ARTable

by

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Abstract

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Examining issues that come with the emergence of technology, such as the fear of boredom, of intimacy, and of face-to-face conversation. This thesis studies the possibility of a customizable design technology whose goal is to mitigate those issues. Pixls is a low cost interactive tabletop allowing users to collaboratively create digital drawings on a 64-by-64 LED matrix screen using mobile phone touchscreen, thereby encouraging social interaction amongst them. Adopting the research through practices approach, insights, and solutions gathered from literature review and relevant case studies are used as a theoretical foundation for the conceptualization and building of the aforementioned prototype. Based on three key findings derived from the analysis of user feedback, this study concludes that the technology stack used within Pixls should be generalized into a platform, upon which different features can be implemented to afford various types of social interactions, including, but not limited to face-to-face interaction.

Keywords: digital media, digital drawings, co-creation, co-located collaboration, Internet of Things, interactive tabletop display, playful interaction, Raspberry Pi, mobile web app.

Acknowledgement

To my parents, thank you for your unconditional love, support and encouragement. I could not have made it this far without you.

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Chapter 1: Introduction

Background and Motivation

The rapid advancement of technology has changed the way we interact with each other. Instead of calling, we would rather send a text message or tweet somebody; in lieu of inviting friends to our house warming party in person, we would rather create an event and invite them through Facebook. In her book "Alone Together", Sherry Turkle – professor of social studies of science and technology at MIT – shows "how we are changed as technology offers us substitutes for connecting with each other face-to-face" and that we see technology as a solution to our vulnerabilities (Turkle, 2011). Feeling lonely, yet fearful of intimacy, we rely on technology to defend ourselves from loneliness and at the same time to control the intensity of our relationships. Turkle finds that people of all age groups have excuses to avoid having a conversation. Teenagers avoid making phone calls because it reveals too much; similarly, adults would rather text because they do not have time. Twitter, Facebook, text message, and communication technology alike offer us ways around face-to-face conversation and grant us the ability to communicate when we wish and to disengage the conversation at will.

Nancy Baym, in her book "Personal Connections in Digital Age" (Baym, 2010), shares a similar view on the inability of technology "to offer the potential for intimacy and connection as face-to-face does". Looking from seven different aspects – interactivity, temporal structure, social cues, storage, replicability, reach, and mobility, digital media seem to provide less potential for intimacy and connection when compared to face-to-face interaction (Baym, 2010). Yet she argues the capability of digital media and mobile devices in providing a meaningful interpersonal interaction should not be discounted and they can be used to strengthen existing social relationships. On a similar note, Turkle, in her book "Reclaiming Conversation", states her belief in our ability and need to design technology that can be used with greater intention (Turkle, 2015).

Recent research in computer technology has shown its ability in promoting face-to-face interaction between users in both work and informal social environments. Several studies suggest that multi-touch tabletop systems enhance co-located face-to-face collaboration for multiple users, encourage equity of their participation, and promote playfulness that leads to improvement of interpersonal relationships (Piper & Hollan, 2009; Piper, O'Brien, Morris, & Winograd, 2006; Rogers, Lim, Hazlewood, & Marshall, 2009; Tang, Tory, Po, Neumann, & Carpendale, 2006; Tse, Greenberg, Shen, & Forlines, 2007). However, current tabletop systems often are expensive. The average price of an interactive tabletop system often ranges from 2,000 to over ten thounds of dollars (Google, 2016). Other challenging issues have also been identified with tabletop systems including complex input method (U Hinrichs, Hancock, Carpendale, & Collins, 2007), orientation of the on-display images (Ioannou, Christofi, & Vasiliou, 2013), and limited number of concurrent users affected by the size of the touch screen or by the touch recognition technology (Ahsanullah, Sulaiman, Mahmood, Khan, & Madni, 2015; Zhang et al., 2012). These challenges hinder prospective users from adopting and using interactive tabletop as collaborative tool.

This thesis, significantly influenced by the study of two books "Alone Together" and "Reclaiming Conversation" by Sherry Turkle, takes on the opportunity of providing a new way of using technology to promote human face-to-face conversation in public spaces such as coffeehouses. Leveraging the ubiquity of the mobile phone, and the mini yet powerful Raspberry Pi along with other off-the-shelf electronic components, this study aims to build a low cost interactive tabletop, called Pixls – an affordable piece of smart furniture to be used at any indie coffee shop. Pixls is designed to stimulate collaborative creation of digital drawings between users and to provide playful interactions through gameplays that are inspired by traditional party games like Pictionary, Exquisite Corpse, thus promoting face-to-face human interaction and conversation amongst users.

Hypothesis and Research Question

This thesis aims to explore the possibility of using technology to promote face-to-face interaction and to strengthen our interpersonal connection through conventional conversation. I believe this can be achieved through the provision of rich and playful face-to-face interactions using an Internet of

Things[1] platform that takes the form of an interactive tabletop device. Hence, the research question that I will be addressing in this study is:

> How can an application that uses the Internet of Things as a technology be designed in a way that it stimulates face-to-face conversation and interaction between people in informal social environments such as coffee shops?

Scope and Limitations

In this study, my focus is on the role of the Internet of Things platform; the cosmetic design of the table itself, e.g., the color of the table, and other general design components, however important, are not the primary focus. Nevertheless, some of design details of the table, e.g., its material, its flat surface, and its height are discussed in chapter 5.

Furthermore, due to the nature of the WIFI connection and its latency, the responsiveness starting from the time users interact with the table via the phone might be out of sync, i.e., the image can be rendered slower than it is being drawn on the mobile screen). Even though it might affect the user experience, addressing this issue is not within the scope of this study.

Overview

Chapter 2, 'Literature Review', presents three insights elicited from relevant literature on how technology can be redesigned to become a tool for greater

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[1] Internet of Things refers to a network of physical objects, such as devices, automobiles, buildings and items that are embedded with electronics, sensors, software, that have the capability to connect with each other through the Internet in order to collect and exchange data.

intention: how technology can be designed for our vulnerabilities; how technology should be designed for vigilant use; and why it should be measured based on a time-well-spent metric. Chapter 3, ‘Research Approach’, describes and justifies the choices of Constructive Design Research approach and several research methods for user testing, i.e., observation and questionnaire, that I use to guide my research and evaluate the outcome of this thesis. Chapter 4, “Ideation Process” describes the ideation process, providing rationale for why an interactive tabletop can be used to promote face-to-face interaction. Insights gathered from this process are used for the construction of the prototype. Chapter 5, ‘Construction of Prototype’, contains the rationale for design choices, use of technology, development process, challenges and solutions. Chapter 6, ‘User Testing’ describes user-testing methodology along with results of every user-testing session and their analysis. Chapter 7, ‘Conclusion’, presents and discusses the outcomes of the study along with its future development.

Chapter 2: Research Foundation

This chapter starts with detailing how technology can be designed such that it encourages face-to-face conversation. Examining the relevant literature has revealed three key insights. Firstly, the technology should be designed with our vulnerabilities in mind (Turkle, 2015). Secondly, the technology in question should supports vigilant usage (Phillips, 2014). Last but not least, it should promote “time well spent” (Harris, 2015).

Design for vulnerabilities

Since its inception, communication technology has been playing an important role in our affective lives. Seemingly magical, technology allows us to always be heard; it enables us to place our attention wherever we want; and it keeps us from being bored and lonely (Turkle, 2015). Yet because of these offerings, we grow increasingly dependent on technology.

We often find ourselves reaching to the smartphone when we feel bored. A study published by the Pew research center in 2015 (Smith, 2015) has shown that the majority of smartphone users use their phone to navigate numerous important life activities, e.g., researching health conditions, accessing education resources, or looking for job and employment resources, to be constantly updated with breaking news, to share and be informed about the happenings in their community. Especially with younger generations, who grew up with the smartphone and social media, technology indeed has been deeply embedded in their daily lives. These so-called “app generations”, as coined by Gardner et al. (Gardner & Davis, 2014), tend to use social networking, video and music apps to avoid boredom and to ignore other people (Smith, 2015). For instance, the kid in the stroller was playing a game on her iPad, ignoring her mother's friend who was talking to her; or a pair of high school kids was walking down the street with phones in their hands, typing, disengaged from each other.

