# Capacitive Touch in Interactive Systems

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**Abstract**

There are numerous types of technologies sensing the presence of a human being. Capacitive sensing is one of them and it is one of the simplest to understand as well. In the following report I describe how I use capacitive sensing and how I integrate it into a real-world object which can improve the life of its possible users.

I use several capacitive sensors in combination with light indication and integrate them into a door handle. The handle controls the lights. A user can perform different grips to choose a desirable light and to indicate his or her presence or absence.

After completing the first prototype I evaluated the opinion of ten users based on their experience with the door handle. The analysis of the results, based on Grounded Theory, helped improve the prototype. Finally, the prototype's workload was tested by interviewing ten more users using NASA TLX.

The final version of the system reached prototype two. Overall, the project is considered a success as users can effectively interact with the handle and find it easy to understand. Nevertheless, based on the results from the evaluation, this report concludes that the ease of use of the handle can be further improved. Many of the requirements, apart from the 'must have', have not been considered and this creates many gaps in the system which could be filled.

# Education Use Consent

I hereby give my permission for this project to be shown to other University of Glasgow students and to be distributed in an electronic form.

Name: Ivan Katzarski Signature: Ivan Katzarski

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# Contents

# Chapter 1 Introduction

## 1.1 Problem and Context

The following dissertation will address two problems. The first one logically leads to the second. The project is focusing on a closed office environment. Having that in mind, when people are using their office, regardless of it being closed or open space, their co-workers often need to know if they are in or out of their office and for how long. This is the general problem which can be decomposed in two simpler ones: the type of indication a person would use to show that she/he is out of the office and how is she/he going to use this indication.

The first problem is choosing the type of indication. Before making this choice, I tried to focus on a certain environment – the office environment. The idea came from the fact that I have spent the last few years of my life in education. Often, as students, we have to contact our supervisors and lecturers for advice or information. E-mailing is of course the easiest and fastest way but meeting a lecturer in person is inevitable sometimes even without arranging a meeting. There are different kinds of indication lecturers would use to show that they are available or not and for what reason. Numerous times, I have seen a certain kind of circular indicators with an arrow pointing to the current location of the lecturer and his/her availability. Unfortunately, the arrow is not always pointing the correct information. I have seen lecturers out of their office, obviously for the day, and at the same time the indicator saying, “Back Soon”:


**Figure 1.1:** The ‘circular indicator’. The photo was taken around 7 pm and the building was almost empty.

Obviously an indicator is only useful if the person in the office is actually using it, or not forgetting to use it. I have decided to come up with a simpler form of indication which could ease the life of the lecturers and their visitors. The indication had to be less informative than the circular indicators because I thought that the amount of information was unnecessary and in fact nobody actually likes reading too much text. After numerous discussions with friends and colleagues it was obvious that the colours red and green are one of the most common forms of showing somebody’s availability. At the same time I thought that using lights could allow somebody to see a person’s availability very fast and even from distance. Thus, I came up with the idea of using traffic light-like (described in detail in the Design section below) indication which is a familiar form of indication for most people.

Since the topic of the actual project covers Capacitive Sensing Technologies, using capacitive sensors was an obvious choice. This leads to the second problem of how a person might use my traffic light indication. I decided that I will create a prototype of a door with the lights on it and with a handle which could control them. Using a door handle is the natural way, for most people, to open and close a door. Connecting the handle to the lights would make it inevitable for people to actually use the lights. Thus, it would be harder for somebody to forget that they have to indicate their presence or absence. Seeing the lights would inevitably remind somebody that there is indication and knowing that it is controlled by the handle would be a further reminder. Therefore, I decided to put capacitive touch sensors on the handle. In this way a lecturer, for example (or in fact anyone who has an individual office), could indicate his/her availability by using different kinds of grips when opening or closing the door of an office.

The combination of using different kinds of grips on a door handle and using capacitive touch sensing to control the traffic light indication solves the problem of showing somebody's availability in a very simple manner. The following dissertation will further support this statement by showing that actual users of the prototype often have this problem and find the prototype to be a very useful solution for it.

## 1.2 Arduino

The hardware that I used for developing my project is Arduino UNO. UNO is a microcontroller board. It is based on the ATmega328P 8-bit microcontroller [1]. An important characteristic of the UNO are its 14 digital pins which could be used for input or output. They are also the ones that I am using in the project:

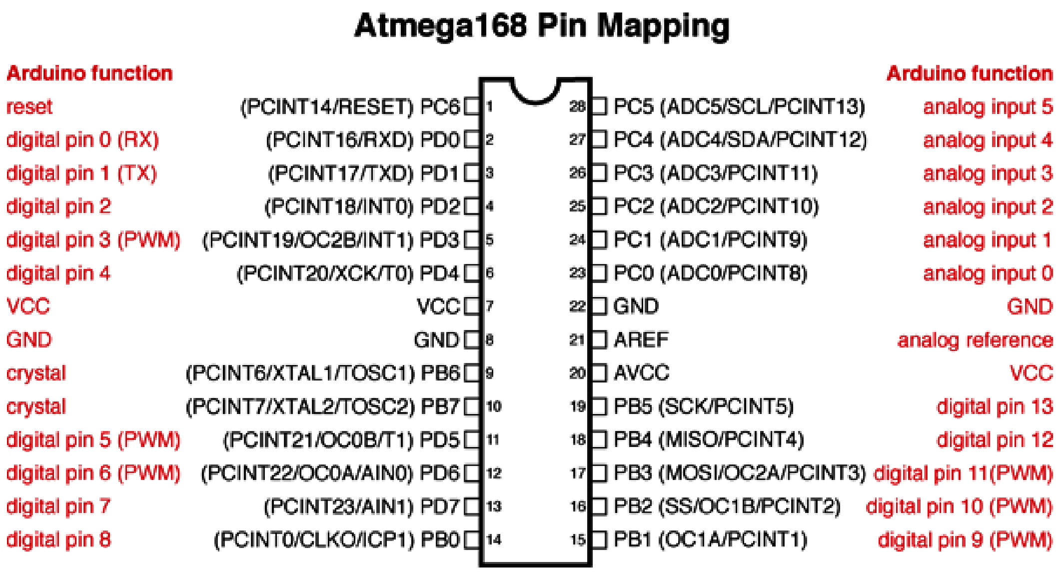


**Figure 1.2 [2]:** ATmega168-Arduino pin mapping.

The UNO can be connected to a computer using a normal USB cable. The cable is used to program it. The official ATmega328P documentation can be seen in [1] and section 32 shows the Instruction Set Summary but the UNO does not have to be programmed using a low level language. It has a bootloader [3] which allows uploading code on it without an external programmer. The bootloader uses 0.5 KB of the 32 KB flash memory which the UNO has.

The UNO can be powered by the USB cable or by an external power supply of 6 to 20 V [3]. I use the cable both for supplying power and uploading code on the UNO using the Arduino IDE. The fact that the digital pins can be used for output allows me to manipulate the traffic light indication.

## 1.3 Capacitive Sensors

Capacitive sensors are a sensing technology that can detect the change in the electrical flow in a circuit. In contrast with pressure sensors, capacitive ones do not produce a signal by using the stress of the pressure, but rather by detecting a change in the electrical flow [4]. Usually capacitive sensors consist of several plates with surface A. The plates are separated by distance d and also depend on the permittivity of the substance ε that defines that distance. Thus, a capacitive sensor is represented by the following formula:

$$C = \varepsilon \left(\frac{A}{d}\right)$$

**Figure 1.3 [4]:** Capacitive value.

A capacitive sensor depends both on the change of the size of the sensor surface and on the change of the distance between the plates of the sensor. The justification for developing capacitive sensors comes from the circumstances of the environment in which they are widely used – the medical environment. Pressure sensors are good at measuring dynamic changes in pressure. When measuring the pressure inside a patient's body though, the sensor has to work for a very long period of time and to measure very low pressure signals. Capacitive sensors are much more sensitive and accurate in such a perspective [4]. Furthermore, they can measure distance without the establishment of an actual physical contact [5]. This characteristic makes them useful in numerous different settings. NASA uses capacitive sensors in robots to help them detect humans and avoid injuries. In the construction industry the sensors are very useful in finding wall stud behind different surfaces. They can also be used in the medical sector to generate images of human organs. The images are based on the natural conductivity and resistance of the human body [5].

A capacitive sensor functions by producing an electric field (ER). When a hand or another part of the human body touches the sensor it disturbs the ER [5]. In the UNO one of the digital pins is set up to produce output, reach the sensor, and another digital pin receives the input. Therefore, there is a current (I) of electricity flowing. More importantly, if the human body is in the proximity of the sensors it can resist the current. According to Ohm's law (Figure 1.4), the resistance equals the flow pressure (V) divided by the current (I). Thus, the higher the resistance, the more time it takes the current to flow since V in the UNO is the Operating Voltage [3] and it is always 5V (it is constant).

$$\frac{V}{I} = R$$

**Figure 1.4 [6]:** Ohm's Law.

If the current is interrupted, the flow is reduced and the UNO can see the change. I use the Arduino Capacitive Sensing Library (will be discussed further in the Implementation) where the relationship between the resistance (R) and the capacitive sensors (C) is C * R [7]. In other words, the higher the resistor used, the higher the capacity of the sensor, which means that the sensor is more sensitive and it will detect touch in a larger area because it has a larger ER (direct touch will not be required). A capacitive sensor can be visually represented in the following way:

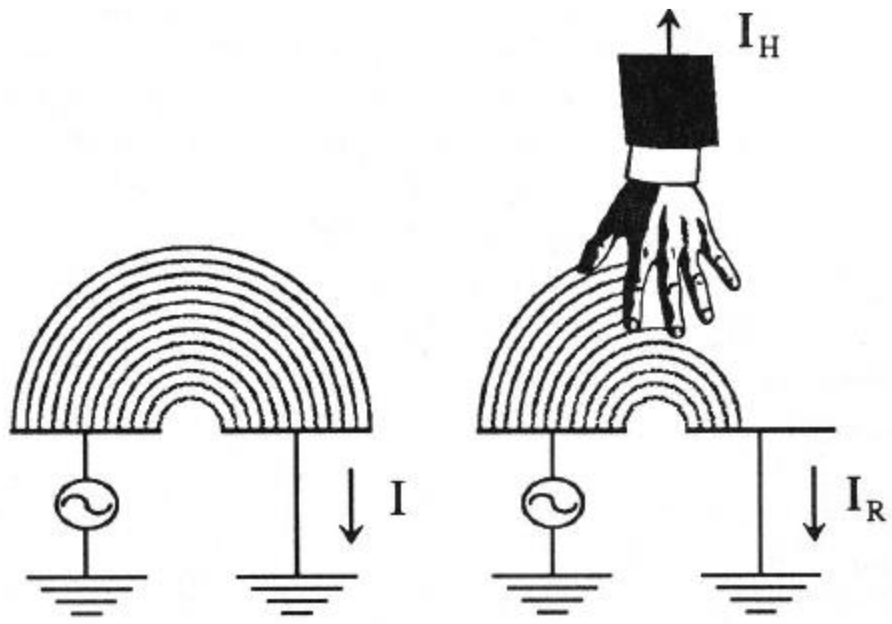


**Figure 1.5** [5]**:** An ER created by a capacitive sensor. The further the hand is in the ER, the more the current (I) is decreased.

## 1.4 Outline

The following sections of the report are: Survey, Requirements, Design, Implementation, Evaluation, and Conclusion sections. In every section I further discuss the different aspects of the project.

In the **Survey** I point out the negative and the positive sides of several different technologies resembling capacitive touch. Each technology involves grasp sensing since the main goal of the project is to improve the usability and the ease of use of the door handle grips.

In the **Requirements** I discuss the way I gathered the requirements and the method that I used to group them. Grounded Theory is the basis of this section.

The **Design** part of the dissertation focuses on the prototypes of the door handle. The first prototype is entirely based on research and my imagination while the second one is improved using the requirements gathered from the users. The traffic light indication was my idea but it is very well accepted by the users of the door.

The **Implementation** has more information on the Arduino Capacitive Sensing Library. It also discusses the final version of my code and explains how it works.

In the **Evaluation** I discuss the second set of interviews that I have conducted using the NASA TLX system. I also discuss the strengths and the weaknesses of my final product.

