Interactive Device Design with Kinoma Create

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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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Abstract

The goal of our capstone project was 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.

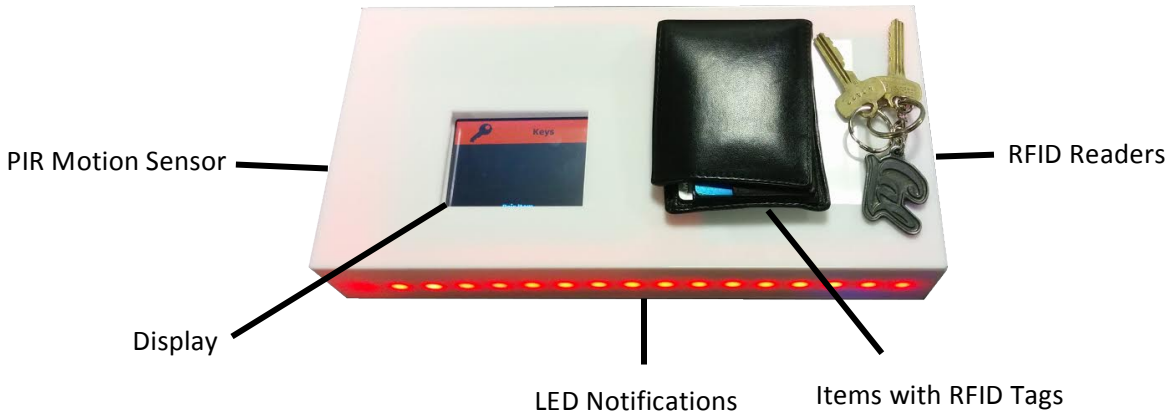


Figure 1: Final prototype of the reMINDer device.

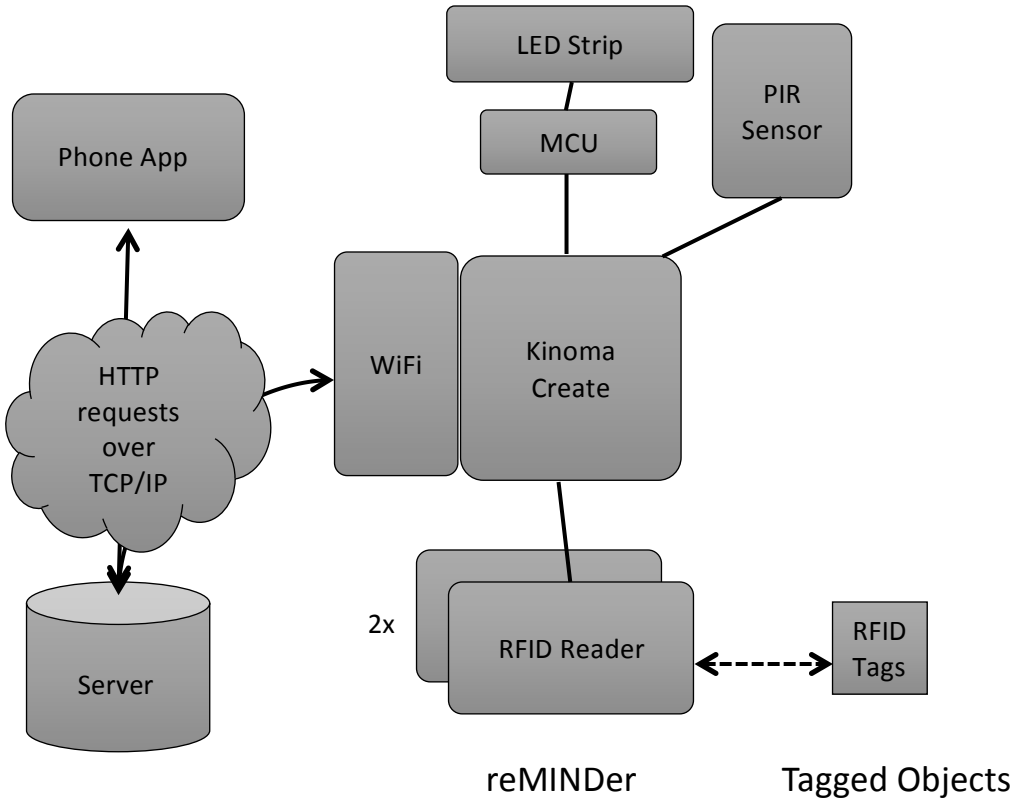


Figure 2: Block Diagram of the reMINDer

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 3 (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).