However, the same behavior is also now exhibited among elders. An exemplary case can be found in Turkle's book "Reclaiming Conversation". A young, 34-year-old father, said that he finds it boring when giving his two-year-old daughter a bath. Instead of talking to his daughter, he sporadically checks his email on his phone (Turkle, 2015). Even though he consciously knows that he should be spending time with his daughter, he felt as if he could not help it. Without the constant stream of news feed from email, Facebook, Instagram, and Twitter, we would have to confront the boring bits of our lives. Boredom is often an excuse for us to turn to our phone entertainment, e.g., a game, and connections, e.g., text messages and Facebook updates, and we often feel anxious when there is no phone in presence (Turkle, 2015). This, so-called "disconnection anxiety" by Turkle, refers the feeling of anxiety triggered when we encounter the "boring bits". So when conversation becomes difficult and emotional or when conversation turns to quiet, we find ourselves instantaneously checking our phones to maintain a constant stream of stimulation. We find ourselves being elsewhere even when we are with each other.

We use technology to stay connected and to find ways around face-to-face conversation. As primates, humans are inherently social beings; our brain are made for social networking; and we are built to form a network with others (Standage, 2013). As such, our need to socialize comes from the natural inclination. The emergence of communication technology ranging from the invention of writing to advent of Internet and social network enables us to communicate and stay connected with each other across space and time. As Standage – a deputy editor at The Economist – claims in his book "Writing on the wall" that technology fulfills a universal human need for connectedness, for self-expression and for information-sharing (Standage, 2013). However, Turkle, in her book "Reclaiming conversation", argues that communication technology like texts, tweets, Facebook posts, emails, and snapchats has consequently replaced our conventional face-to-face conversation (Turkle, 2015). In fact, we rely on technology to reduce human contact, to flight from conversation, and to hide from circumstances where things get too emotional. In my experience, people would rather text each other than talk, even when they are just a few feet away; people would rather say: "I am sorry" over an instant message than say it face-to-face; and they would rather end a relationship over the Internet rather than do it in person.

In her research, Turkle notes that even though people avoid face-to-face conversation, they are comforted by staying connected to others who are emotionally kept at bay (Turkle, 2015). People are afraid that when meeting others face-to-face, they could do something that other people might not like, or say something that makes them look stupid. Therefore, to them, conventional conversation is too risky and that face-to-face unrehearsed conversation, which happens back and forth in real time, makes them unnecessarily vulnerable (Turkle, 2015). Through technology (e.g. texting, Twitter, Facebook), people can put their friends in a not-too-close, not-too-far, but just right distance. This is an instance of modern Goldilocks where people use technology to control their connections, to titrate their availability, and to maintain a right emotional distance such that they can avoid appearing vulnerable. Through the provision of features that allows us to compose, edit, and revise, technology allows us to show ourselves as invulnerable or with as little vulnerability as possible (Turkle, 2015).

As we use technology to mediate our communication with others, not only do we slowly lose the ability of making face-to-face conversation but we also lose other auxiliary abilities that come with conversation such as being aware of posture and tone, making eye contact, and comforting and challenging each other. Therefore, we need to know the extent to which we are vulnerable to the substitutes offered by technology. However, vulnerability is not necessarily a weakness. Brown, a researcher professor at the University of Houston Graduate College of Social Work, defines vulnerabilities as emotional risk, exposure, and uncertainty (Brown, 2012). To her, vulnerability can be the birthplace of innovation, creativity and change and embracing vulnerabilities is the key to our happiness, our creativity and our productivity (Brown, 2012).

By designing our technology to take vulnerability into account, we can find a way to reclaim face-to-face conversation, to regain intimate relationships and to become more creative and productive.

Design for vigilant usage

Vigilance is a state of watchfulness endemic to "the compulsion for which maps directly to the perceived consequence of missing on possible observations" (Phillips, 2014). Vigilance is instinctual and it is about self-preservation (Edmunds, 1974). Motivation for being vigilant correlates with the possible occurrences of dire consequences resulting from the lack of attention, e.g., the radar operator during World War 2. Research shows that sustained vigilance is mentally demanding, it associates with a considerable level of workload, and it reduces task engagement and increases stress (Warm, Parasuraman, & Matthews, 2008).

In the context of digital media, vigilance is evoked by three factors: firstly the importance of completing the task – a task that is related to self-preservation is often of high importance, with dire consequences for failure to complete the task – if the task is done out of self-preservation, the failure of completing such task would put users in harm's way; secondly, by exogenous cues; and thirdly, endogenous cues. Exogenous cues refer to some type of alert or notification (audible and visual) that captures the attention of users, while endogenous cues refer to the desire to check for some form of update or response. For example, in the context of Facebook app usage, the fear of missing out (Tandoc, Ferrucci, & Duffy, 2015) is often the endogenous of vigilant behavior, while email notifications or audible alerts and vibration are exogenous cues that catch the attention of users informing them to check for the update. As social networks and smartphones become important tools for social interaction and communication, we have consequently developed a behavior of being watchful over developments within these systems, i.e., we frequently check social networking apps on our phones, and in so doing we make sure that we are not missing any updates from our connections. In his research, Phillips finds that mobile devices are the main factor in increasing the prevalence of vigilant use and vigilance is extremely prevalent amongst everyday smartphone users (Phillips, 2014).

To support this new form of vigilant behavior emerging from our evolving technological landscape, Phillips (Phillips, 2014) suggested that a smartphone interface should be designed in such a way that it is less engaging to users. Designers should consider the following a set of specific design (Phillips, 2014). 1) *Vigilance first*: the interface should be optimized for vigilant use. It should present sufficient information to complete the task, action should be enabled via efficient and intuitive paths, and all unnecessary distractors should be eliminated. 2) *Disengagement*: instead of encouraging users to stay connected for as long as possible, the interface should be designed to shorten usage sessions; when the task is completed the session should be terminated. 3) *Habituation*: user interaction should be standardized and not novel, users should be able to form habitual usage patterns that require less cognitive focus.

Therefore, instead of an app that keeps us sucked in, we want to design a tool that allows us to focus on a specific task and then releases us after the completion of such task.

Design for time well spent

Designers often focus on the attributes of an engaging user experience because user attention is valuable to companies (Phillips, 2014). The reason for keeping users engaged and immersed is often due to the monetization, i.e., the longer users spend with the product, the more opportunities for displaying advertisement. In fact, the length of user sessions and the average number of user interactions are often the metrics based on what companies can determine the amount of money they can charge for ad impressions (Phillips, 2014).

In his manifesto called "Time well spent", Tristan Harris – product manager at Google, an advocate for a mindfulness approach to technology – argues for better designed apps, ones that do not seize our attention but help us to live our lives and to spend our time well with all the benefits from technology. Accordingly, the success of such design should not be measured by how long the consumers stay on the app but by the time well spent metric (Harris, 2015).

To do so, the app should be designed in a way that users can get the most out of what the app offer and they can stop using it whenever they no longer benefit. The design should empower users to set the boundaries between work and life, to adjust their use according to their preferences, and to set aside time to focus. Most importantly, the design should help user to attend to one thing at a time minimizing task switching, interruption and unnecessary choices. Choices also should be organized by what is most empowers and matters to users in the long term (Harris, 2015).

Chapter 3: Research Approach

In the previous chapter, three main key insights constituting the theoretical foundation for this research were discussed. They are:

- Design for vulnerabilities
- Design for vigilant usage
- Design for time well spent

These design principles will guide my prototyping process, which plays an important role in validating my hypothesis and answering the research question. To be more precise, as the goal of this research is to design a technological product that promotes face-to-face interaction, this research heavily focuses on the construction of a working prototype that employs current prominent technologies such as the Internet of Things, beacon, and web technology. To do so, this research adopts the *design through reflective practices approach* as the main research approach.