Finally, in the **Conclusion** I summarize my achievements and the possible future work that can be done on the door handle. There are also several Appendices which include: the requirements that I have gathered; the information on the two sets of interviews; the code that I use; my project log; the ethics checklist.

# Chapter 2 Survey

Currently there are numerous kinds of touch technologies being developed. They try to solve a variety of problems, but in terms of interaction with the user, and his/her final goal after using the technology, they are similar to the door handle (my prototype). In this section I discuss several of them and give my opinion on their strengths and weaknesses. The Conclusion section uses these positive and negative sides as the basis for comparison with the door handle.

## 2.1 The Tango [8]

Paul and Dinesh discuss in their journal the novel design of their product, the Tango, which has for a goal to manipulate and interact with robots [8]. The Tango is a ball which consists of 256 pressure sensors. It has been tested by manipulating 3D objects. Holding the ball in your hand would result in exerting pressure over it, while moving the ball will collect data on the acceleration of the motion.

There are numerous positive aspects of the novel project. Previous projects, for example, require the use of additional materials over or around the user's hand (e.g. gloves and straps) [8]. This could restrict a device only to collecting data based on one feature – either pressure sensing or acceleration sensing. The Tango, on the other hand, can use both. Furthermore, it can also recognise a variety of grips based on the user's finger positioning. Due to the fact that the ball has 256 different pressure sensors embedded inside of it, it can cluster them depending on how they are pressed with the user's fingers. That's how it can understand the shape of a pre-specified number of grips – it has an approximation of how a certain grip's finger positioning is clustered with the pressure sensors [8]. Of course, we could move our fingers when holding an object. As long as we do not change the grip while using the Tango, it could automatically reposition the clusters if a user moves his/her fingers a bit. All of these aspects give the Tango the possibility of great usability and some flexibility.

One of the negative sides of the Paul and Dinesh's invention is the fact that it is really hard to engineer. I believe that this could be considered a drawback if you are not a very experienced engineer or a programmer and you want to test the product or create a similar one. Special equipment would be necessary to put all of the 256 sensors in just one ball that can fit in a person's hand. Of course, the Tango is supposed to be used to control robots and maybe such a technology is not necessarily easy to create or cheap to implement.

Another problem of the Tango might occur when somebody uses a grip that has not been pre-specified in the system. There are several grips that can be used and have been thoroughly tested and anything else would not work with the ball. It might even confuse a slight movement of the fingers with a different grip instead of just repositioning the clusters.

Implementing such a system into a ball might be considered good since a ball as an object itself is quite natural to people. Nevertheless, it is not naturally considered an object comfortable for manipulating other objects. In other words, it could require quite a lot of training before a user can freely and confidently use it for its intended purpose.

The size of the Tango and its weight are also of great importance. They are fixed and this could mean that some people might not find it comfortable enough for use. I am mainly thinking of people with larger hands who could find the ball to be too small. Not only that, but somebody with a larger hand might naturally grasp the whole ball with his/her full hand and thus with the palm as well. The Tango works only with pressure clustered based on the fingers. This is quite a big restriction having in mind the number of sensors used.

Finally, the Tango has to store a lot of data while somebody is touching it. The data is based on the pressure exerted and on the acceleration of the actual ball. The output data of the different grips used is very similar though. That is an example of two different grips:

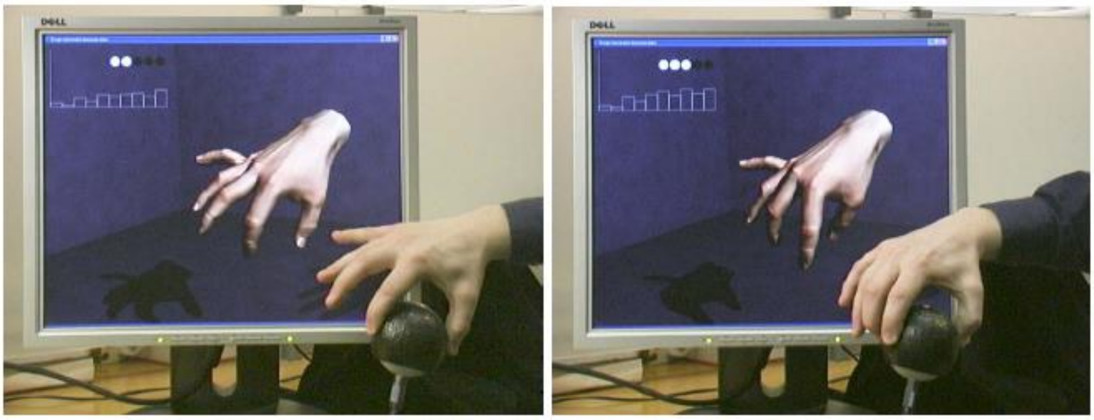

**Figure 2.1 [8]:** Pressure data based on two different Tango grips.

I believe that the data defining the different grips is so similar that the system could be prone to errors. A simple example of an error could be using a grip which the system recognises incorrectly.

## 2.2 Graspables [9]

Compared to the Tango the Graspables System is much more adaptable and simpler in terms of use which could be considered both positive and negative. The system has for a goal to sense a human's touch and depending on the actual grip or point of touch, it performs different actions. The actual functionality is determined by the user. Taylor and Bove discuss two of their prototypes but I am focusing only on the second and more finalised one – the Ball of Soap [9].

Compared to the Tango the Ball of Soap is much more abstract in terms of use. This could be great for a user since it allows much more flexibility. It also requires some thinking of what you want to do, of course, and this could be burdening for some users that want more immediate experience. Nevertheless, Bove and Taylor are more considered about the user's comfortability which could possibly lead to a better product.

The researches also focus on an easier to implement engineering. First of all, the Ball has only 15 sensors. They seem to perform their job correctly in the implementations which are suggested in the journal. It also has the shape of a ball – most people would be used to this shape.

The device has been implemented in a way that makes its functionality very abstract. Thus, if a user wants to make the ball do something specific, she or he has to program it and put it into an appropriate object. One possible implementation of the Ball of Soap is to use it to recognise a baseball player's grip. Creating a 3D image of this grip could help baseball coaches or even game developers to create a more realistic view of how professional players handle the balls.


**Figure 2.2 [9]:** The Ball of Soap on the left. On the right the Ball of Soap is embedded into a real baseball.

The microcontroller of the ball can also be manipulated from distance. The system has a Bluetooth chip which makes it even better in terms of portability and usability. A user can put the ball into a desired object and then start controlling it through Bluetooth which is great for testing purposes.

I consider the abstractness of the Ball of Soap a drawback as well. Although it makes the system extremely flexible and very interesting for creative projects and experimentation, not having a fixed goal and implementation prevents it from being thoroughly tested in a specific setting. This greatly questions its effectivity. Nevertheless, it is much simpler and easier to understand than the Tango.

## 2.3 Multi-Touch Pen [10]

The Multi-Touch Pen or MTPen is a tool which is used to sense a user's grip depending on the position of his/her thumb or index finger. The researches use their own grip recognition algorithm. The algorithm takes as values the contact points on the pen and their size and orientation [10].

Compared to the Tango and the Ball of Soap, the MTPen's developers have done a lot more thorough study on the users before implementing their system. For example, they use studies conducted by Napier University which show how the shape of a pen can improve the performance of a user's writing and his/her comfortability while using the pen. In other words, the researchers have based their prototype on the user's requirements which is definitely a positive feature of the product.

Another positive aspect of the MTPen is the fact that capacitive touch removes the need for any buttons to switch between different kinds of ink. This greatly improves the comfortability of the product plus it gives the freedom to use the whole surface of the pen as a sensor.

The pen's grips are also supposed to work based on different contact points all over the surface. This means that a person with a larger or a smaller hand can still achieve his/her desired functionality by using a certain grip.

One drawback of the MTPen is the fact that the microcontroller is attached to its surface. Of course, it is just a prototype but it still greatly reduces its comfortability. Furthermore, the microcontroller is attached to a computer which means that there is a USB cable connection between the two devices. This could create pressure on top of the pen and result in a user tilting it or adjusting his/her grips. Such a drawback could also mean that many of the tests that have been conducted might have results which are not entirely accurate.

Another problem which occurs according to the researchers is the fact that sometimes when users touch the pen the grips might merge [10]. Thus, a user might expect to use a specific functionality but the system detects that he/she is performing a different grip and, therefore, performs a different function.

Finally, a major drawback of the MTPen occurs when the pen is put down on a surface. Sometimes the system might register that as a grip. Therefore, there might be some unwanted noise over the data that affects the pen even when somebody is touching it with a specific grip.

## 2.4 SmartSkin [11]

The SmartSkin is a technology that can be implemented as an interactive surface. Its goal is to move the everyday workspace of a person from the computer to another platform or surface. It uses two main components – capacitive sensors and an antenna. The capacitive sensors help in detecting touch while the antenna (in combination with the sensors) is used to detect the distance between the user's hand and the surface [11].

Compared to the rest of the technologies so far this is definitely a novel one. The size of its surface can be adjusted depending on the necessary usage. It is called a 'Skin' because the 'sheet' which makes it up is flexible and can be adjusted to numerous surfaces.

One of the most important positives of this system, I believe, and something that I have a problem with in the project as well, is the fact that Rekimoto has developed a noise adjusting system for the sensors. He calls it a "lock-in-amplifier" [11] which reduces the noise over a specific sensor caused by its surrounding circuits.

Another important positive side of the SmartSkin is the fact that it can recognise several different hands, which also means that several users can use it and interact with it. All of the movements that are developed for the SmartSkin are also very natural to its users:

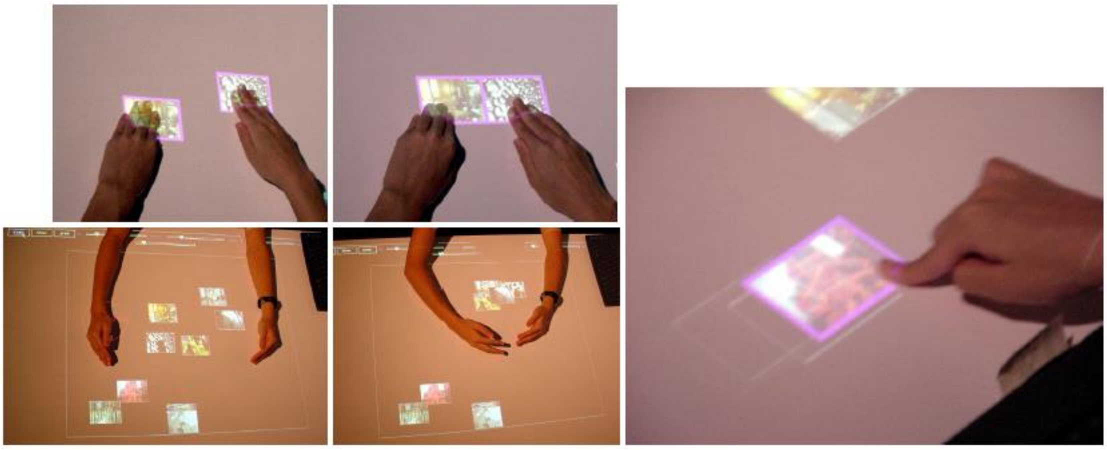

**Figure 2.3 [11]:** Several gesture examples that a user can implement on the SmartSkin.

I believe that a possible drawback of the system in terms of its potential mass production, as with several of the above inventions, is the fact that it is hard to design and expensive to produce. There is a huge variety of situations in which the SmartSkin could be used but I assume that it will also be expensive to actually implement it.

Another drawback concerns the fact that the SmartSkin can calculate the proximity between the surface of the system and the user's hand. Unfortunately, this calculation is based on the amount of pressure exerted on the SmartSkin and the values produced are more relative than accurate [11]. Thus, many of the functionalities which depend on distance measurement might not work properly.

The last aspect, which I consider a drawback since it makes the system even more complex, is the fact that it uses two different microcontrollers. One of them stores information on wave lengths measured by the antenna, and the other performs calculations on these measurements. Therefore, a lot of data is produced and manipulated which makes the system prone to errors and even harder to implement.