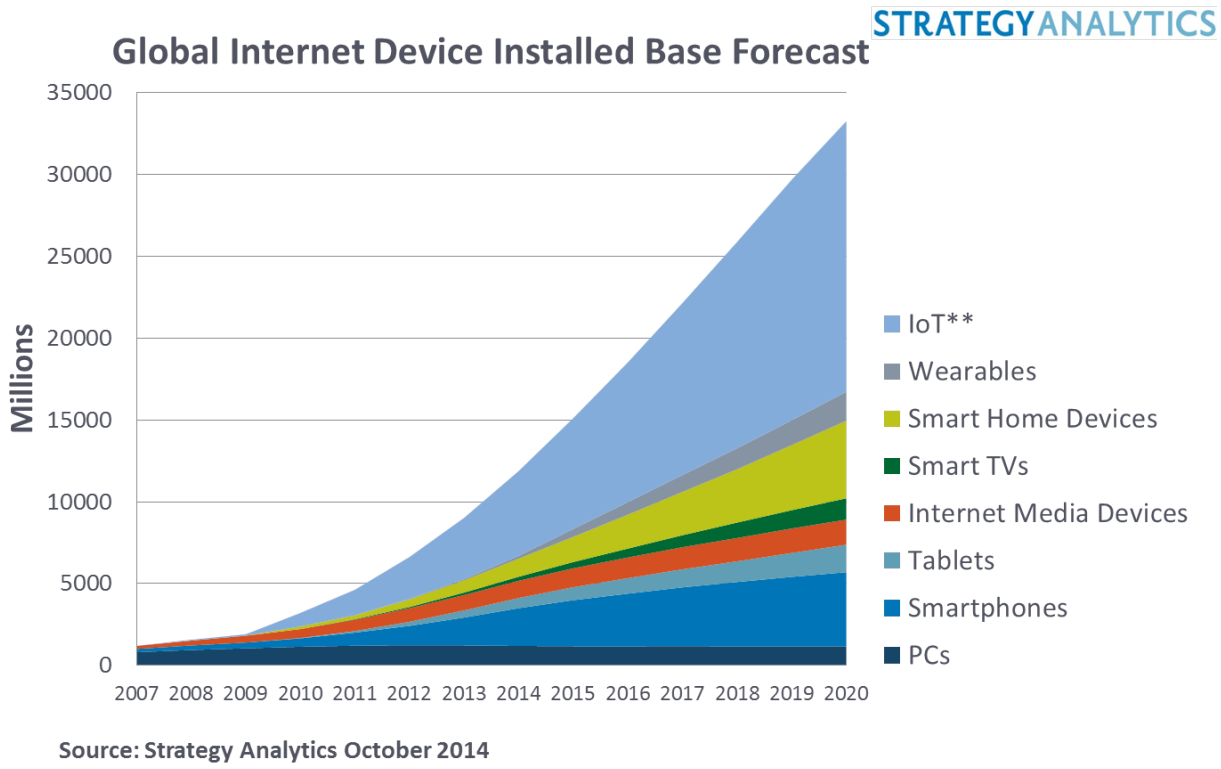


Figure 3: Projected growth in number of installed Internet devices, with Internet of Things connected devices experiencing the most growth in the projected time period

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 4 (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 5 (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

Project Overview and Context

The overarching goal of our Capstone project is to create a new interactive device with Marvell's Kinoma hardware and software prototyping platform. Within this loosely defined end goal our tasks began with the process of ideation and brainstorming product ideas, learning and using rapid prototyping methods, user needs analysis and user testing. Through this iterative design oriented process emerged the product concept of the reMINDer, a product that reminds users to take personal items (like keys or wallets) with them when they leave their homes. As members of a small three-person team we were each involved with several elements of the product creation process.

A novel interactive consumer device cannot rely solely on its technical ingenuity and engineering prowess independent of the context in which it is to be used by everyday consumers (Hunter 2013). The three primary layers of the technical stack of the reMINDer are the hardware, software and the design and fabrication of the physical enclosure. The hardware needs to be capable of uniquely identifying items placed in the reMINDer and provide visual feedback to the user reminding them to place and take items in and out of the reMINDer. The design of the enclosure needs to be a friendly and attractive addition to a home, contain within it the hardware components necessary for detection and feedback and adopt familiar patterns of usage. The software layer is composed of both the application that runs on the reMINDer, the companion smartphone application, the communication middleware and the data store for maintaining application state. This section of the paper will describe the last of the three layers listed above in some detail and the motivation for some of the choices made in the architecture and composition of the reMINDer software stack.