Design through practice is "design research in which construction – be it product, system, space, or media – takes center place and becomes the key means in constructing knowledge" (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2012, p.5). In this approach, a design concept will be built based on a theoretical foundation derived from literature review and from design ideas curated from different sources of inspiration regarding the look and feel, color, and materials, e.g., relevant articles and books, similar products, trends, and personal experiences. To test the design concept, a prototype must be built. Prototyping is the only way to "understand touch, materials, shapes, and the style and feel of the interaction" (Koskinen et al., 2012, p.134). Not only does prototyping act as physical hypothesis that can be evaluated, but it is also a means of inquiring into the context of use. Through the evaluation of the prototype, new ideas and knowledge will arise.

In this study, there will be only one prototype, however, the development and evaluation process of the prototype consists of several iteration. In every phase of iteration it will be improved and evaluated. To evaluate the prototype I employ two user centred design (UCD) methods for design feedback and design evaluation, i.e., task analysis (through observation and informal interviews with novice users) and usability testing using System Usability Scale (SUS) (Sauro, 2011). During this evaluation phase, new knowledge and design improvements will arise, which will be applied to the next iteration of the prototype. There will be three iteration phases. They will be done accordingly to the following order:

1. Development of initial prototype based on theoretical foundation / prototype improvements based on feedback and reflection obtained from steps 2, 4 (below).
2. User testing with observation
3. Usability evaluation with SUS questionnaire
4. Informal interview

This approach will produce both quantitative and qualitative data (e.g. observation data on efficiency and effectiveness, user satisfaction coming from informal interview, and the quality and length of face-to-face conversation facilitated by the use of the prototype). However, my focus is on qualitative data. To analyze the qualitative data, I grouped the data into thematic categories, i.e., usability, effectiveness in promoting face-to-face conversation, and analysed them based on the theme of their category.

Chapter 4: Ideation Process

This chapter depicts the process of coming up with ideas of how and why an interactive tabletop would encourage face-to-face conversation. Informed by all the design criteria defined in literature review, the study began with researching for technology and products that conform to these criteria, in which I looked into a wide variety of tools and practices used in team building and cooperative learning activities as they have been proved to help prevent anti-social behavior, while developing and improving social skill (Li & Lam, 2013). Understanding the importance of these activities, companies and educational institutions have been providing their employees/students with leisure programs, services, and specialized leisure areas, where they have access to recreational/educational tools, e.g., bookshelves, fitness equipment, game consoles, table tennis, billiards/pong table (McLean, Dayer-Berenson, Seaward, Hurd, & McLean, 2014). Amongst various tools and media that are used to facilitate activities used in cooperative learning and team building, tabletop stands out as a technology that can be used for promoting social interaction and face-to-face conversation.

Tabletop as face-to-face conversation catalyst

The history of tabletop provides a fairly accurate account of how it has been used as a focal platform upon which people converge and converse. From the advent of mechanical machines such as foosball (invented in 1922), and billiards (15^{th} century), to the proliferation of electronic enabled tabletop games like Pac Man (1980), and Ms. Pac Man (1982), tabletop has become a place where people usually gather in social contexts, either for participating in the game or watching others play while engaging in informal conversation. In my previous workplace, my colleagues and I often gathered around a billiards table stationed in a dedicated recreational area after work to play a game or two against each other. During these instances, we would talk and discuss various topics including work-related problems that cannot be resolved during the work hours, news, and sometime social issues. This kind of social activity surrounding the tabletop benefits me tremendously as it usually affords new knowledge in terms of solving problems encountered during work and life, support for emotional health, i.e. boosting my mood, and means for growing both in personal skills and professional skills. Evidently, not only are these machines there for entertaining purposes, but they also serve as places that bring people together in social occasions (refer to figure 1).

Figure 1 Typical foosball game (Photo courtesy of SiteGround)

Recently, researches have shown that by leveraging the existing social interaction practices of traditional tabletop, digital interactive tabletop can be designed to foster collaboration (Battocchi et al., 2009), improves social interaction skills (Al Mahmud et al., 2007), and "encourages coordination, serendipity, simultaneous and parallel interaction among multiple people" (Shen, 2007, p.1). As a result, the use of digital interactive tabletop is steadily gaining more popularity in the research community in both social science and educational fields (Al Mahmud et al., 2007; Battocchi et al., 2009; Morris, Lombardo, & Wigdor, 2010; Piper & Hollan, 2009; Rogers et al., 2009; Schneider et al., 2012; Shen, 2007; Soller, 2001; Tang et al., 2006).

DIY interactive tabletop

The idea for building a Do-It-Yourself digital interactive tabletop stemmed from three key insights that I discovered during my research. Firstly, it is costly to own a digital interactive tabletop. As of today, the average price of an interactive multi-touch tabletop is between 2,000 USD to over 10,000 USD (Google, 2016), hindering adoption as it is not widely affordable. The price of any tabletop display is heavily dependent on the quality of hardware (C Müller-Tomfelde, 2010). Low budget tabletops usually utilize less accurate sensitivity of touch screen, limited number of touch points, and slower processing power.

Secondly, Hinrichs et al. (Uta Hinrichs & Carpendale, 2011) found that when using large interactive table people will most likely browse the content by themselves without much interaction with other people. The size of tabletop screen plays a crucial role as it influences the establishment of tabletop territories and personal space, e.g., a small size table compels people to sit closely together, however, it also compromises the ability of a group of people to share table space, but an overly large table may prevent people from accessing the shared items (Scott & Carpendale, 2010). At the moment, the average size of tabletop display is around 42 inches measured diagonally (C Müller-Tomfelde, 2010), which in my opinion is leaning toward the overly large end. Nevertheless, the size of interactive display is also proportional with the price, i.e., the bigger the screen goes, the more expensive tabletop becomes.

Finally, direct touch display has always been utilized as the main input mechanism for interactive tabletop (Scott & Carpendale, 2010; Tang et al., 2006; Zhang et al., 2012). The main argument for such adoption is often because of the notion that directly touching the graphics on the screen feels more natural, intuitive and compelling to the users than using other means to interact with the tabletop (e.g. mouse, or third party peripherals) as all screen affords touching (Norman, 1999). However, direct touch technology is often expensive. Depending on the technology, e.g., capacity touch screen, infrared, surface acoustic wave, optical, the price of interactive table can go from a few thousand to ten thousands. Newer touch technology supports more touch points and better accuracy in manipulating artifacts displayed on the screen.

To tackle the price and other technological and user experience obstacles mentioned above, my plan is to make a low cost but effective interactive tabletop to achieve the goal of encouraging face-to-face conversation. To do so, I build my own interactive table using various off-the-shelf, low cost electronic components such as Raspberry Pi 2, LED (Light-Emitting Diode) matrix, Bluetooth dongle and other electronic parts (refer to chapter 5 for a complete list of components). Adopting a retro style, the tabletop is incorporated with a 64-by-64 pixels resolution used for displaying digital drawings.

Furthermore, inspired by the concept of graffiti – a person or a group of people must be in a physical place to create graffiti, and to see what they have written at a later time, compelling them to come back and gather at a same physical spot, I adopt the physical web approach from Google (Jensen, 2015). The approach utilizes EddyStone beacon technology to enable users to interact with the table when in close proximity without having to install an application on their phone making the table as accessible and convenient to use as possible.

On the other hand, with the smartphone deeply integrated into our lifestyle, I would like to leverage people's familiarity with the technology in order for them to use their phones as the input device interacting with the table. The current smartphone also affords multi-touch and other technology like accelerometer and magnetic compass that can be used to enhance the user experience. A mockup of the table, namely Pixls, can be found in figure 2.