## 2.5 Touché [12]

Touché is a system for sensing touch that uses capacitive sensing. It can provide capacitive sensing capabilities to different objects. The novel part of the system is the fact that it uses a different type of capacitive sense – Swept Frequency Capacitive Sensing (SFCS) [12]. As discussed in the Introduction (1.3 Capacitive Sensors), a traditional capacitive sensor would detect the change in the electrical signal after being touched. SFCS considers the fact that the different body parts, including the organs, have different natural resistance to electricity. Therefore, the returned signal would differ depending on the organs it goes through. Thus, Touché uses these differences in resistance in the form of frequencies instead of recording and manipulating just one data point.

Like the Ball of Soap the Touché sensor can be embedded in numerous different objects and can make them interactive. Additionally, it can also be attached to a water tank or to any object filled with water. Since the liquid is conducting electricity it can also be made interactive which further broadens the capabilities of the system.

Compared to the rest of the systems Touché is much easier to implement by everyday users. Of course, a user might need to know how to manipulate the data and work with software but this is a problem applicable almost any new project or invention.

One of the best parts of Touché, I believe, is the fact that it uses only one sensor. This might also mean that the software working behind it is more complicated since machine learning has to be implemented in order to consider different kinds of gestures. Nevertheless, having just one sensor makes the system very portable and a lot easier to integrate into other objects.

A big drawback is the fact that the frequencies returned strongly depend on the person using the object. A simple example is the difference in the body composition of male and female users. A female would naturally have a higher natural body fat and it would take more time for the electrical signal to get back to the microcontroller. There might be big difference in the frequencies returned by the bodies of different users.

The frequencies returned also depend on the surrounding environment. This limits the system because when it is embedded in an object the object has to be used only in a specific environment to ensure noise reduction or at least to reduce unexpected noise. Air humidity, for example, is a feature of the surrounding environment. If air is in direct proximity with the sensor, which is absolutely possible, this could lead to a lot of noise in the values produced by the system since air is also conductive; the higher the humidity of the air, the higher the conductivity.

# Chapter 3 Requirements

## 3.1 Gathering Requirements

In order to develop a project that is user friendly and as efficient as possible I decided to collect the requirements directly from the users. As already stated in the introduction, my project is focused on a closed office environment and that is why all of the people that I interviewed are working in offices. Half of them are male and the other half are female. 80% of them work in academia which ideally fits in my goals.

I collected the requirements by doing interviews. The interviews gave me qualitative data (Appendix B) which I needed to improve the first prototype.

Interviewing is a well-established and proven approach for gathering requirements. My project requires the use of an actual physical object. That is why it is much better if the users can accept it and be trained to use it as fast as possible. According to Lethbridge and Laganiere using interviews helps exactly this aspect of the development process [13]. Furthermore, I had the opportunity to observe the users and their actions and I audio recorded the interviews. This greatly improves the analysis of the requirements and the validity of the results.

There were a total of ten interviews. They are based on Grounded Theory (Section 3.2). In all interviews I listened carefully and to showed empathy. This is important since the interviews were long. My goal was to receive accurate information by asking a variety of questions, which put the interviewee at ease, do not make her/him feel intimidated, and stimulate the conversation [13]. I always asked the users about their opinion and tried to make sure that they understand that none of their answers is incorrect. I tried to make the questions as specific as possible but I did not always stick to an exact order. For example, some users answered some questions before even I was able to ask them. In such a case I would try to brainstorm with them and ask them questions that just come in my mind but are connected to the topic. In this way I was able to collect even more information and to not bore the interviewees too much.

I also used the method of Prototyping to gather the requirements. According to Lethbridge and Laganiere prototyping for requirements gathering should be fast and messy since it is just a sketch. I tried to spend more time on the first prototype, though, because I intended to use the initial door frame for the final prototype as well. This saved a lot of time but it also made the user experience much more exciting. Nevertheless, I tried to do some of the things on the first prototype not exactly in the way I envisioned them. For example, the traffic light indication was positioned horizontally. My initial goal was simply to see if the users would understand the system even if it did not exactly resemble a traffic light. Additionally, I intended to test if the interviewees would actually recommend a different positioning. The design of it is further discussed in the Design section.

## 3.2 Grounded Theory and Documenting Requirements

Grounded Theory (GT) greatly helped me in grouping the requirements and in creating an overall idea of the most important information that they give me. Having in mind the limited period of time available, it was not possible to make all improvements that the users wanted. I focused only on the most important ones.

GT is a method that can be used to get the opinion of people about their experience with a certain technology [14]. The goal of GT is not to focus on particular concepts or literature but to gather your own data and to try finding the connections inside of it.

Performing the GT method involves several different steps. Firstly, a set of people has to be interviewed. The interviews have to be audio recorded. Then they have to be transcribed. The transcripts have to be coded and the codes have to be grouped and connected to find important data.

After performing the initial three steps, I took notes in the form of memos as suggested by Charmaz [15]. In contrast with her suggestion I did not try to look for gaps in my data but to find information that is regularly repeated. I wanted to know which features of my product mostly irritated people or vice versa.

Finally, I started the coding process. I bolded the words in the transcripts that I thought are important for the improvement of the project. Then I grouped the words below their corresponding questions:

**Figure 3.1:** Codes of all interviews grouped below the question they belong to (Appendix B Section 16 gives all GT questions and the codes below them).

After finishing this step all memos were read again and I tried to find logical ways of grouping the codes. The first four questions regarded the interviewees more personally and I kept the codes below their questions. Then I grouped the rest of the information in sections which are based on the different physical parts of my project:

**Figure 3.2:** The grouped codes (Appendix B Section 18 gives the names of the groups and the codes below them).

In Appendix B Sections 16 and 18 some of the codes are in bold. These are the codes that were repeated most often by the interviewees. Based on this information and on my memos I grouped some of the codes using MoSCoW (Appendix A). In the second prototype of my project I focused only on the must have requirements. I was not able to implement only requirement 1 and this is a sufficient drawback of the system.

## 3.3 Reviewing Requirements

According to Lethbridge and Laganiere requirements should be documented and grouped iteratively [13]. This is a rule that I have definitely followed. Ideally, I should review a specific iteration with the users before going to the next one, but instead I was only able to do something similar through small discussions with friends and colleagues due to the limited time available.

Lethbridge and Laganiere state that all requirements should be: essential, realistic, complete, consistent, verifiable, organised, unique, prioritised, and clear [13]. All of my requirements were organised and prioritised (see Appendix B). The essential and more realistic ones were grouped once more using MoSCoW (see Appendix A). All of the Appendix A requirements are unique, clear and realistic to implement. I have also implemented only the must have requirements and, therefore, I have prioritised them. In conclusion, there is not a requirements gathering procedure that will ever be 100% complete. If another GT is conducted, I will undoubtedly find additional information which can further be used to improve the prototype.

# Chapter 4 Design

Chapter 4 is divided into three sub-sections: Prototype 0, Prototype 1, and Prototype 2. Prototype 0 involves my early tests on the Arduino and the Capacitive Touch (CT) sensors. Prototype 1 is the first full prototype that I created. It is also the prototype used in the grounded theory (GT) requirements gathering process. Finally, Prototype 2 is the final upgraded prototype based on the requirements gathered from Prototype 1.

## 4.1 Prototype 0

To fully understand the concepts discussed in the Introduction (1.2 Arduino and 1.3 Capacitive Sensors) numerous experiments were conducted. I will discuss only the ones that I find most important for the development of the project.

My first experiment involved only turning on and off an LED. I needed to understand how the different digital pins on the UNO work (see section 1.2) and how I can set them up as input or output. I inserted the LED into the pins corresponding to 13 and GND (ground). Grounding is important since it redirects all excess energy into the ground in a case of a storm or a power surge; therefore, it acts like a safety feature [16]:

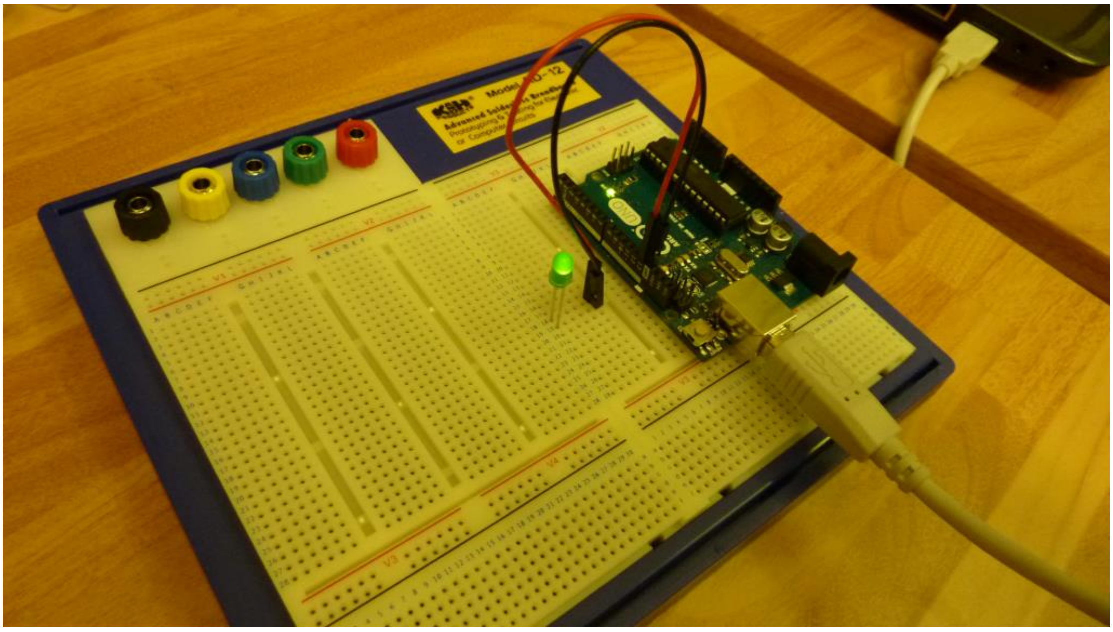

**Figure 4.1:** Arduino UNO attached to a computer and a breadboard. Pins 13 and GND are used to power the LED.

After I was able to power the LED on and off I needed to understand how the CS sensor works. I used the CS Arduino Library [7], the code of which I further discuss in the Implementation. At first I just wanted to test if the sensor can actually sense touch and what kind of data it produces when I touch it. I used the breadboard to connect a small jumper wire to the Arduino. The wire's end was the sensor. The difference with the classic CS sensor, discussed in 1.3 Capacitive

Sensors in the Introduction, is that the wire is not constructed of two plates with space between them:

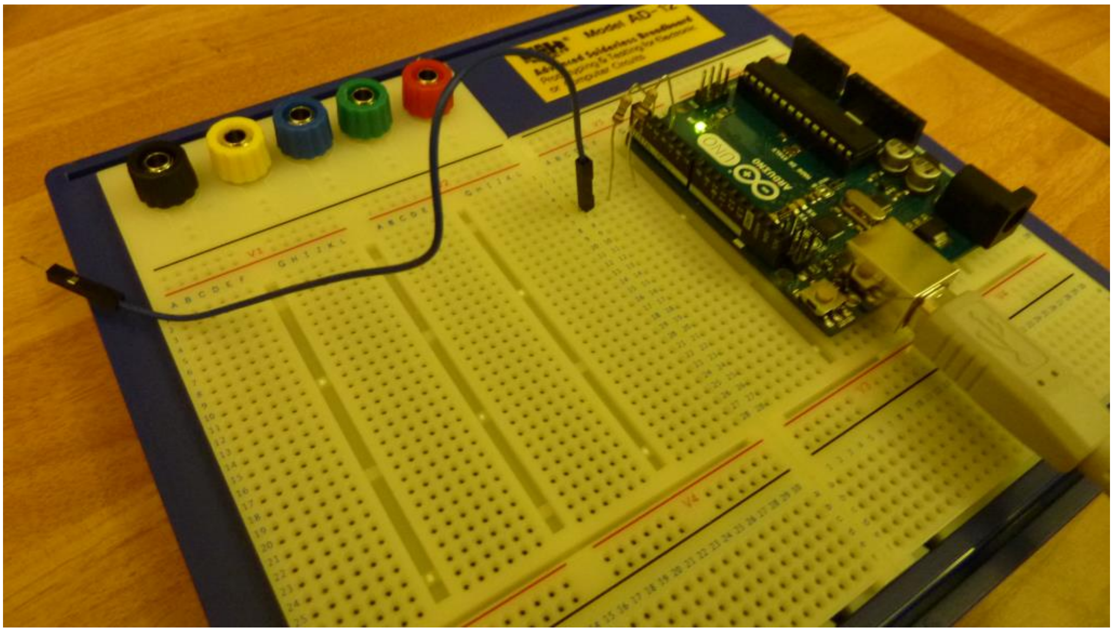

**Figure 4.2:** The first CS I experimented on. It consists of a jumper wire and two 1M resistors which ensure absolute touch. The resistors are connected to pins 2 (send pin) and 4 (receive pin).