High Level Overview of Smart Devices Software

The bar for creating smart connected devices has been lowered significantly in the last couple of years. Platforms like Arduino (Arduino 2015) have gained significant adoption and decreasingly require the garage entrepreneur to have domain expertise. By creating high level software interfaces and a thriving online community willing to share information freely new generations of amateur makers are joining the wave of smart connected device creators (Kubitza et al., 2013). However, in order for these devices to move from garage experiment to consumer product they often need to be integrated into the new technology stack (Porter, & Heppelmann, 2014), which includes the embedded and application software, network communication and application server software that houses and optionally analyzes the application data. Figure 5 illustrates the various layers of the reMINDer software stack. I will give an overview of related work and trends in each of these software layers and the methods used in the reMINDer software stack.

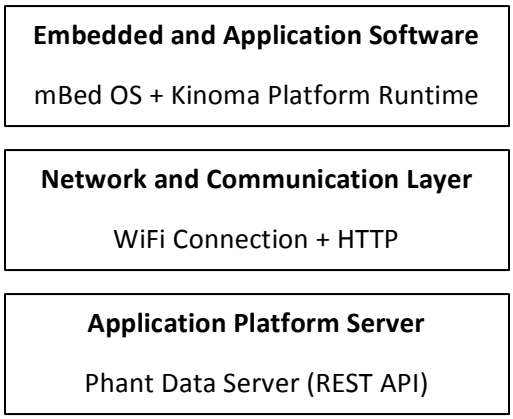


Figure 5: The reMINDer Software Stack consists of multiple layers, including the embedded and application software that reside on the device and smartphone, the network and communication layer which provides the fabric of communication with the application platform server housed in the cloud.

Embedded and Application Software

The software that runs on the reMINDer is composed of embedded software running on an ARM chip and application software running both on the Kinoma Create hardware and a smart phone. We use ARM's mbed OS and development platform for the embedded software (Mbed, 2015). The mbed platform takes an unusual approach to embedded software development by providing a cloud based integrated development environment (IDE) that can be deployed to the chip as easily as moving a file to a USB drive. Unlike traditional embedded software development the high level interface and the many libraries available through a community portal allow developers to concentrate on higher level programming constructs instead of low-level optimization. We restrict the responsibilities of the embedded software to controlling the light emitting diode (LED) light strip that surrounds the reMINDer enclosure and reading information from the Radio Frequency Identification (RFID) reader. The Kinoma Create is responsible for controlling the liquid crystal display (LCD) on the reMINDer, enabling users to pair new items (detected via RFID tags) via a visual interface (see Figure 6), detecting motion using a passive infrared (PIR) sensor and higher level communication with the cloud based server and data store.

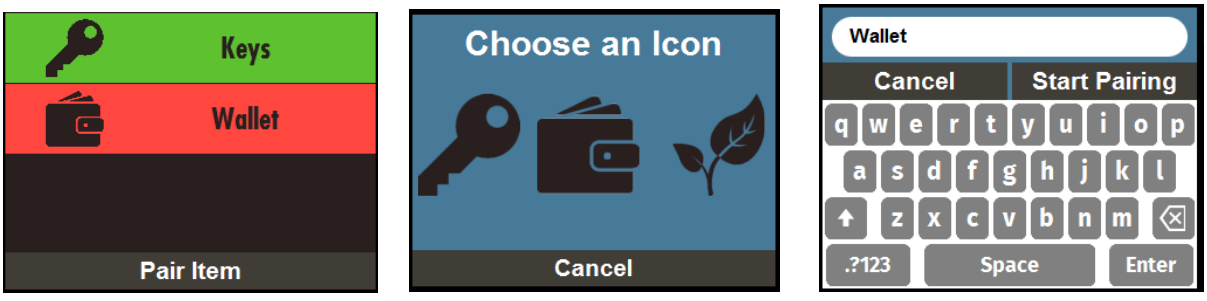


Figure 6: The reMINDer interface for pairing new items with the device.