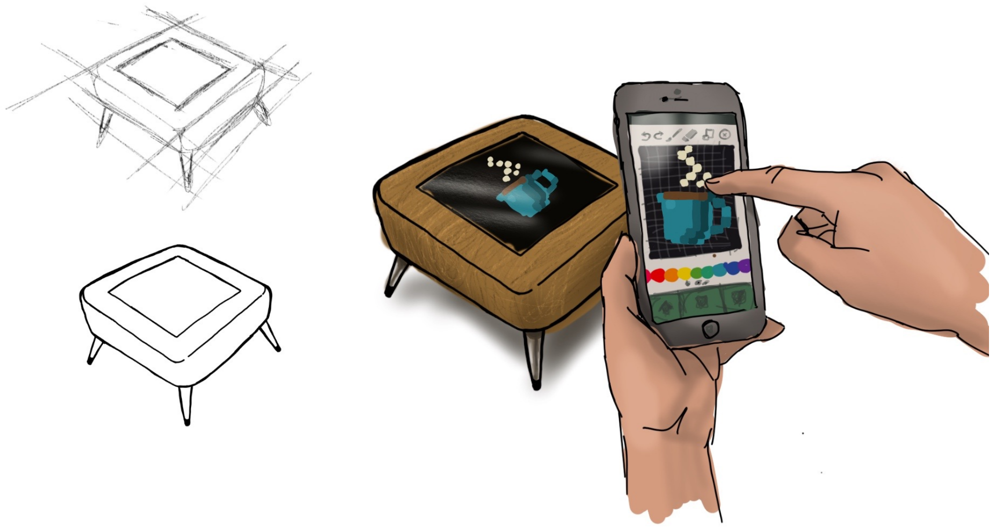


Figure 2 Mockup of Pixls

Chapter 5: Construction of Prototype

The development started with a mockup of Pixls (refer to figure 2) envisioning the look, material, shape, and size of the table. After several experiments, a set of hardware configuration, software, and physical housing has been identified.

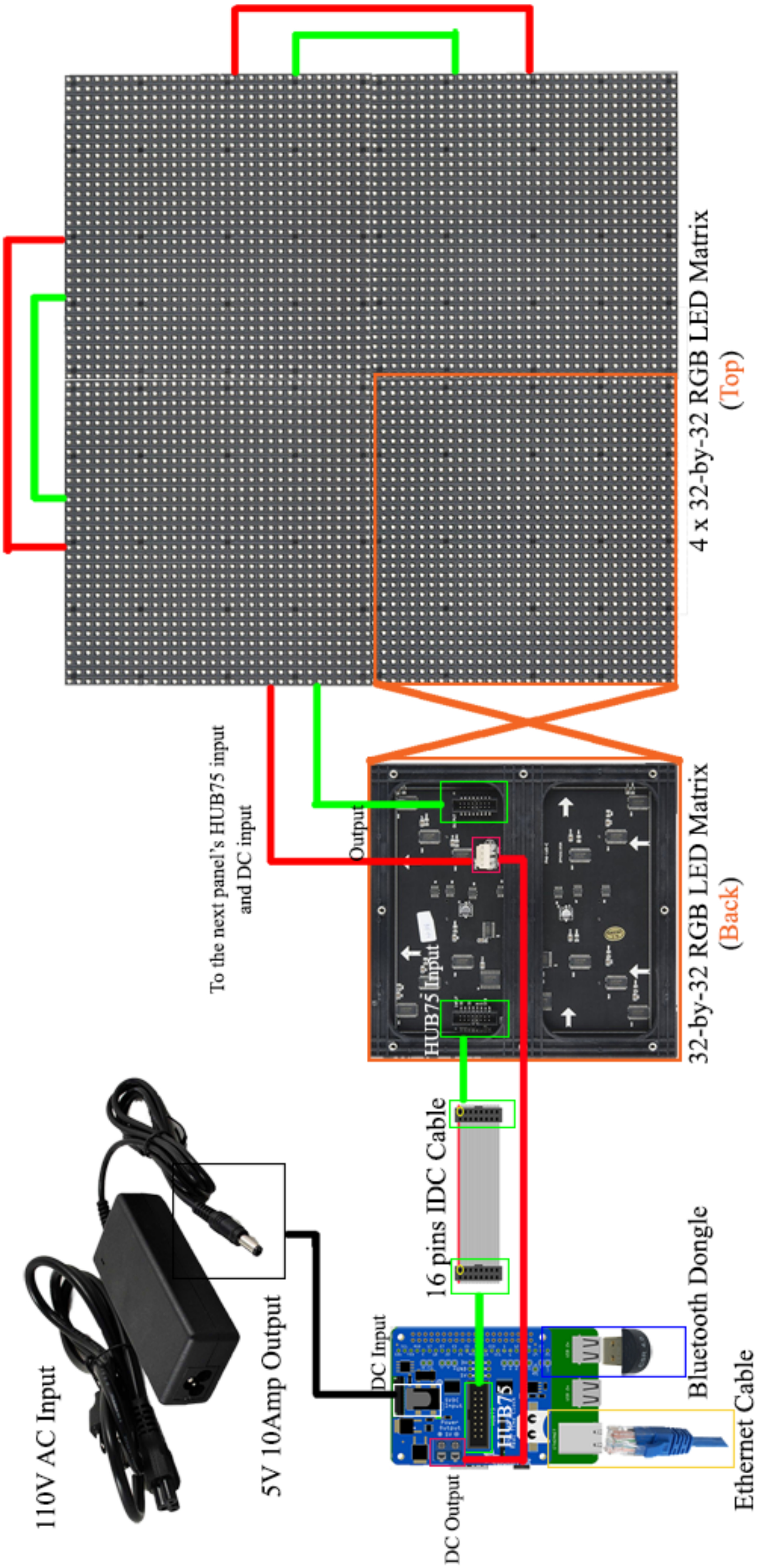
Construction of the prototype

Hardware

The prototype hardware comprises of:

- *A Raspberry Pi 2* acts as the brain of the tabletop processing all the input and output. The reason why I chose this miniaturized computer is because it possesses a significant computational power despite being the size of a credit card, and a good level of extendibility that allows it to interface hardware like LEDs, sensors, and Bluetooth dongle via its GPIO and USB ports (Raspberry Pi Foundation, 2015).
- *Four RGB LED panels* are arranged in the square formation creating a 64-by-64 RGB LED matrix display.
- *An Adafruit RGB matrix hat* is the controller driving the RGB LED matrix.
- *A Bluetooth dongle* broadcasts the URL using EddyStone protocol that directs users to the web application hosted on the Raspberry Pi, through which they can interact with the table.
- *A 5V 10A power supply with 2.5mm jack* supplies the power to the LED panels and Raspberry Pi.

Ideally, the prototype will be connected to the Internet using an Ethernet cable and people will connect to the table via wifi using their smartphone's browser (refer to figure 3 for the wiring diagram).



110V AC Input
5V 10Amp Output
DC Input
DC Output
HUB75
16 pins IDC Cable
Bluetooth Dongle
Ethernet Cable
HUB75 Input
Output
To the next panel's HUB75 input
and DC input
32-by-32 RGB LED Matrix
(Back)
4 x 32-by-32 RGB LED Matrix
(Top)

Figure 3 System's diagram

Software

Like any computer, the Raspberry Pi needs an operating system to manage its resources. In this case Raspbian Jessie, a free operating system optimized for Raspberry Pi (Thompson, 2015), is installed and upon which a software application is developed, deployed, and ran on startup. The software application consists of a backend built on top of NodeJS (Joyent, 2016) – an open-source, cross-platform JavaScript runtime environment, and frontend built with ReactJS – a JavaScript library for building user interface (Facebook, 2016). This combination provides two main features: hosting a web application, whose interface enables the interaction between users and the web application; and translating users' action to signal that turn on and off individual LED on the LED matrix screen. Users will use their smartphone's browser to establish a web socket connection with the tabletop system via the Internet and then interact with the tabletop system through its web application's user interface (refer to figure 4 for the holistic view of the whole system).