The sensor worked but it was directly exposed to the outside environment and that is also why it was affected by noise. The electrical current flows from pin 2 (the send pin) through the 1M resistor, through the sensor (the jumper wire), and back through the next 1M resistor attached to the receive pin 4. Thus, if somebody touches the jumper wire, the natural body resistance would affect the EF (1.3 Capacitive Sensors) of the sensor and it would increase the time it takes the electricity to flow back into the Arduino. This time is measured with a time constant C * R (1.3 Capacitive Sensors) in milliseconds. It appears in the Arduino Serial Monitor (Figure 4.3). The 1M resistors ensure that the sensor would only activate if there is absolute touch involved [7]. Using a higher sensor of 10M for example would result in creating a larger EF. Thus, the sensor would get affected if there is a human finger, for example, 10-15 cm away from it.

As already mentioned, the data produced when the sensor is touched appears in the Serial Monitor of the Arduino. Figure 4.3 shows the output of the monitor. The second column of data is the time constant. The left monitor represents an untouched sensor while the CS in the right monitor is in contact with a finger. Obviously, the values in the right monitor are higher since it takes more time for the electrical current to get back into the Arduino. More interestingly, the values in the left monitor also change from time to time due to noise. This is not necessarily a desirable outcome.

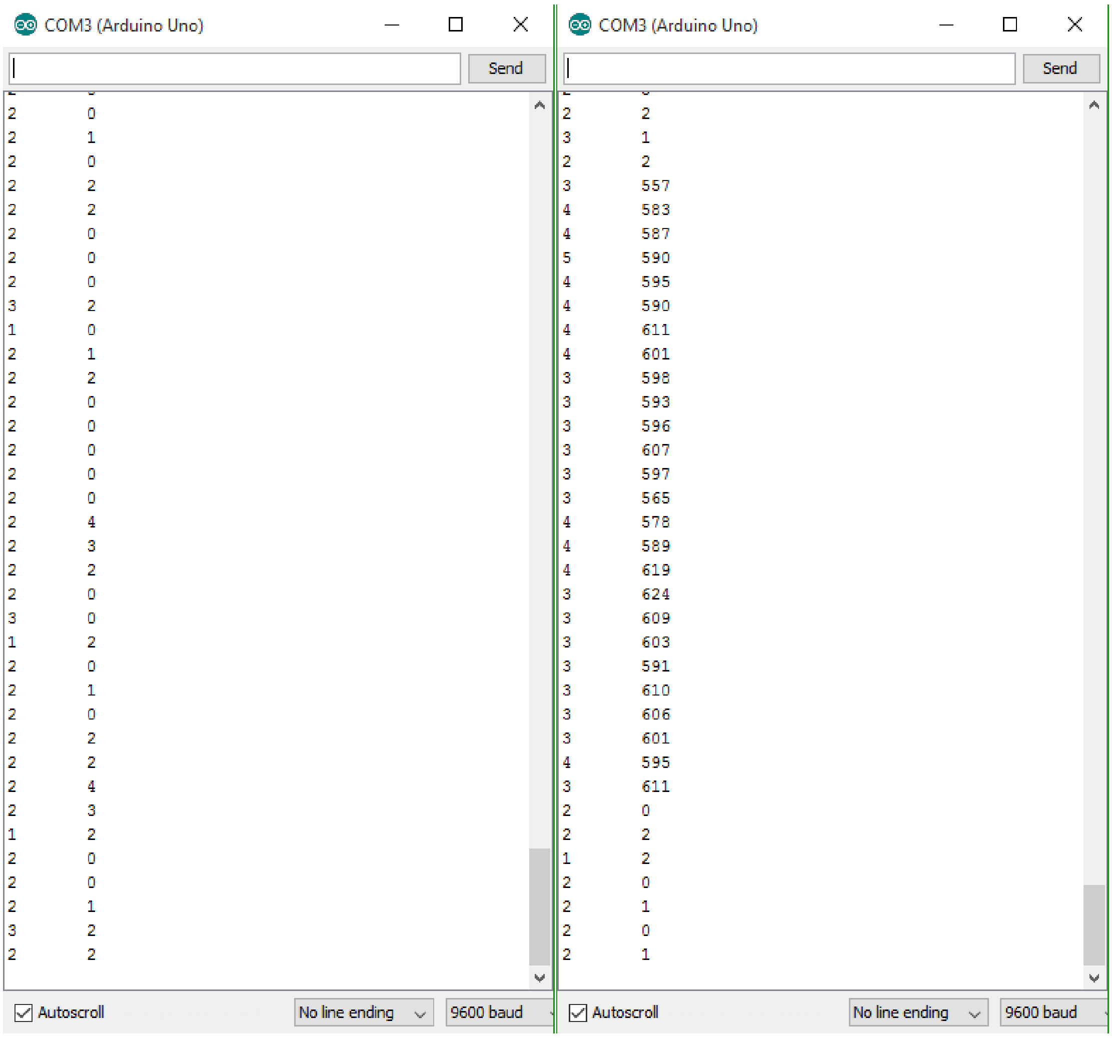


**Figure 4.3:** Two serial monitors – left and right. The left one represents data from an untouched sensor while the right one is in contact with a human finger.

Finally, by using the change in the time constant I was able to control the state of the LED by combining my first and my second experiment.

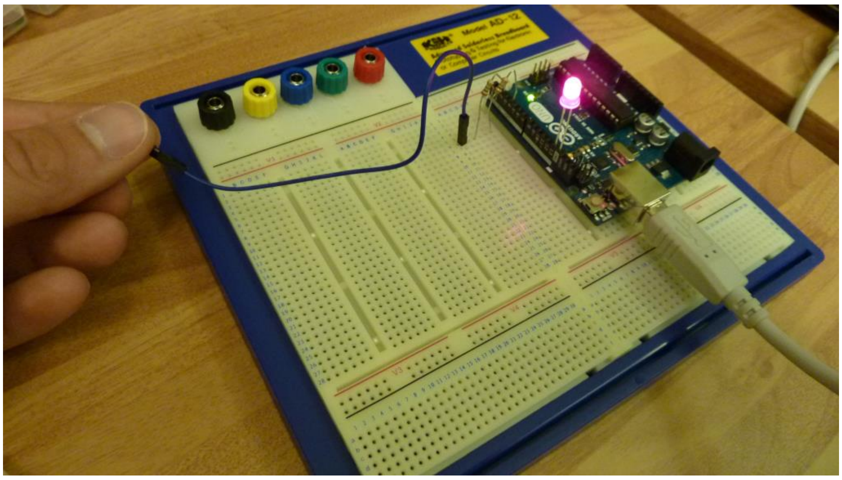


**Figure 4.4:** A capacitive sensor turning on a LED.

## 4.2 Prototype 1

Before creating the first prototype which I was going to use to conduct my Grounded Theory interviews, I created a small sensor which could be attached to almost any handle:

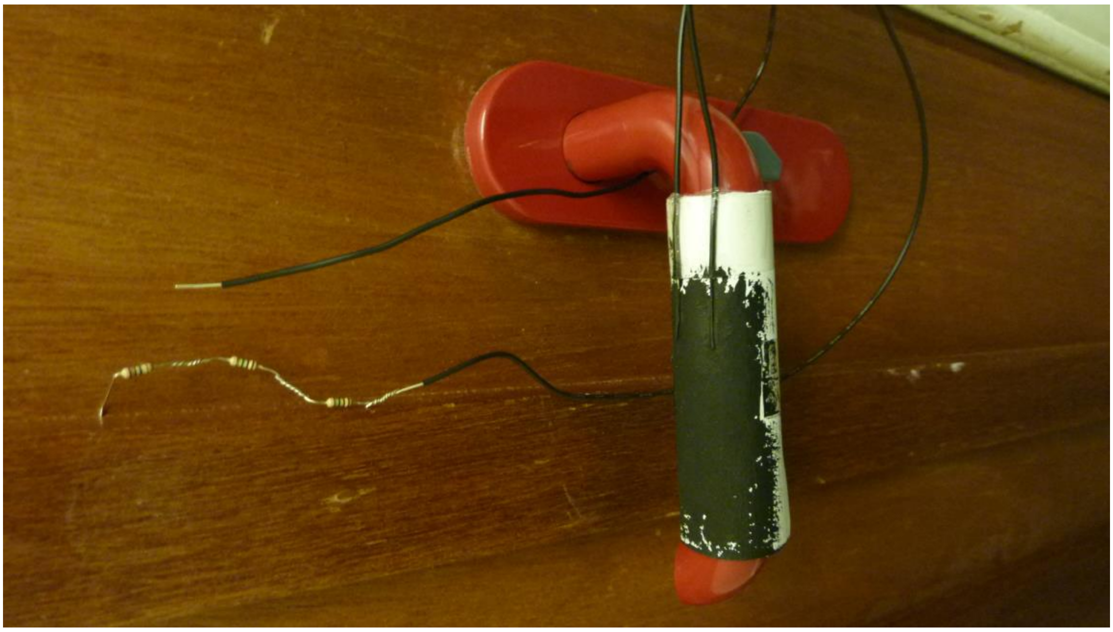

**Figure 4.5:** A capacitive touch sensor attached to a door handle.

I wanted to test several different grips on the actual sensor and to roughly see how it could work. I used paper and two wires for the send and the receive pins on the Arduino. I attached them to the paper and painted the surface with conductive tape which formed the actual sensor. I tested several different grips and a week later I was done with my first prototype:

**Figure 4.6**: Prototype 1 – a door frame with a door handle attached to two capacitive sensors and three LEDs.

I made a door frame from cardboard and insulating tape and I attached a door handle and the three LEDs to it. The LEDs were in the paper cubes in the top right corner of the door frame. There are two capacitive sensors attached to the handle. One of them affected the amber light and the other was connected to the red light. Using both of them affected the green light. The sensors were positioned on the inner part of the handle:

**Figure 4.7:** The red wire is a capacitive sensor affecting the red LED. The grey wire is a capacitive sensor affecting the amber LED. Using both of them turns on the green LED.

Thus, there were three different grips which could be used on the handle. Using a full grip turned on the green LED. This means that the door is unlocked and the person inside of the office is Available. Holding the inner part of the handle with one finger turns on the red LED – the door is locked and the person in the office leaves for the day. Touching the outer part of the handle with one finger turns on the amber LED – the door is locked and the message conveyed is: "Will be back soon". The overall idea was clear but I was not sure how well the users were going to accept it. I was not sure if the different grips were comfortable and if the message of the lights was clear and that is why I conducted the Grounded Theory interviews discussed in the Requirements.