One of the challenges with creating software for the Internet of Things (IoT) is that it often has to target multiple heterogeneous endpoints and platforms. Prior research has attempted to address this problem by developing systems that simultaneously target multiple platforms. JADE is hybrid programming language that provides a unified programming framework that is capable of running on both the device and the server (Ghosh et al., 2014). Similarly, smartphone application developers writing applications for multiple smartphone operating systems have attempted to address this issue by using the universal language of the web (HTML, CSS, Javascript) rather than writing native applications. This is the approach taken by PhoneGap, Sencha and Appcelerator. We followed suit by primarily using the Kinoma Platform Runtime (KPR), a Javascript based runtime environment capable of targeting several platforms including the Kinoma Create, iPhone and Android (Kinoma, 2015). A screenshot of the reMINDer smart phone application is show in Figure 7 running in the KPR Android simulator. By using the Kinoma runtime both the smartphone application as well as the reMINDer application use the same programming language, constructs and libraries.

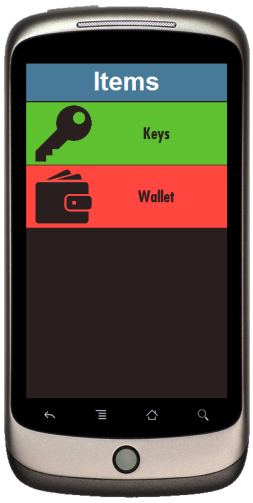


Figure 7: Smart phone interface for checking status of items in the reMINDer.

By using the same environment and developer tools for both end user applications we were able to build several iterations of prototypes rapidly. Furthermore, by programming once and being able to deploy to many devices we are not burdened with the challenge of updating multiple device specific software code bases as platforms evolve. In addition, leveraging some of the existing libraries on the KPR platform eased the development of certain core components of the application, particularly in the network and communication layer of the reMINDer software stack.

Network and Communication Layer

For the reMINDer and smart connected devices in general the communication middleware and the data store are essential components. Beyond just allowing information to be exchanged amongst devices, creators and users, it enables products in the cloud to analyze these streams of data and create new product offerings and services (Porter, & Heppelmann, 2014). We chose to house the data centric software of reMINDer in the cloud primarily because of the ability to easily make software updates remotely and unobtrusively. We further envisioned additional uses of the activity data that was being collected by the device and potentially linking it to other smart connected devices in the home. Devices, sensors and physical sources of information will no longer just be single nodes of information; they will form a coherent fabric of intelligent distributed applications. In this section I describe some of the dominant choices for network and wireless protocols available to developers of smart connected devices and describe our motivation for choosing wireless local area network (WLAN) or WiFi for the reMINDer.

Network Protocols for IoT

In anticipation of the evolution of smart connected devices some researchers have proposed new protocols for high throughput network backends that take into account this change in network traffic from a few large data objects (file sharing and multimedia streaming) to a large number of small messages (from control and sensory devices) (Kovatsch et al., 2014). Message Queue Telemetry Transport (MQTT) is a communication protocol designed for machine-to-machine (M2M) communication, designed to be lightweight, energy efficient and having a low bandwidth footprint. ZeroConf and Simple Service Discovery Protocol (SSDP) are sets of technologies that automatically create a computer network without requiring the use of Dynamic Host Configuration Protocol (DHCP) and Domain Name System (DNS) services. Familiar instantiations of Zeroconf is Apple's Bonjour discovery service or the wireless universal plug and play protocols that allow computers to discover nearby printers and other services (UPNP, 2015). We explored some of these network protocols when iterating through early prototypes of the reMINDer software. SSDP and ZeroConf are both supported by the Kinoma Platform Runtime which allowing us to quickly build low fidelity prototypes for the reMINDer.

Low Power Wireless Protocols

Research surrounding low power wireless protocols like network protocols for IOT have similarly followed a pattern of growth. Many like Bluetooth and Zigbee have established standards for local and long range wireless networks with low power consumption characteristics. Bluetooth Low Energy (BLE) is a wireless personal local area network protocol designed to be used devices powered by small coin cell batteries that have very low power consumption (Bluetooth, 2015). BLE has gained wide spread adoption and is supported by most

smartphones natively. In essence, BLE radio signals hop between several channels at a high frequency, making BLE both less likely to interfere with other household wireless items and more secure (Bluetooth, 2015).