Similarly to the hardware, the software is also one of the technical enablers allowing features that users can use to interact with the tabletop display, either doodling or partaking in small games related to drawings (refer to user interface section for further details). This combination of hardware and software provides a seamless and non-interrupted experience for the end-users. Such combination has been proved through several case studies amongst the

DIY and Internet of Things communities (Adafruit, 2015; John, 2015) to be very robust – continuing to function normally even if there are an internal or external issues, and resilient – being able to adapt to user's error and other unforeseen errors happening within the system.

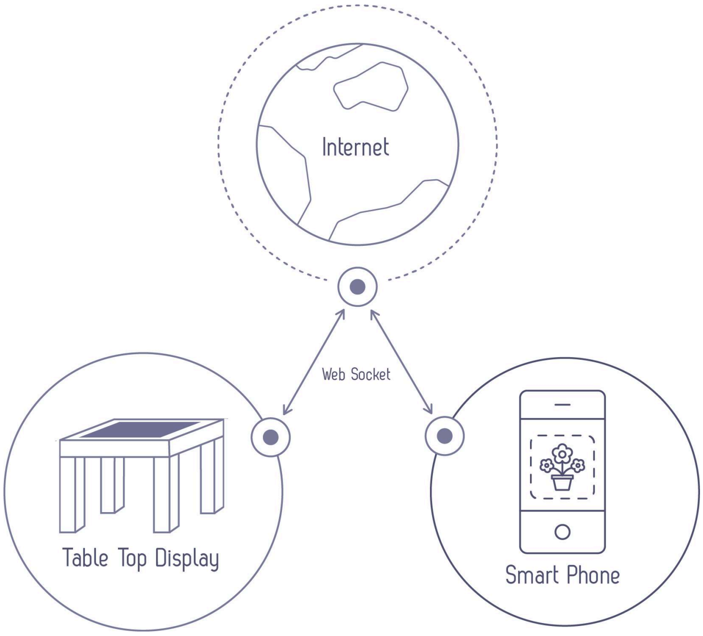


Figure 4 System network diagram

User Interface

The user interface has been constructed with criteria defined in (Phillips, 2012). It consists of 4 interactive components: the sketchpad, color selection, control buttons: clear and rotate canvas, and Pictionary words generator. Each component has its own distinctive role. Sketchpad provides a canvas area, where users can draw different shapes and lines using their smartphone's touchscreen. While it takes a very simple shape, i.e., an empty area with white border, sketchpad is considered as the most important component of Pixls's user interface as it translates users' interactions into displayed shapes and color on the tabletop LED display. Having said that, other components such as color selection and control buttons also provides necessary features, those that make the user experience unique and playful.

The interface went through two major iterations; each of them contains improvements based on feedback from the user testing sessions. The first iteration involves fixing the issues related to orientation and input. Solutions to these issues can be found in *Challenges and Solution section.* Whereas the first iteration was to provide solutions to existing issues, the second iteration involves implementing a new feature: the Pictionary. As seen in figure 5, the user interface contains a section where a random word is provided. This word acts as stimulus prompting users to partake in the game of Pictionary – a very popular word guessing game played within a group of participants whose goal is to identify words from drawings done by another participant. This simple addition to the interface was suggested by one of the users during the testing session, in which he proposed to utilize the drawings feature of Pixls for games that involve drawings such as Pictionary and Exquisite corpse.

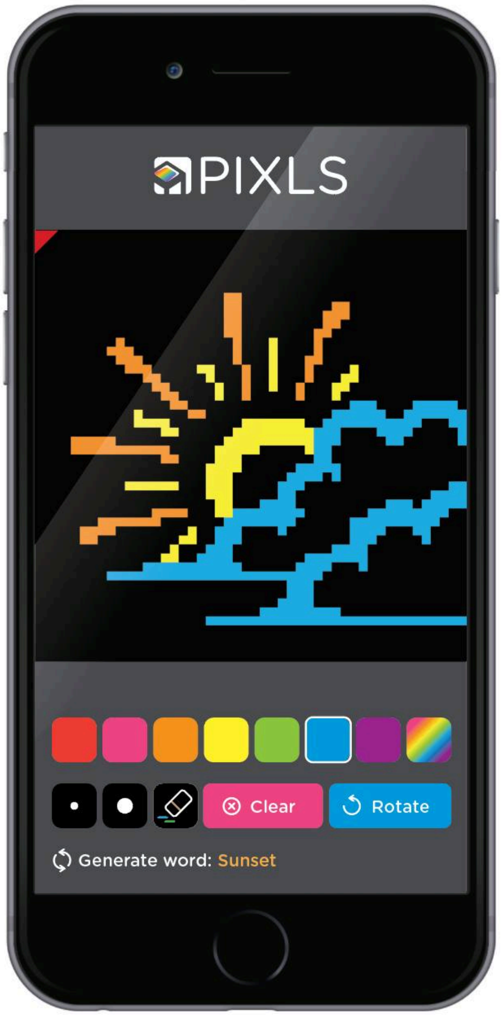


Figure 5 User interface

Wooden table

The interactive tabletop consists of two parts: the table and the electronics. The table is made of solid wood with the width of 21-5/8 inches and the length of 21-5/8 inches, and 19-5/8 inches in height. Ideally, to keep the cost of the whole table minimal, the table should be an off-the-shelf product that can be easily modified to accommodate the electronics. After researching for different type of table, I chose IKEA's Nornäs coffee table (see figure 6 for the visualization of the table with the display on top). The surface of this table will be modified to house several electronic and non-electronic parts: a Raspberry Pi, 4 LED matrix panels, power supply adapter and a black matte acrylic sheet with thickness of 15mm. The purpose of the black acrylic is to diffuse the light coming from the LED matrix panels such that their perceived luminance will be less than 10,000 cd/m^2 below the unsafe level (NCCEH, 2013). Refer to Appendix B for the physical construction of Pixls.

The traditional coffee table has been known to afford a common space for meetings and social gathering. It is a functional piece that is often involved in social interactions, be it between family members who live under the same roof or between people who reside within public or private gathering places, e.g., parks, town squares, coffee shops and theaters. In my opinion, the table with its social affordance by nature, is a perfect complement to the aesthetics of digital drawings and digital interaction, and when combined together will likely encourage the social interaction between users.


Figure 6 Picture of the final prototype

Challenges and Solutions

During the construction of the prototype, two challenges were identified. They are:

Display orientation versus input orientation: preliminary user testing result indicated that there is discrepancy between users and the input. Without the knowledge of their input orientation, users, in the beginning of the interaction, found it confusing when their drawings on the user interface of mobile phone web app do not match with the image displayed on the table. Notice that this is a common issue encountered in the development of tabletop display. Users of tabletop systems often do not share common perspective on the object displayed on the table. Depending on their locations around the table, users will have a different view on the displayed information, e.g., what is displayed at top-left corner of the table for one user is top-right for another; similarly what is presented right-side-up for a user can be upside-down for others (refer to figure 7). This design challenge has a profound implication on comprehension, collaboration and coordination between users (Kruger, Carpendale, Scott, & Greenberg, 2003). Similar issue has been identified in several research papers (Hancock, Vernier, Wigdor, Carpendale, & Shen, 2006; Schlatter, Migge, & Kunz, 2012; Wigdor & Balakrishnan, 2005), whose solution is to adopt the rotating mechanism, i.e., displayed object will be rotated to the direction of the target user.

