our microcontroller using Serial Peripheral Interface (SPI). The two readers are position as depicted in figure 7, where the green rectangles are the antennae of the two readers. By using two readers we are able to have a larger surface area where items can be placed (approximately within the red rectangle). In future designs these two individual readers could be replaced by a single reader which toggles between multiple antennae.

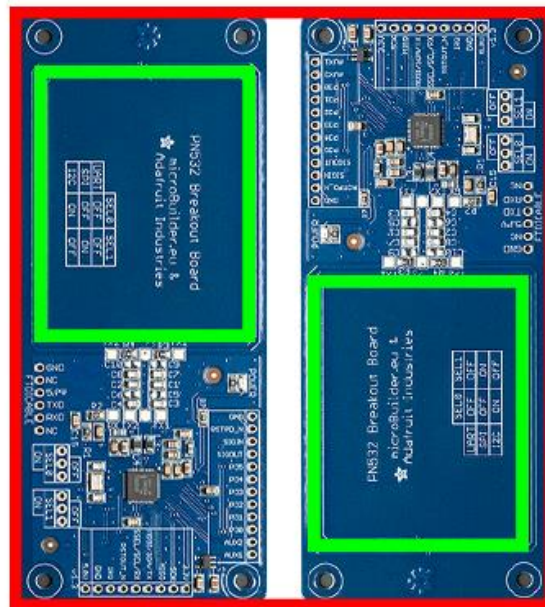


Figure 8: RFID Configuration

## **Additional Embedded Systems**

In addition to recognizing objects, the embedded systems of our device must also recognize when users are either entering or leaving the home, and then notify them if they need to interact with the bowl. Our current solution for detecting whether the user is leaving or arriving is through a passive infrared sensor (PIR), depicted in figure 8, which detects motion within its field of view. This sensor is mounted on the bowl itself. The Kinoma platform is currently developing a remote sensor capability which will allow for this sensor to be placed separate from the main device, so the user can place the sensor near their door, and the bowl elsewhere. This will greatly increase the accuracy as currently the size of the bowl makes it difficult to direct the motion sensor solely at the entry way, causing false positives from simply moving around the home.



Figure 9: PIR Motion Sensor

In order to determine how best to notify our users that they are forgetting an item, we performed user research on the effectiveness of different notification techniques, namely lights, sound, and via smartphone. We performed a test in which we asked users to go through their normal morning routine. At some point during the routine, we would either have a solid light, a flashing light, a sound play, or send them a text message. We found that half the users noticed the solid light, all the users noticed the flashing lights and the sound, and only 3 out of 10 noticed

the text. Additional feedback from the users showed that they didn't want a sound to play since it is more invasive than a light. We settled on a pulsating light as a notification technique in light of these results.

The specific LEDs we are using are NeoPixels. They are a strip of RGB LEDs like that in figure 9 which can each have their color and brightness individually controlled using a single-wire control protocol. These lights allow for very expressive lighting due to the high degree of control, which allows us to do a subtle pulsating notification system which catches attention without being invasive.



Figure 10: NeoPixel Strip

## Conclusions

These systems come together to provide a new interactive experience which helps users build new habits around the items which they need to remember on a regular basis. By applying RFID and motion sensing technology in this way we are able to find a novel application which can reduce forgetfulness and stress in people's everyday lives.

## **5. Concluding Reflections**

We are currently beginning to test the reMINDer with users. While we anticipated several iterations of development, we ultimately have gone through more prototype iterations than expected. These additional iterations have pushed back our testing, however we did still receive limited amounts of user feedback between iterations.

Project management is an important part of the Master of Engineering capstone project, and I have learned the benefits of solid project management. Sharing the role of project manager is not an effective method for a successful project. If I were to repeat the project, I would make sure earlier on that we have a dedicated project manager who will set milestones and make sure they are met on time. This would help guarantee everyone gets their necessary work done quickly and efficiently.

To carry the project forward, or if I were to start over, I believe an important change would be to have a designer involved in the process. While we all learned a lot about the design process throughout the capstone, our expertise lies in software and hardware. Having a designer in the team would improve the overall user experience, as well as accelerate development time. The current prototype demonstrates the key functionality of the reMINDer, but it lacks the elegant design required in a consumer product. These design elements are where I would place my emphasis moving forward as they are what will truly excite users and help them see the value behind the reMINDer.

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