Zigbee, although similar to Bluetooth in its energy consumption characteristics can be used for longer range wireless communication through the use of mesh networks. By connecting several small zigbee transmitters one can effectively improve its range. In addition, because of their low bandwidth their signal loss rate is much lower than WiFi making them ideal for larger range sensors. As a result, zigbee's have recently been growing in adoption. However, a drawback of zigbee is that it isn't as widely adopted by device manufacturers as bluetooth. This is often ameliorated by having several zigbee devices communicate with a central hub that in turn connects to a WiFi network.

Our team was familiar with Bluetooth and Zigbee having used them in the CITRIS Invention Lab on campus as a part of experiments for a class titled Interactive Device Design. However, we unanimously chose to use WiFi for the reMINDer device and the accompanying smart phone application. We needed to be able to communicate between the reMINDer device, the application server hosted in the cloud and the smart phone application effectively. We chose to use WiFi primarily because of its ubiquity and familiarity with end users, making both the first time setup experience and maintenance seamless for reMINDer userss.

Establishing Seamless WiFi Connectivity

WiFi is the wireless technology most consumers are familiar with, powering their home wireless local area networks and allowing high bandwidth communication suitable for the streaming content like music and videos. For most IoT devices the power intensive WiFi

protocols are inappropriate, but for devices that are plugged into a wall socket and are stationed primarily in one location this is not a concern. The Nest learning thermostat adopts this approach by powering its WiFi transceiver from a wall electrical cable.

We envisioned precisely this scenario in the use of the reMINDer. From our preliminary user studies we found that are subjects typically leave their keys and personal items in the same physical location or region in their homes. Once the device is connected to the wireless network, WiFi credentials rarely have to be updated. The challenge is to painlessly and seamlessly connect the reMINDer to a home or office wireless network the first time, improving the unboxing experience for the end user.

There are several methods of provisioning IoT devices with WiFi. Provisioning a new device usually involves selecting a network name (or SSID) and providing security credentials to gain access to the wireless network. Often the IoT devices do not have a visual display or keyboard to easily configure the device. This encouraged the development of WiFi Protected Setup (WPS) that was adopted by many WiFi access points. WPS enabled access points typically provided two methods of gaining access to a wireless network without knowledge of the network name or the password; a Personal Identification Number (PIN) based method and a Push Button Connect (PBC) method. However this method has was discovered to have security flaws, allowing an intruder to gain access to the network using a brute-force method in less than four hours (Reiter, 2015). An alternative method adopted by devices like the Withings Smart Scale is to spawn an independent wireless network that a user explicitly connects to in order to configure the network (Reiter, 2015). We chose to use the LCD display on the Kinoma create to assist users in joining the a wireless network, since the software on the Kinoma Create follows familiar

modes of interaction for connecting to a wireless network and eases the process for a user to connect to their home or office wireless network.

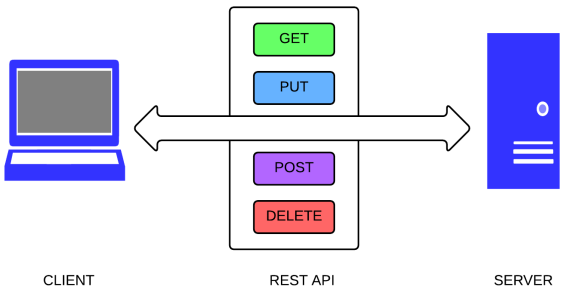
Application Platform Server

The IoT revolution has spawned the growth of a large number of heterogeneous embedded devices like the reMINDer. These devices interact with services in the cloud or on the web to form useful data and analytics services. Although standards at the network layer are standardized and maturing, in order to compose these various devices and their data feeds into useful larger level systems one requires a standard means of communication and composition at the application layer as well.

Researchers have developed several methods to address the issue of composing heterogeneous IoT endpoints. The Web of Things (WoT) for instance takes the approach of using a service oriented architecture to describe objects, devices and sensors in the physical world (Guinard et al., 2010). Others have explored methods of transforming feeds traditionally used for blog posts and podcasts to represent high frequency real time data from sensors (Dickerson et al. 2008). In contrast the Open Service Gateway initiative (OSGi) and similar groups have developed specialized architectures for service discovery and registration (Rellermeyer et al., 2008). This is still an active area of research and there is no uniform consensus for an application layers for managing a massive amount of distributed sensors.