## 4.3 Prototype 2

After completing, transcribing, and coding the interviews it was clear that the door should be improved and in many different ways. Unfortunately, I did not have the time to do all of the improvements that I wanted. That is why I tried to structure the essential requirements with MoSCoW (Appendix A). Even after squeezing all of the requirements data so much it was not possible to implement all changes. I implemented all requirements except the MUST 1. I believe that these were the most important requirements that could improve the user experience and convey the message of the lights in the most appropriate manner. The final product looks in the following way:

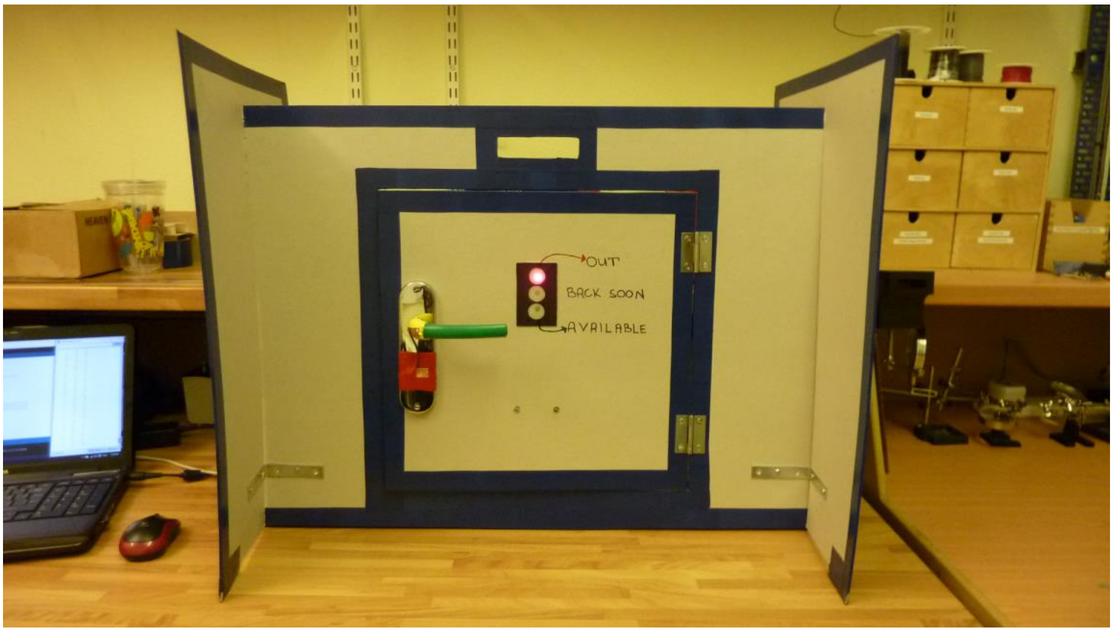


**Figure 4.8:** Final prototype.

The lights were moved and a traffic light resembling system was created. I have also put messages next to each light because this improves the understanding of the users and is helpful for colour blind people. Different coloured insulating tape was used on the handle depending on the position of the different grips and on their connection with the lights. Now a user can understand which grip exactly affects a particular light. Furthermore, the handle is bigger and more comfortable and the grips are different as well. According to the users the previous 'one finger grips' were very unnatural. Many users preferred using their thumb in manipulating a handle and now a user can perform a full grip (green light), a full grip with a thumb (amber light), and a simple touch of the lock (red light). The lights and the sensors are connected via the Arduino on the back of the door:

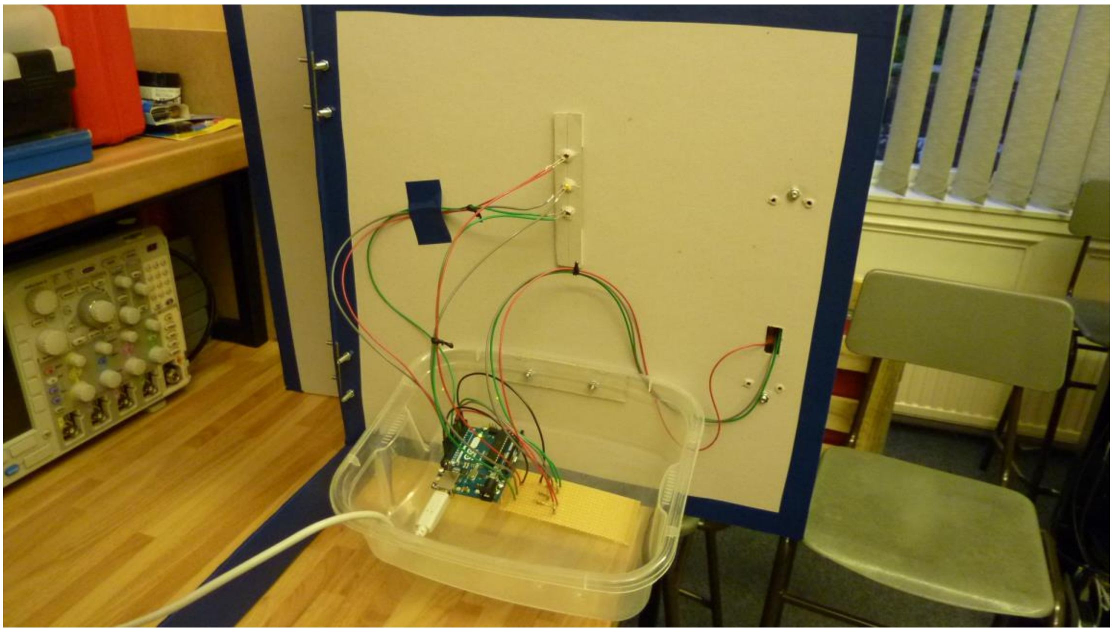

**Figure 4.9:** The Arduino connects the lights and the sensors.

# Chapter 5 Implementation

## 5.1 Arduino Capacitive Sensing Library

To produce my final code for the door handle I used the Arduino Capacitive Sensing Library. The final product of my code is in Appendix D. It has been changing gradually from Prototype 0 to Prototype 2.

The Arduino CS library transforms the Arduino board's pins into capacitive sensors. I have already discussed CS in the Introduction and in the Design. The sensors that I have created, in contrast with the ones described in the Introduction, use just one plate in the form of copper tape. A wire is connected in a circuit between the send pin and the receive pin of the Arduino (similar to Figure 4.2). The wire is soldered on copper tape forming the capacitive sensor.

Arduino programs are called sketches. The files produced have .ino extension. There are two important methods that should always be in an Arduino sketch: setup() and loop(). The setup() method (line 22, Appendix D) is always called when a sketch starts [17]. It is used to initialise some variables and I particularly use it to initialise the state of my LED pins. The setup() method is run only once after starting a sketch while the loop() method contains the core code of the program and loops consecutively [17].

Line 2 in Appendix D imports the CS library into the Arduino sketch. On lines 15 to 18 I initialise my variables and more particularly I reserve three pins for my LEDs. The THRESHOLD variable is the minimum value a sensor needs to reach to turn on an LED.

Then I create three instances of the library (lines 21 to 25). Each instance needs a send pin and a receive pin. I use pin 2 as a send pin for all of my sensors. It has a 1M resistor attached to it. Pins 3, 5, and 7 are receive or sensor pins. All of them also have 1M resisors.

In the setup() method I start the communication between the Arduino and my computer using a pre-specified port. Then I set the state of the three pins I initialised as instance variables to OUTPUT. Thus, there is an electrical current flowing through them. I can adjust the current to turn the LEDs on and off.

Finally, the loop() method is where all of the program logic is. The long on line 40, start, stores the time in which the sketch (program) has been working in milliseconds. The three longs between lines 45 and 47 contain the capacitance of the three sensors in arbitrary units [7]. After I create the longs I print them on the Serial Monitor (lines 50 to 57) to observe how their values change (Figures 4.3 and 5.1).

The if-else statement in lines 60 to 72 controls the state of the LEDs depending on which sensor is touched. Since the LED pins have already been set to OUTPUT in the setup(), their state can be changed using the digitalWrite() method. The method requires an LED pin and an operating voltage which could be LOW or HIGH. As already mentioned in 1.3 Capacitive Sensors in the Introduction, the Arduino operating voltage is 5V. Thus, the HIGH value is 5V and the LOW one is 0V. In other words, when the LED is set to HIGH it is on and vice versa. If a particular sensor's arbitrary value is higher than the THRESHOLD value that I have set as an instance variable, then the LED corresponding to that sensor will be turned on.

In the if-else statement the amber LED has priority over the green LED which in turn has priority over the red LED. The priority of amber over green is particularly important since the grips used to activate them are very similar. Simply said, if someone wants to use full grip (activate green; unlock the door; state that he/she is 'Available'), the green LED will go on; but if he/she wants to turn on the amber LED (indicate that you are going to be 'back soon'), then it is necessary to use full grip with a thumb. Since the amber sensor has priority over the green one, only the amber LED will get activated.

The delay() method on line 74 requires a value in milliseconds. In my case it is 500 milliseconds or half a second. This means that it will take half a second before the next printed value appears on the Serial Monitor. The values printed on the monitor, as already stated, are arbitrary, and look in the following way:

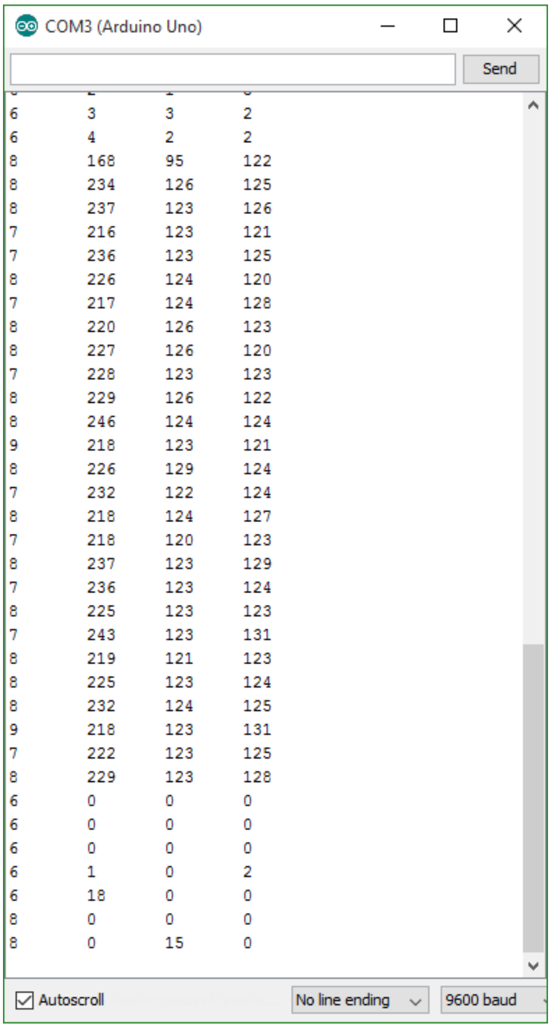


**Figure 5.1:** Arduino Serial Monitor. The arbitrary values for the three sensors appear. Full grip is used here; therefore, the value of the green sensor is the highest.

Figure 5.1 shows an increase in the values of all three sensors. Only full grip is used though. On Figure 4.8 the handle has three colours of tape. The green colour represents the position of the full grip. The combination of green plus yellow requires a thumb to be used on the yellow insulating tape – this is the amber grip. A valid question regarding the data in Figure 5.1 is: why are all values so high if only the full grip is used? The green sensor is inside of the actual handle, the amber one is on top of the yellow insulating tape and the red sensor is on top of the red insulating tape. Since the handle is made out of metal, it conducts electricity. When touching the handle all sensors get affected. Ideally, they should not get affected at all since they are covered in insulating tape. Nevertheless, this does not really matter even when the tape is working only partially. In Figure 5.1 full grip is used (green), all sensors are affected, but the one with the highest value is the green one. Thus I use my TRESHOLD instance variable in the if-else statement to distinguish between the grips. A grip with a value of the sensor higher than the TRESHOLD will turn on its corresponding LED.

## 5.2 Testing

My testing procedure was very simple. It follows the design process from Prototype 0 to Prototype 1.

First I tested only the code for the LEDs. I wanted to get familiar with the Arduino sketches. I only used the pinMode() and the digitalWrite() methods.

After this I tested the CS library with one sensor only. My goal was to see how the values appear on the Serial Monitor depending on the resistor used. Only one instance of the CS library was used (since it was just one sensor) and, of course, the methods for printing on the Serial Monitor. Then I tested exactly the same code with the handle on Figure 4.5.

The LED code and the CS library were combined and a simple if-else statement was included. After making sure that I understood the basics I created my first prototype. Then the GT interviews were conducted and the prototype was improved.

The improvements in terms of the code included 3 instances of the CS library instead of just 2 (Prototype 1 had just 2 sensors). Because of that, my if-else statement became a bit longer and it was obvious that I had to prioritise the amber sensor over the green one.

# Chapter 6 Evaluation

## 6.1 NASA TLX

The NASA Task Load Index is a rating procedure. It provides a workload score which is based on the average rating of six features: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration [18].