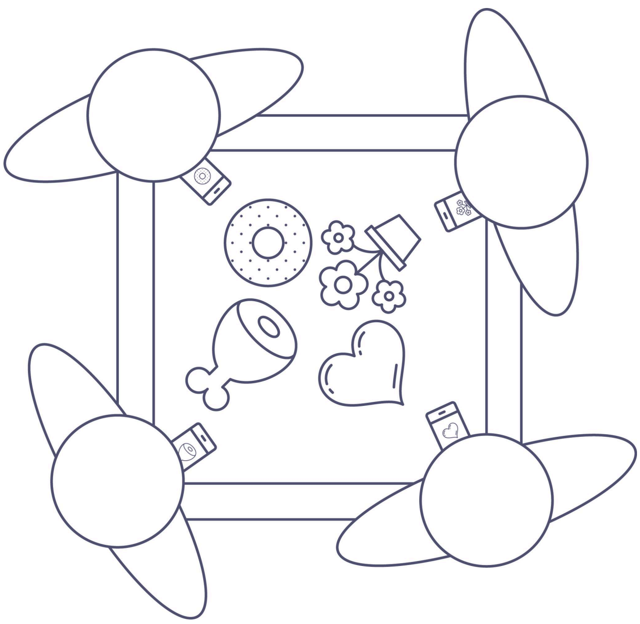


Figure 7 Users' location around the table

However, since Pixls utilizes the touchscreen of mobile phones as input device and it does not employ a direct touch input as other tabletop displays, the solution has been altered slightly: instead of rotating the object on the table, the user will rotate the web application's user interface on the smartphone, such that its orientation matches the tabletop display's orientation from their current view using a physical marker positioned at a corner of the table and a virtual marker on user interface as reference points (refer to figure 8).

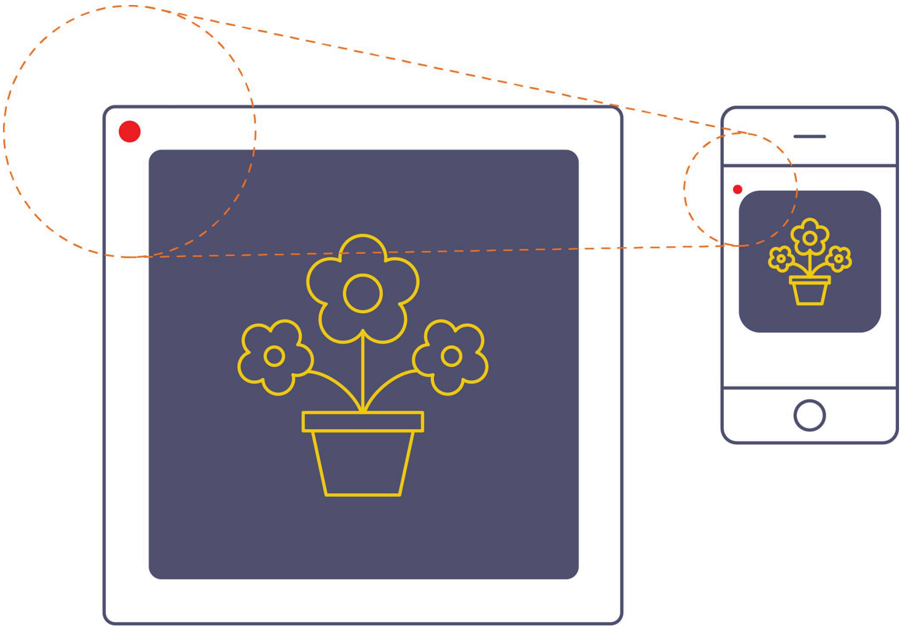


Figure 8 Reference points for the orientation

Input and feedback: preliminary user testing showed two main factors influencing the user input: the size of the smartphone's screen and the type of web browser on the phone (Chrome, Safari, Firefox, and Internet Explorer) used to access the web application.

As the user interface is responsive, its size and look is adapted to various screen resolution. Thus, the size of input area is proportional to the resolution of screen, i.e., smaller screen size means smaller input area. This also means that the resolution of the mobile's touch screen has a great influence on the accuracy of the input. To overcome this challenge, a design compromise has been made, in which the accuracy of input has been traded off for a better, easier and potentially more unique interaction.

Moreover, throughout the development of the app, making its appearance identical across aforementioned major web browsers is a huge technical challenge. Thus, for this prototype, even though I adopt a certain web standard and software library, i.e., Material UI (Call-Em-All, 2016) to make sure that the look and feel of the web application's interface across different browsers is as consistent as possible, I chose to focus and optimize my design for Chrome browser. The reason for this selection is because at the moment Chrome is the most popular web browser for smartphone (StatCounter, 2015).

In terms of the input feedback, to indicate that the user's input has been registered by the system, I adopt visual feedback, i.e., the input cells on the user interface and the LED mapped to such input cells on the tabletop will light up as soon as users touch screen of the smartphone. Due to the technical constraints, no audio and tactile feedback was used for this prototype.

Chapter 6: User Testing

This chapter describes the adopted user testing methods along with their results and analysis. Three methods have been adopted for evaluating the usability and user experience of Pixls: System Usability Scale, Observation, and Informal Interview. The user testing session takes place at OCAD premises in a controlled environment. Prior to the user testing session, participants in the user testing session are divided into groups of at least 2 to 4 people. They are then handed a consent form and informed that: during the session, should any discomfort arises, they can request to stop the session at anytime; that during the session they will be observed and after the session has ended, they will be asked to fill out a multiple-choice usability questionnaire, i.e., System Usability Scale (Sauro, 2011) and to participate in an informal interview.

Methodology

System Usability Scale: Released by John Brooke in 1986 (Brooke, 1996), the System Usability Scale has become an industry standard for measuring perceptions of usability with references in over 1300 publications (U.S. Department of Health & Human Services, 2016). Consisting of 10 multiple-choice statements with 5 response options from strongly agree to strongly disagree (refer to Appendix A), SUS allows researchers to quickly and reliably assess the ease of use of various systems, e.g., website, application, hardware and devices, with relatively small sample sizes.

With given score from one to five for each question, the SUS score of the system can be calculated by summing up the score contributions from each statement. For question 1, 3, 5, 7, and 9, the score contribution is the scale position minus 1. For question 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. The sum of all those scores is then multiplied with 2.5 in order to obtain the overall value of system usability. Only the overall value of system usability matters other scores from individual statements are not meaningful on their own.

SUS score ranges from 0 to 100. Bangor (Bangor, Kortum, & Miller, 2009) presented a SUS rating chart (see figure 8) from which a researcher can get a general idea of how usable their system is based on its SUS score. A score over 85 indicates that the system in question has excellent usability, a score between 73 to 85 means good usability, 50 to 73 indicates that the system's usability is OK even though it requires some improvement, and scores under 50 means that the usability of such system is not acceptable and improvement is needed.

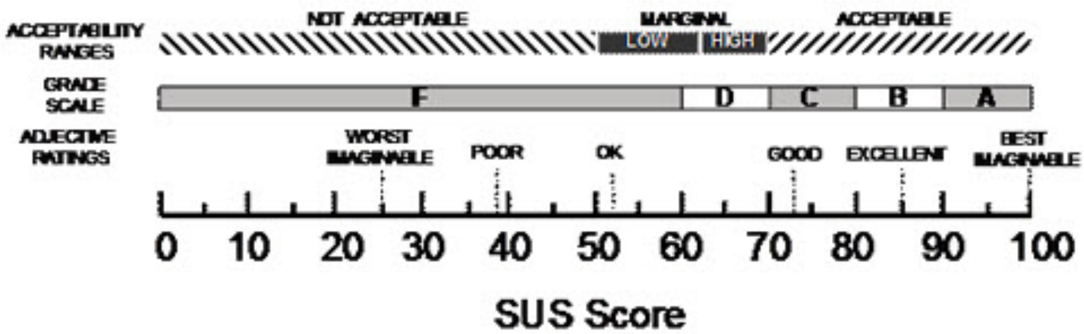


Figure 9 Bangor's acceptability ranges for SUS score

Observation and Informal Interview: During the user testing session, users will be observed for any exhibited reactions, e.g., facial expression, hand gestures, verbal interaction, and eye contact. Their direct interaction with one another will be measured quantitatively, e.g., how many times they initiate conversation, express emotion, and how many times / how long they make eye contact, and qualitatively, e.g., quality of conversation in terms of topic, tone of conversation, engagement, commitment and attention. Right after the user testing session, informal interview will be carried out. This method allows me to engage participants in an informal manner inquiring users about their experience and reaction during the session, as well as opinion and feedback for improvement. The questions used in the interview will be informed by the data derived from observation, e.g., why did you do what you did? Or tell me about the experience.