In the reMINDer we adopt a widely used and well understood method used for web services called REST (Representational State Transfer). Originally proposed by Roy Fielding in his doctoral thesis, REST services are conform to a set of simple constraints that make describing resources uniformly in which requests encode wholly information about application state

(Fielding, 2015). We use the common Hyper Text Transfer Protocol (HTTP) methods POST, GET, PUT and DELETE to create, read, update and delete the reMINDer's activity data which is hosted on a server (see Figure 8). This architectural pattern and our adoption of REST encourages the creation of loosely coupled services that can easily composed, reused and modified if necessary.




```
// Log Event with a HTTPS Request
var uri = "https://data.server.com/input/XGXZnXXXXX?" +
    serializeQuery({
        private_key: "1Jgz8vY7zXXXXXXX",
        deviceID: "5",
        tagID: "204",
        tagname: "Wallet",
        action: "insert"
    });
parent.invoke( new Message( uri ), Message.DOM );
```

HTTPS Request in Kinoma Javascript

deviceID	tagID	tagName	action	timestamp	...
5	0		motion	..23:54:33..	...
5	28	Keys	remove	..23:54:53..	...
5	0		motion	..21:30:37..	...
5	204	Wallet	insert	..21:30:46..	...

Log Data in Server Database

Figure 8: The reMINDer uses a REST API to communicate with a HTTP server. The reMINDer client software sends and receives data via HTTP requests, creating, reading, updating or deleting activity data hosted on the server.

On the server the reMINDer application layer makes use of Phant, the REST driven data logging service published by SparkFun (Github, 2015). Communication between the reMINDer and the possibly many running phone applications occurs by posting HTTP requests to a server

running Phant. Phant allows provides a Representational State Transfer (REST) API for interacting with data stored on the server. Be delegating the task of feeding data to both the phone application and the reMINDer application to the server we decouple the architecture of each of the parts, enabling each to evolve independently (Fielding, 2015). This allowed us to change not just the smart phone application and the reMINDer application but also the software that resides on the server without affecting the remaining components giving us a tremendous amount of flexibility as we iterated through different versions of the software.

5. Concluding Reflections

While we were able to create a high fidelity prototype of the reMINDer, it lacks the finesse and polish of a commercial product. The prototype we created is able to perform the core functions we envisioned and can be used effectively in a users home, however there is certainly room for improvement in certain aspects of its design, form factor and cost of manufacturing. In particular the enclosure of the reMINDer is relatively large and bulky and its contents are currently expensive. To some extent the dimensions of the enclosure are constrained by the two commodity RFID readers and the Kinoma Create device it encloses. The original plan was to transition to the smaller Kinoma microchip during the second semester of our program, however it was not ready in time for us to make the transition. Working with a new platform like the Kinoma has its unique set of challenges. A lack of documentation and software libraries for interfacing with common hardware components when we began the project made it harder to quickly translate our ideas to physical prototypes. However, we took advantage of the Kinoma platforms unique strengths. The common JavaScript runtime allowed us to easily target and build a smart phone application and the Kinoma libraries made communication with common network protocols over a wireless network seamless. From a developer's perspective the Kinoma platform has matured significantly since we started making it easier for future individuals and teams to adopt the platform for rapid prototyping.

It can be challenging to predict exactly what resources, expertise and tools one needs when moving from napkin idea to product. Adopting an agile project management style proved to be effective for our project because of the iterative nature of the reMINDer product development cycle. We planned short sprints and revised them during our weekly meeting with our advisors incorporating the feedback we received from users and tests. Milestones in the Interactive Device Design class in the fall semester helped align our goals for this project and

prepared us with rapid prototyping skills that we would need. Having regular brief weekly meetings and updating the team and our advisors as we progressed through the semester was an effective way to keep us aligned with our immediate and long term goals as they changed.

For future work, further research into RFID readers and antennae would improve both the latency in RFID tag read time and increase its range allowing for more flexibility in the design of the form factor. In addition, although the Kinoma platform is well suited for rapid prototyping, exploring alternative embedded platforms and custom circuit board printing for the final product may be necessary. Both these endeavours would directly influence the form factor and price, which can significantly improve the experience for the end user and make the device accessible to a wider audience. The final look and feel of the enclosure needs to feel unobtrusive and capable of being absorbed into a user's home with ease. With the aid of an RFID expert, Industrial Designer and feedback from long running user tests I feel confident that a team can take this project to market.

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