To test the performance of the door handle and to gather quantitative data I used NASA TLX. I performed 10 interviews, the procedure of which is summarised in Appendix C. Initially, I asked every interviewee to all grips 3 times, therefore, an overall of 9 tests. The goal of each test was to record the time it took the interviewee to perform a grip, the grip that the interviewee used and the light that appeared. Thus, every factor (grip, light and time) has been recorded 3 times from 10 interviewees – a total of 30 times per factor.

After that I used the NASA TLX tool developed by Keith Vertanen [19]. The tool asks each participant to rate each of the six TLX features on a scale of 20 (1 is Low and 20 is High). Then every interviewee is given a total of 15 pairs of features and has to choose one feature in each pair. The pairs are based on the original NASA TLX Paper/Pencil version [18]. Finally, the tool outputs data which contains the weighting of every TLX feature as well as its rating and the total average workload. All interviewees have used the tool three times for the three grips – green, amber, red. Finally, I have asked the participant to leave more comments on every grip.

## 6.2 Data Analysis

First, I will discuss the 9 tasks I have given to the participants to perform (Appendix C Section 110: Testing the Grips). The three features tested are the grip, the light, and the time it took to perform the test. The data about each grip is summarised in the following table:

| | | PERFORMED | | |
|---|---|---|---|---|
| | **GRIP** | Green | Amber | Red |
| SUPPOSED TO PERFORM | Green | 30 | | |
| | Amber | 1 | 29 | |
| | Red | | | 30 |

**Figure 6.1:** The performed grip compared to the grip that was supposed to be performed.

Every grip was performed 3 times by 10 participants. Every interviewee was given instructions about how the handle and the light indication work. Almost all grips were performed properly from the first time and there was no confusion regarding their use. The target of correct tries is 100% or 90 tries. Only one try was out of target which is a total of 1.12%. The grip out of target was the amber one. The next task that every interviewee performed concerned the lights:

| | | PERFORMED | | |
|---|---|---|---|---|
| | **LIGHT** | Green | Amber | Red |
| SUPPOSED TO PERFORM | Green | 29 | 1 | |
| | Amber | 2 | 28 | |
| | Red | 1 | 2 | 27 |

**Figure 6.2:** The light that appeared after using a grip compared to the light that was supposed to appear.

The data in Figure 6.2 is more scattered. The light appeared correctly according to its corresponding grip 84 out of 90 times. Therefore, the out of target percentage this time is 7.14. The main problems appeared in the green and the amber lights. Amber appeared once when green was supposed to light up and green appeared twice when amber was supposed to be turned on. The problem here is obvious after going through the qualitative data in Appendix C, Section 112. Since the amber grip requires using the green grip as well, some people lift their thumb first before lifting their full hand and vice versa. This results in outputting the incorrect light. The problem could be solved by adjusting the if-else statement in the code (Appendix D). A timeout of a few seconds has to be created. For example, if somebody has used the amber grip in this time period, regardless of her/him removing her/his finger or full hand first, the sensor has been touched and the correct light (amber) will appear.

There is also a problem with the red light. 3 out of 30 times the light was incorrect. I believe that the main problem here is in the green grip again because it is in the actual handle. All sensors must be much better insulated so that they do not interfere with each other's data output. Finally, I have also recorded the time it took for each participant to perform the grips:

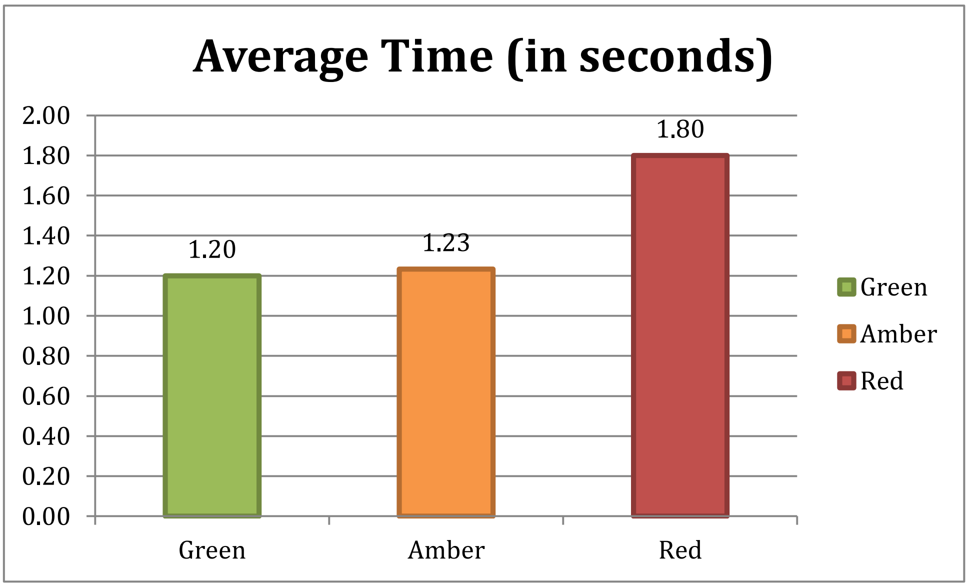


**Figure 6.3:** The average time it took to perform each grip measured in seconds.

It took every participant roughly one second to perform each grip. I consider this result to be good since one second is approximately the time necessary to actually move your hand to a handle. Therefore, participants have not been thinking too much about what grip they need to perform which shows that the grips come naturally to them.

The red grip's time is higher than the times of the other two. The interviewees were mostly just slightly touching the red sensor. The problem is that the sensor requires absolute touch to go above the THRESHOLD value. There are two solutions to this problem. I could put some support behind the door so that it actually does not open backwards. Thus, a user will eventually absolutely touch the sensor. Another solution is to just change the resistor of this sensor with a slightly higher one which will make it more sensitive.

After conducting the tests I asked all interviewees to use the NASA TLX tool for every grip to test the workload of the grips. Next I will analyse the average workload of each component for each grip and the weight of each component compared to the rest of the components.

### 6.2.1 TLX for Green Grip

The overall average workload for the green grip is 321.67. Of all components contributing to this workload the highest is the Performance:

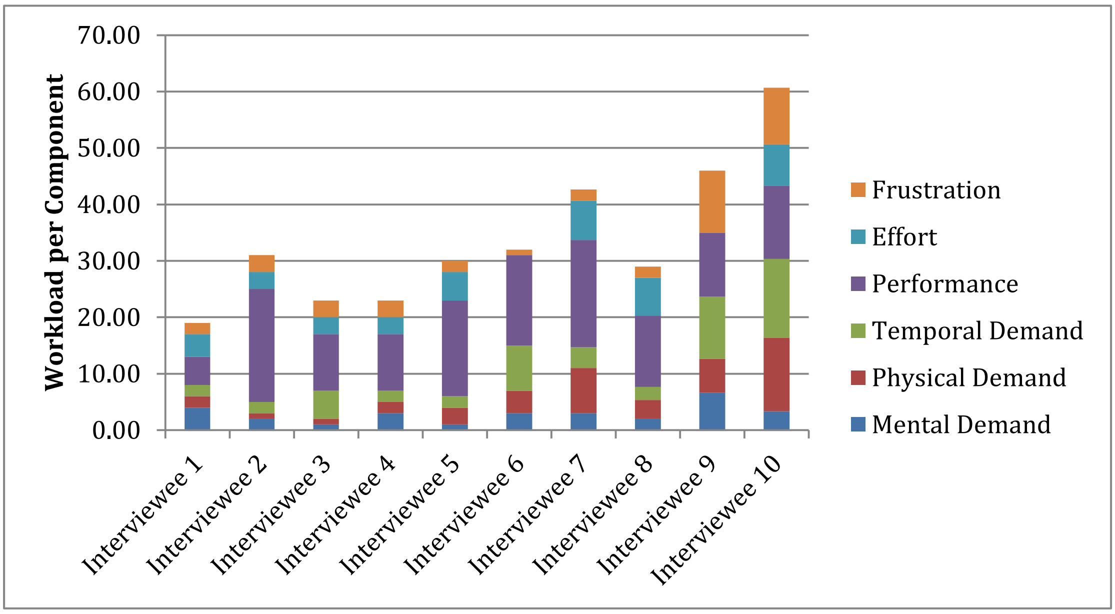


**Figure 6.4:** Workload of every component per interviewee.

Although most of the interviewees were very successful in performing the green grip it seems that the Performance factor was the most burdening in terms of workload. I believe that the main reason is the fact that many people were not sure when they had to use their thumb or not and if they are allowed to use their full hand as well or only their thumb. The amber grip requires the use of the green and the amber sensors and I think that the indication on the handle is not clear enough to account for that. That is why some people were maybe insecure about their performance of the green or the amber grips. Overall, no particular factor dominated any of the other components for each interviewee:

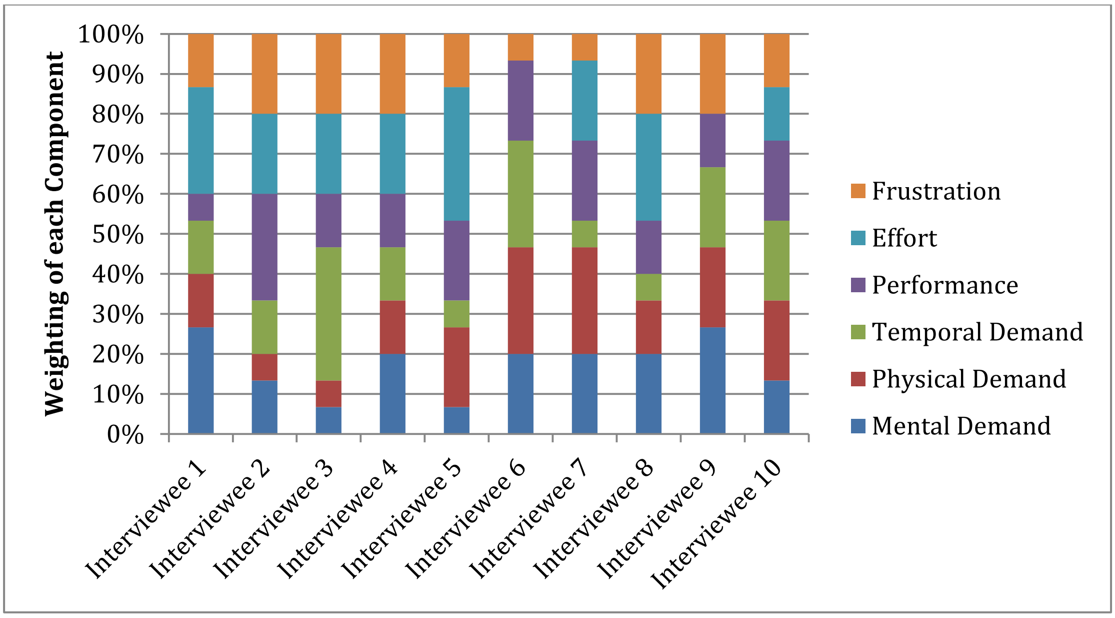


**Figure 6.5:** The overall weight of all components per interviewee is 1. The chart shows the weight of each factor per interviewee.

There were no particular components that dominated the rest of the factors per interviewee although Effort is the factor with the highest overall weights. This makes sense since the overall performance for the green grip is quite high. According to the interviewees they had to put a lot of effort in reaching their performance, therefore, the instructions on the door have to be improved and better training has to be given.