The metrics used for measuring the success of Pixls in encouraging face-to-face conversation are:

- SUS score of Pixls – the higher the better
- The number and duration of conversations initiated during the testing session. Notice that all kind of conversations count and they do not have to about or relate to Pixls – the higher the better
- The number of interactions between users divided into 2 categories:

    - Negative interactions: for example, one of testers uses his phone to do something else (checking email, texting, Facebooking) and/or does not pay attention to other users.
    - Positive interactions: making eye contact, making physical contact, and changing the tone of conversation.
- The quality of those conversations based on the feedback of users and based on observational data.

Results

The data from my first user testing session, which involved 3 participants, shows an acceptable result with an average SUS score of 79 indicating a good usability (refer to figure 9). The general feedback is in favor of the simple interaction and aesthetic of the digital drawings displayed on the tabletop screen. However, several issues were raised during the testing. Firstly, the orientation of the screen initially confused two testers who were sitting in an opposite direction to the orientation of the screen (refer to challenges and issues section). But it only took them less than two minutes to figure out how to cope with the issue, thus showing that the system affords good learnability. Secondly, even though face-to-face conversation between participants was initiated naturally without having any prompt, it was mostly about their interaction with the table and drawn images. When we talked about it during the informal interview, their feedback was mainly about the lack of features of the Pixls, specifically one that stimulates a broader topic. They suggested a gamification approach in adopting traditional games, such as Pictionary and the Exquisite Corpse. An implementation of a feature that suggests a random word (detailed in user interface section) has been added as an immediate response to the feedback and this feature was used in my next user testing session.

The second user testing session was conducted with 2 participants. The average SUS score was 81, a small increase comparing to the previous score, indicating that the tabletop has steady level of usability and learnability. One finding that I found interesting is that people incorporated other objects such as phone and coffee cup as part of the digital drawing creation, e.g., flowers around their cup of coffee. However, such interaction was not recommended during user testing due to potential electric shock hazards because the tabletop display was not waterproof. The Pictionary feature played out nicely creating a playful interaction between individuals. During this session, the tabletop generally received highly favorable feedback; even though the issue with drawing orientation still persists, it apparently did not prevent users from playful experience.

Feedback from the third user testing sessions revealed that Pixls has the potential for doing many other things dependent on how it is framed. However, not until I had the discussion with members of my thesis committee did it become apparent that the technology stack used in Pixls could be transformed into a platform. As a platform, Pixls provides a set of ready-made technologies and algorithms that allows makers to rapidly build their own interactive tabletop or develop a new interactive medium. For instance, during my defense, one of the committee members suggested that Pixls could be developed as interactive billboard letting audience in ice-hockey stadium to create drawings and send messages to other audience. On another hand Pixls could be an interactive advertising billboard where consumers can interact with the products, thus giving them a reason to engage and to learn about the product. Several interactive billboards have shown its ability to capture passers-by attention. For example, Pictionary mall surprise from Mattel Games, in which a regular advertising poster was transformed into an interactive billboard that serves a simple Pictionary game (Games Mattel, 2014). Other exemplary cases can be found from companies like KLM with the Perfect High-Five (KLM, 2014), Axis agency with MegaFaces (Axis agency, 2014), and British Airways with the Magic of Flying (OgilvyOne, 2014).

Chapter 7: Conclusion

This thesis delineated a creation process of how an application that uses the Internet of Things as its core technology can be designed to promote face-to-face interaction in an informal setting like a coffee shop. As discussed in my literature review section, problems endemic to the emergence of new communication technology, such as fear of boredom, of intimacy, and of social interaction can be mitigated by a technology whose design is informed by human vulnerabilities, done in accordance with design principles that support vigilant usage, and made for the purpose of helping users to live their life and spend their time well.

In addition to the above theoretical findings, the development outcome of this thesis is an interactive tabletop, namely Pixls, which was built entirely of low cost off-the-shelf components and is used in an informal social environment like coffee shop. The total cost of this prototype in terms of raw materials is under 500 Canadian Dollars, which makes it more affordable than any other tabletop interactive system currently available on the market. Being low cost was one of important factors that would make the adoption of Pixls possible for small and indie coffee shops. Furthermore, taking the form of a coffee table allowed Pixls to afford a common space for people to gather around, which is a fundamental prerequisite for the establishment of a face-to-face interaction.

In terms of usability, with the average SUS score of 80, the interactive tabletop was deemed to have a good usability and learnability thanks to its simplicity in both user-interface and user interaction. However, the data from user testing sessions also implied that having a usable user interface and an easy-to-use feature, i.e., free drawings, was not sufficient to promote a good face-to-face conversation, which requires more breadth and depth of topics discussed within the conversation. Throughout the discussion with test users, it was evident that in order for Pixls to be able to effectively encourage good conversations it needs features that act as conversation prompts.

Data from the informal interviews also suggests that playful interactive experiences have the possibility of making people more engaged in social interaction. For example, Pictionary-like feature has a positive impact on the quality of conversation, e.g., broader topics. However, there isn't any conclusive evidence that Pixls effectively encouraged a face-to-face conversation amongst users. Some test users disagree with the use of smartphone as the means to have a face-to-face interaction. In fact, feedback from users also strongly suggests that Pixls should not be constrained to the form of an interactive tabletop. The technology stack used in Pixls should be transformed into a platform providing an infrastructure for different applications that afford various types of social interactions, including, but not limited to face-to-face interactions. For examples, Pixls could take the form of an interactive tabletop board game or an interactive billboard where users can interact with each other asynchronously (not at the same time) via the products displayed on the LED panel using their smartphone.

Future works

Pixls as a platform

As noted in my conclusion, the technology stack used in Pixls can be generalized into a software platform providing an infrastructure for makers to develop their own application that manipulates LED panels without having to reinvent the wheel, i.e., writing the algorithm to control LED panels on Raspberry Pi from the scratch. To do so, Pixls should be modularized, i.e., separating functionality of the program into independent modules, such that each module serves a specific aspect of the program, e.g., front end module is responsible for rendering user interface to mobile device, meanwhile, back end module is responsible for providing connection between users and translating user's action to electrical signal that turns the LED on and off.

In addition to code refactoring, further assessment of technical feasibility should be made to determine the capability of Raspberry Pi, i.e. maximum resolution and maximum connection. As noted during the development of Pixls, to achieve a full color with the refresh rate (higher refresh rate means flicker will be less noticeable) higher than 100Hz the number of panels when chained together should be equal or less than 12 panels, thus having the total resolution of 384 by 384 pixels. To overcome this constraint, further exploration to alternative hardware should be made. In the meantime, the software should be designed and developed independently of the hardware.

As soon as the hardware specifications have been defined and the software have been refactored and documented, a guideline showing how this platform can be used as foundation for other application to be built upon will be published on several major websites like GitHub and Instructables.

Pixls as an interactive tabletop

The combination of Raspberry Pi along with pixel matrix panels and Bluetooth peripheral can be re-appropriated to serve different purposes via hardware addition and modification. For example, adding physical buttons, sensors, or camera will respectively allow users to physically interact with the tabletop, enable the table to be aware of the occlusion of physical objects on the tabletop display, and help the tabletop to detect the presence of users. Not only can Pixls' hardware be upgraded, but its software can also be updated. While constructing this prototype, several ideas have been discussed about how Pixls can be incorporated with more tabletop games via software updating, e.g., Exquisite Corpse, Pong, Pac-Man, snake, and Donkey Kong, to provide deeper playful experiences.