### 6.2.2 TLX for Amber Grip

The overall workload for the amber grip is 224.33 which is a lower value than the one of the green grip. Presumably this means that the Amber grip is less work loading. Of all components which contributed to the workload the most significant is the Temporal Demand:

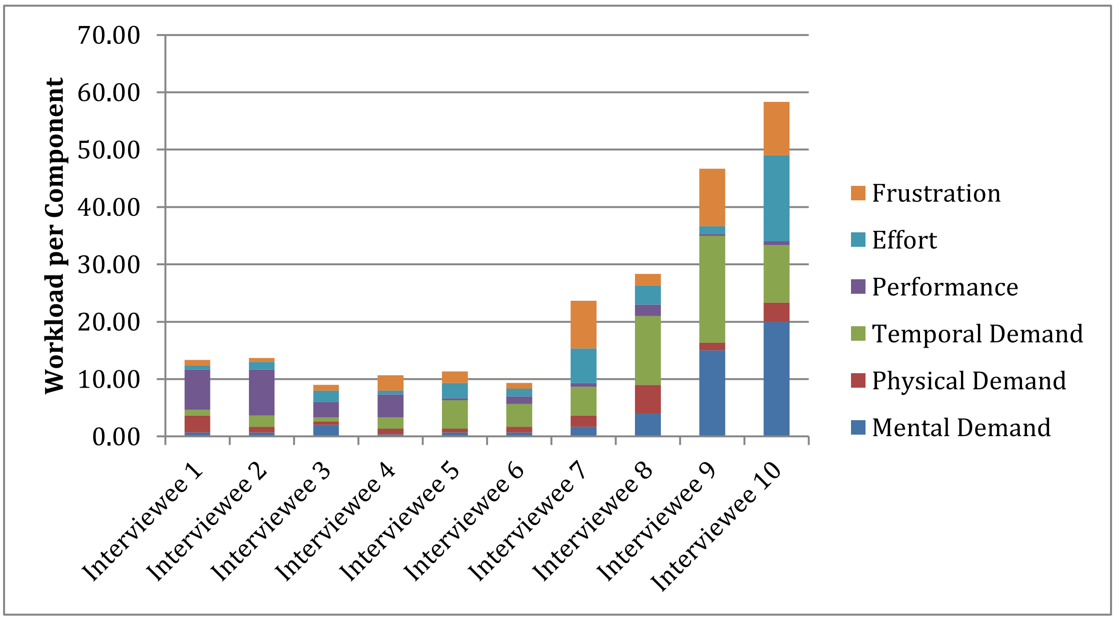


**Figure 6.6:** Workload of every component per interviewee.

No specific component contributes to the overall workload overwhelmingly. Mental demand is slightly higher than the others though. This contributes to the discussion of Figure 6.4. For many of the interviewees it was harder to understand just based from the handle indication that the amber grip requires the use of the green one as well. Sometimes the light did not appear properly because of somebody lifting their full hand or their thumb first. This confused some of the interviewees and is also the reason for the higher Temporal Demand. The handle indication definitely has to be improved and the green and the amber grips have to be made more functional and much easier to distinguish. No factor greatly dominated any of the other components per interviewee:

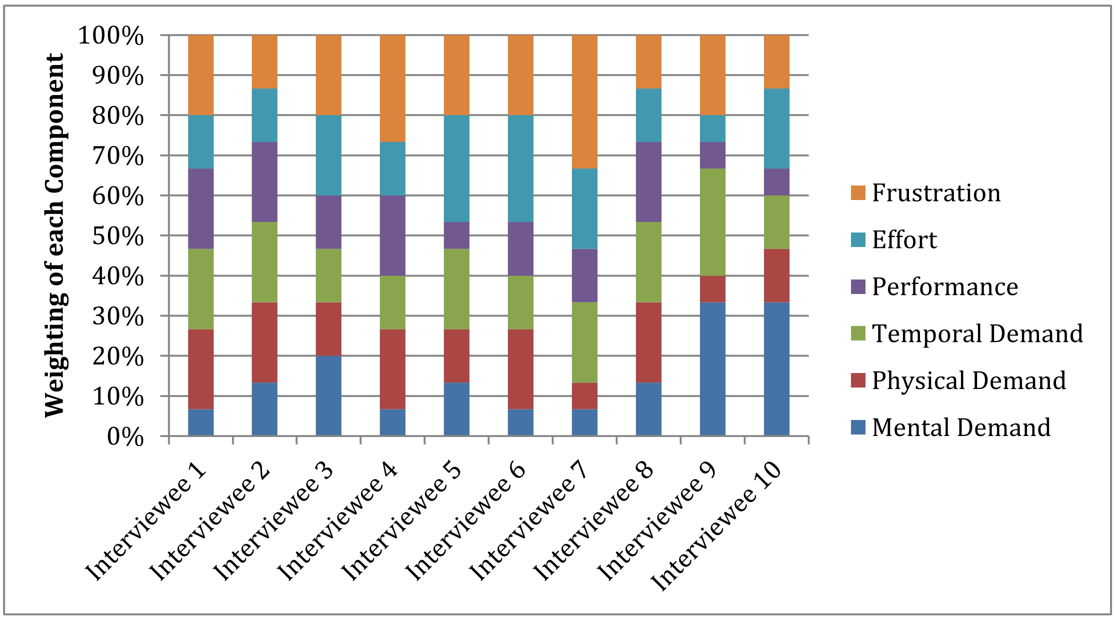


**Figure 6.7:** The chart shows the weight of each factor per interviewee.

Although no factor dominated any of the others Effort and Frustration were with the highest overall weights. They are not the factors with the highest contribution to the overall workload but they seem to be important for the interviewees in terms of weighting. It can be concluded that additional work in the future is required in order to improve the project and reduce the workload of Effort and Frustration even more. The point of having the handle and the indication is to ease the life of its users but the data says that it is still confusing them more than it is actually helpful.

### 6.2.3 TLX for Red Grip

Finally, the workload for the red grip is 232.67. This value is again lower than the one for the green grip and slightly higher than the one for the amber. The factor with the highest contribution to the workload here is the Effort:

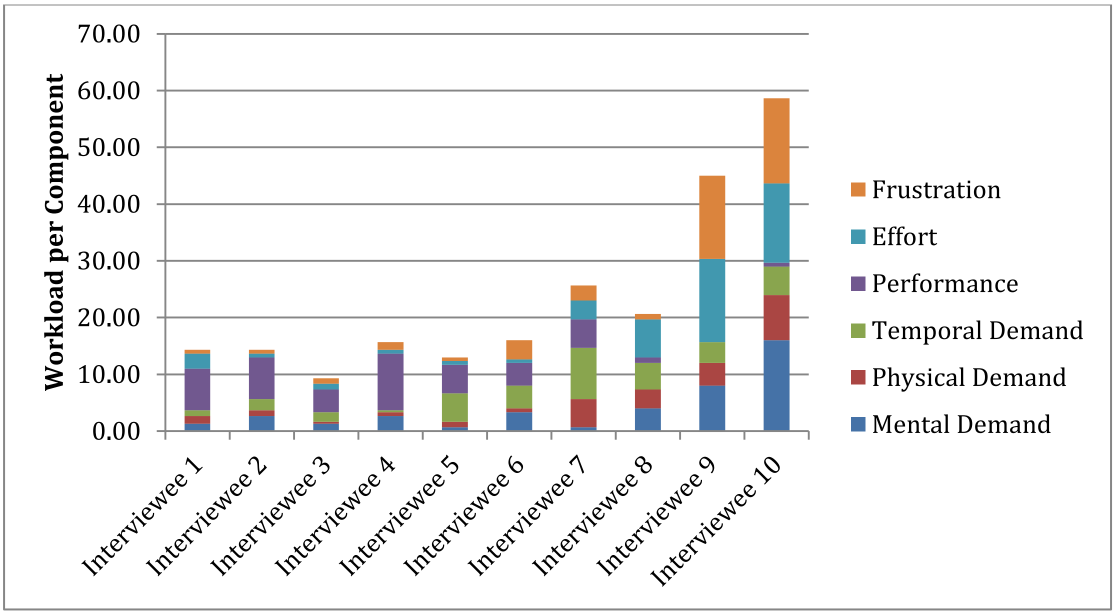


**Figure 6.8:** Workload of every component per interviewee.

The workload of all of the factors in this column chart is much more similar than any of the workloads in the previous data. Nevertheless, Effort and Performance again appear as two of the highest contributors. A lot of the interviewees complained in their comments that they had a problem using the red grip. Pressing the red sensor was difficult for many of them and it often required several attempts before performing the task correctly. It is also the grip which leads to the highest number of incorrect light appearing. Therefore, it is normal for the Effort to be higher. Again no factor significantly dominated the others per interviewee:

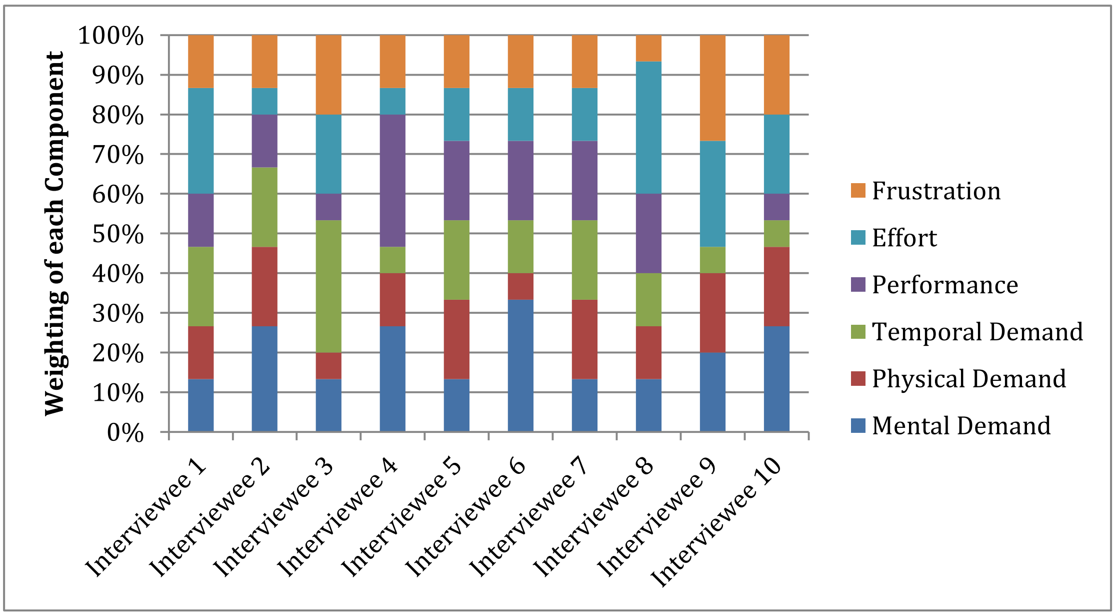


**Figure 6.9:** The chart shows the weight of each factor per interviewee.

Mental Demand and Effort are with the highest overall weights. Effort appears for a third consecutive time and it also has a high workload in all three grips as well. Therefore, the weights of the two components have to be reduced to create a better performing prototype.

## 6.3 Summary

The data makes a few points very clear. First of all, the time it takes to perform the red grip has to be reduced. The grip needs to function properly and has not been designed and insulated well enough.

Furthermore, the indication on the handle (the different coloured insulating tape) is not very good. More particularly, it is important to distinguish between the green and the amber grip.

The code also has to be improved so that the light indication functions correctly when using the amber or the green grip. The user's comfort is very important and that is why a user cannot be made to lift his or her hand in a specific way that will prevent the light from functioning incorrectly.

Overall, the previous three factors contribute a lot to the high workload in terms of Effort that the users had to put when using the door. Effort is a very important factor to the users as well and that is why more work has to be done in reducing it.

In Figures 6.4, 6.6 and 6.8, Interviewees 9 and 10 have much higher workload than the rest of the interviewees. Their contribution to the higher workload for Effort and Performance is significant. They were interviewed in a different setting than the rest of the participants. Although this could have affected the produced data, I do not consider it as a problem but as a factor which makes the output more realistic. If the door handle is used in a real work setting, the environment will change.

# Chapter 7 Conclusion

Throughout the development of the project I was able to create a prototype and to improve it into a version which is better and more comfortable for its users. My initial goal was to create a door handle which could control a light indication, and as a result can ease people's life when using their offices. I think I was able to accomplish the first part of my goal – creating the handle and use it to control the lights. After performing the GT interviews I also partially accomplished the improvement of the comfort of the users. In other words, I was able to complete the project physically but my final product is very far away from improving the life and the comfort of its possible users. A lot more GT and NASA TLX interviews have to be performed to accomplish this goal.

Nevertheless, I learned a lot about electronics and about the way microcontrollers work. I improved my understanding of the different ways in which Capacitive Sensing can be used and how it functions. This helped me in coming up with the door handle idea. I also learned about the different ways in which data could be gathered and I definitely improved my communication skills by conducting the interviews. This greatly helped me in improving the second prototype.

Being able to learn so much helped me in reaching my initial goal. There would have been no way for me to create the whole project without knowledge in electronics, microcontrollers and requirements gathering and analysis.