In addition to those new features, as found during the user testing sessions, participants wished to incorporate their coffee cups into their drawings on the tabletop display. However, such interaction poses potential risks to Pixls as currently it is not waterproof and heat proof. Were this work to continue, waterproof could be achieved through the use of sealant applied to the areas where the acrylic plastic meets the table, meanwhile, heatproof could be done by adding a layer of transparent thermal insulation layer between the acrylic plastic and the LED matrix panels.

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Appendices

Appendix A: System Usability Scale

Participant ID: _____ Site: ___________________________ Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark <u>one</u> box that best describes your reactions to the ARTable *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2.	I found this system unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☐	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found this system very cumbersome/ awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

Please provide any comments about this system:

Figure 10 SUS form

Appendix B: Construction of the prototype

The following images depict the construction process of Pixls from inception to completion

Figure 11 Coffee table from IKEA

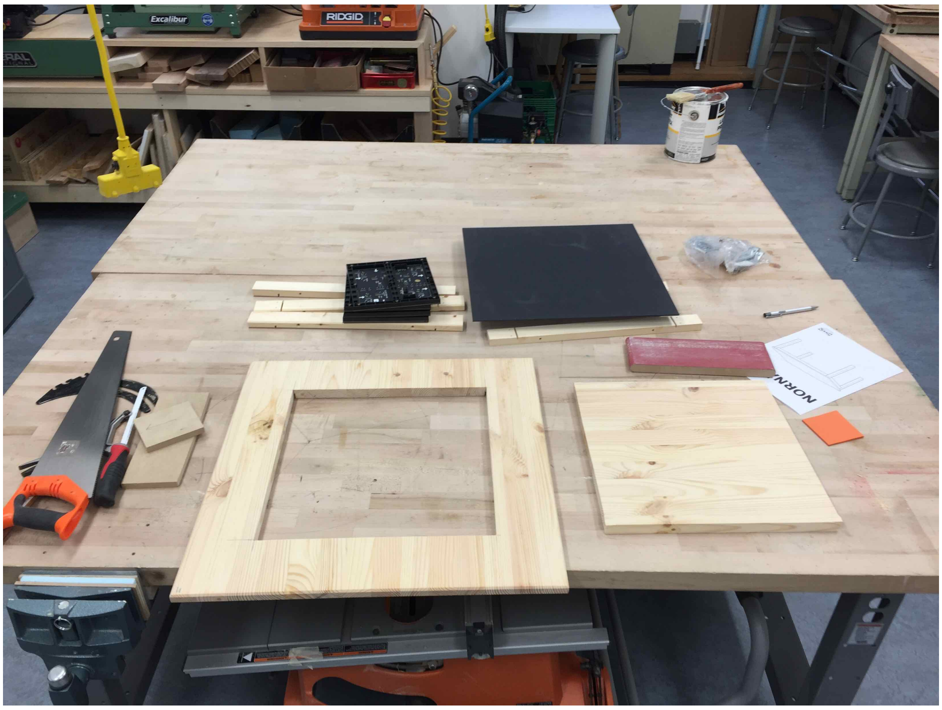

Figure 12 Preparing table for the LED matrix panels

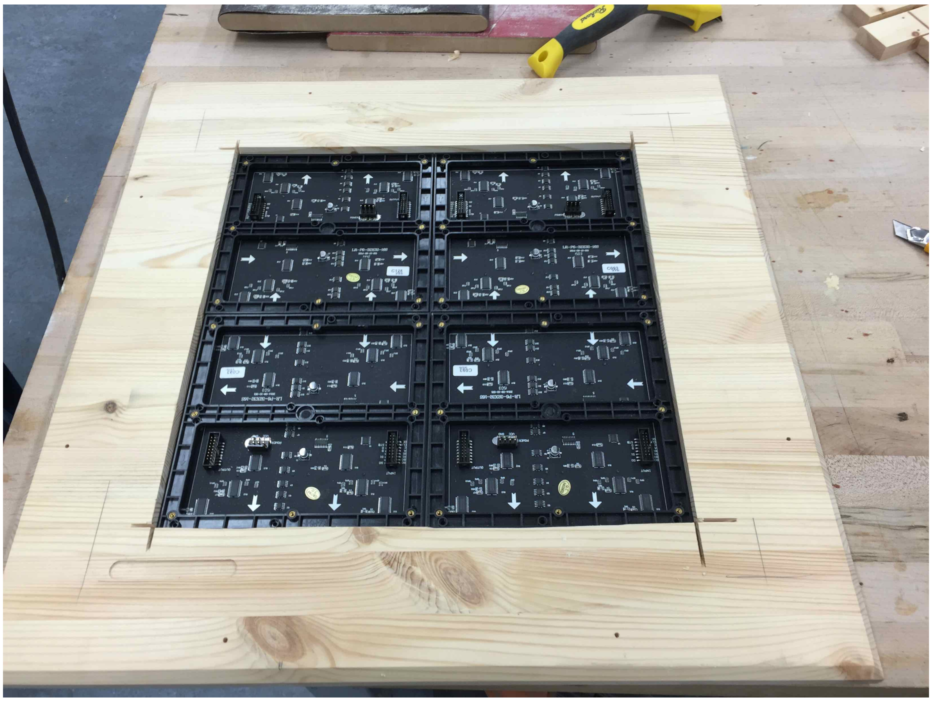

Figure 13 Table with LED matrix panels

Figure 14 Table with flushed with acrylic plastic

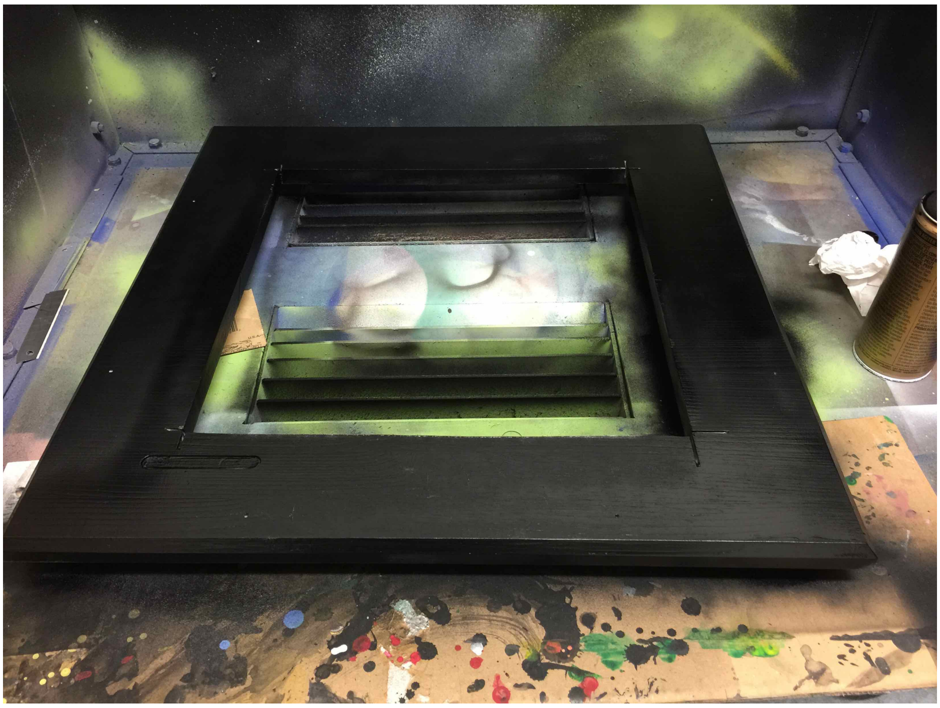

Figure 15 Table painted in black

Figure 16 Table assembly

Figure 17 Final prototype