Although the project's state is not conclusive it could be compared to some of the other technologies discussed in the Survey. First of all, I can conclude that the door handle's sensors are much easier to test and use than the sensors in any of the five systems previously discussed. I have also provided a lot of the data in terms of the requirements gathering and analysis which is not really apparent in these systems' reports. My project is a lot less sophisticated in terms of the technology used and the type of data gathered as well though. That is why the responsiveness of the different grips is maybe worse than the one in the Touche or the Tango, where the developers have been able to reach almost 99% responsiveness. My project is also a lot less portable than the Graspable or the Touche for example. It also shares some of the problems that the Tango and the MTPen have. More particularly, sometimes the users are trying to perform a specific grip, but due to the fact that they are not lifting all of their fingers from the object, the output is not as predicted. This is exactly what happens when a user tries to perform the green or the amber grip of my handle.

In conclusion the project is considered a success. It can efficiently perform the tasks it was intended to. It is easy to operate and aesthetically pleasing. The disadvantages discussed above could be easily improved in the future with more time provided.

## 7.1 Future Improvements

There are two main improvements that have to be made. First of all, the sensors that I am using are too exposed to the outside environment which creates a lot of noise in the data. In fact, if only one sensor could be used that can distinguish between the different kinds of data by itself, this would be ideal. This would also mean that the data output of each sensor has to be changed and the CS library has to be improved. A possible solution is to use the Touche technology which returns the frequency of the data returned by the human body's capacitance instead of the arbitrary units produced by the Arduino CS Library.

The second major drawback is in capacitive sense itself. The sensors change their values drastically when exposed to different environment and variety of users. There are a lot of factors which affect the data: humidity of the air, moisture over a person's hand, even the type of shoes a person is wearing and the floor on which she/he is stepping. If a person's shoes are very thick or the floor is made out of metal, the human body would not be directly connected to ground and thus, the capacitive sensor data might not reach the THRESHOLD value in the software. Noise to the data has to be reduced as much as possible which requires better engineered and much better insulated sensors.

There are a lot of other improvements that have to be done. One of the most essential ones is a must have in Appendix A. The door handle must automatically lock the door when using the amber and the red grip. It should get unlocked when using the green grip. A locking mechanism has to be attached as well which will also change the software. This automatically brings another problem – the handle must recognise who is locking or unlocking it. My solution is to create a phone application and connect it to the handle via Bluetooth. The microcontroller can allow the door handle to be manipulated only when a specific phone is in a close proximity. Otherwise, the door will always be in a red state and locked. This solution, of course, creates additional security issues.

The rest of the undiscussed requirements in Appendix A could improve the project a lot as well. I believe that it is important to find a way to implement such a door handle in an open office with a lot of people as well. After performing the previously mentioned improvements, the handle could be connected to a board with a traffic light indication for every person in an office for example. Thus, the system will convey the same message and if there is a phone application produced as well, it could also recognise a large number of people.

Lastly, but maybe most importantly, the door handle has to be tested in a real office environment on a real door where a lot of people could try it. This time the users should not be given any training. This will reduce the bias as much as possible and I believe that the results from the gathered data will be much more realistic and useful.

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# Appendix A Requirements

## 11 MUST – are essential

1. The door handle must automatically lock the door when the red or amber light is on.
2. The handle must have indication for both long and short term leave.
3. The door handle must be controlled only by grips natural to its users.
4. The traffic light indication must be vertically oriented.
5. The door must have directions/instructions for use both on the light indication and on the handle itself.
6. The lights must be distinguishable.

## 12 SHOULD – should be met somehow

1. The door handle should have a way to recognise its user or users to improve security.
2. There should be an additional form of light indication for ‘do not disturb’.

## 13 COULD – are not essential

1. The door handle could have and additional function for sending an e-mail to the whole team of the user when he/she leaves on a holiday.
2. The door handle could be connected to another form of indication – a board, a screen, or anything else that shows the presence of a larger number of people in the office.
3. The door handle’s capacitive sensors could be repositioned on the door itself or beside the lights (essentially they will play the role of buttons).

## 14 WOULD – are not in this version

1. The door handle would be integrated for both individual and group offices.
2. The doors in a building would open automatically in a case of evacuation.
3. The door handle would switch different appliances in the office.
4. The door handle would be connected to a phone application to record if somebody is going in or out.
5. The door handle could have instructions in the form of sound or texture (e.g., Braille) to support the use of visually impaired people.

# Appendix B Grounded Theory Questionnaire and Coding

## 15 INTRODUCTION

The aim of the experiment is to test the usability of and the need for a smart door handle. As to identify the usefulness of such a system, we ought to run experiments like this one. They would also help us in improving the comfort the door handle would bring to its users. Firstly, I will ask you several introductory questions, then I will show you the prototype, invite you to use it, and ask you a few more questions. I will audio record the experiment and use the data only for analysis in regards to this project. I will also observe you while you perform the tasks. Please ask questions if you need to.

Please remember that it is the door handle, not you, that is being evaluated. You are welcome to withdraw from the experiment at any time without giving any reasons. Do you agree to take part in this evaluation? Do you have any questions before we start?

## 16 QUESTIONS AND CODING

1. What is your job?
    - Finance
    - Project manager
    - Work on sight
    - Shared office
    - Team manager
    - Research assistant (CS)
    - PHD Student (CS)
    - Intern (CS)
    - Systems manager (CS)
    - Commercial team
    - Teacher (CS)
    - Web developer
2. In what kind of building/office do you spend most of your work time?
    - Different companies
    - Smart cards
    - Open space
    - Individual offices
    - Self-contained
    - Share office
    - Lock the door when I leave
    - Office block
    - Meeting rooms
3. Under what circumstances and how often would you leave your office throughout the day?
    - Lunch
    - End of the day
    - Toilet
    - Swipe card every time
    - Store
    - Outside
    - Not leaving
    - Meetings
    - Phone calls
    - Infrequently
    - Walk between offices
    - Once a day (meetings)
4. Does the job that you perform rely on other people knowing if you are out of your office?
    - People on my team
    - Sometimes
    - Phone, e-mail, receptionist
    - Emergency (very important)
    - When I stay at home
    - Supervisor drops by
    - When I leave work
    - Communicate when out
    - No, knock and see if you are in

- Wheel indicators
- Co-workers

5. Do you indicate to others in a specific way that you are out of your office?
   - Out of office e-mail
   - Tell them
   - Wheel indicator
   - Online timetable teaching system
   - No system for indication
   - Note in a diary or whiteboard
6. If you do, could you please describe the kind of indication you are using?
   - None which is not handy
   - Rotary dial with a pointer
   - No – it will be useful
7. Do you feel this is an effective way of indication?
   - No – no indication only telling
   - Yes, everyone can see me or my stuff missing; open space
   - Wheel – poor, useless
   - E-mail – for me yes, for people outside of my office – no
   - Enough
   - Yeah, effective enough
   - Yes, within my team
   - Wheel – no, not accurate reflection; have to use it; judgements whether I'm working or not
   - Works
8. What, if anything, do you know about smart door handles?
   - Indicate if someone was in or not
   - Not familiar
   - Key-card system
   - Lock opening with a phone app
9. If you have not heard anything about smart door handles, what would you imagine them to do?
   - Recognition
   - Finger print
   - Touch to lock/unlock
   - Security
   - Notify if inside or not
   - Don't need a key
   - Switch appliances automatically
   - Alert if someone opens your door
10. Could you describe how you would usually grab a door handle when you close a door?
    - Strongly hold
    - Thumb
    - Full hand
    - Leg
    - Other body parts when hands busy
    - Push
    - Open quietly
    - Put foot down for support – back problems
    - Right hand
    - Open hand
    - Forearm
11. If you were to use some kind of grips, what would they be?
    - Push
    - Full hand
    - Rarely
    - Couple of fingers
    - Just a finger when full hands
    - Elbow
    - Upside down click
12. Does the door handle in your office/work space have any particularities or defects that you could share with me?
    - Card reader would not open – jams
    - Tend to work
    - Have to pull very hard to lock it
    - Round circulating doors waste time
    - Always had to be locked – there is no indication, so I unlock but someone is in, so I actually lock

- Heavy door - security

13. What do you think about the three different kinds of grips that you can use on this handle?
    - Agree with green – natural
    - Thumb
    - Most pressure at first part
    - Red awkward
    - Easy after you explain it
    - Time to remember
    - Instructions
    - Orange – something I might use
    - Always full grip
    - One finger – hard for a small person when the door is heavy
    - Unnatural
    - Forget to use them
14. Do they feel comfortable?
    - Straight forward
    - Red and orange are similar and confusing
    - Confusing
    - Red – not comfortable
    - Have to change how I open a door – not user friendly
    - Natural
    - Effort to remember – will forget
    - Hands too big – will touch two parts at once
15. Would you change these grips?
    - Swap yellow and green
    - Indication on the handle
    - Thumb – more natural
    - Top and bottom grips
    - Pressure sense instead of capacitive
    - Use buttons instead
    - I always open in the same way, so I will always forget
16. Is the purpose of the light indication and the message that in conveys clear to you?
    - Traffic light – immediately associate
    - After it's been explained
    - Both red lights
    - Amber – 'do not disturb' or add another light
    - Much simpler
    - Green – positive; red – negative; amber – in between
17. Do you think the light indication is helpful for its intended purpose?
    - Time is precious
    - See from distance
    - Well known simple message
    - Takes time to read text
    - Good enough
    - Helpful if you have an office that does not have glass windows
    - Could have a phone or a PC app, so that I don't have to get up
18. Would you prefer seeing just one light, changing its colour, instead of three different lights?
    - Easier with three – more information
    - Bad idea if the light stops working
    - 3 lights – like a traffic light
    - Clearer
    - Colour blind
    - Vertically
    - No difference
19. How would you improve the light indication?
    - No more information
    - Vertical orientation
    - Stronger lights
    - More distinguishable colours
    - Orange much like red
    - Just two colours
    - Eye level

- One more light for 'do not disturb'
- Positioning is important for colour blind people

20. How would you improve the door handle?
    - Indication on the handle
    - Red sensor on the lock
    - Longer
    - Actual door
    - Click up for 'do not disturb'
    - Texture for sensors
21. Can you think of any other types of indication that would be better/clearer for you?
    - Small screen
    - Heat
    - Sounds
    - Amber not needed
    - Vertical
    - Text beside lights
22. Do you have any other comments that you would like to share about the door handle?
    - Test in a building
    - Secure
    - Improve ease of use
    - Staff will feel easier when approaching an executive's office
    - Indicator for every person in an open office

## 17 DEBRIEF

The main aim of the experiment was to test the usability of the smart door handle. However, I was particularly looking to see whether you made use of the three door grips, and whether you were clear about the 'traffic-light'-like indication. I wanted to know how easy the door handle is to use.

Do you have any comments or questions about the experiment? Please take a note of my email address and the email address of my co-ordinator, and please let us know if you have any further questions about this experiment. Thank you for your help.

**Ivan Katzarski:** 2163018K@student.gla.ac.uk

**Dr. Julie R. Williamson:** Julie.Williamson@glasgow.ac.uk

## 18 CLUSTERING

1. Interviewees
    - Finance
    - Project manager
    - Work on sight
    - Shared office
    - Team manager
    - Research assistant (CS)
    - PHD Student (CS)
    - Intern (CS)
    - Systems manager (CS)
    - Commercial team
    - Teacher (CS)
    - Web developer

2. Environment
    - Different companies
    - Smart cards
    - **Open spac**e
    - **Individual offices around**

- **Self-contained**
- Shared office
- Lock the door when I leave
- Office block
- Meeting rooms

3. Reasons for leaving
    - **Lunch**
    - **End of day**
    - **Toilet**
    - Swipe card every time
    - Store
    - Outside
    - Not leaving
    - Meetings
    - Phone calls
    - Infrequently
    - Walk between offices
    - Once a day - meetings

4. People dependent on an interviewee that has left the office
    - People on my team
    - Sometimes
    - Co-workers
    - Emergency - very important
    - When I stay at home
    - Supervisor drops by
    - When I leave work
    - Communicate when out
    - No, knock and see if you are in

5. Types of indication
    - **Out of office e-mail**
    - **Tell them**
    - None - not handy
    - No - no indication, only telling
    - Yes, everyone can see me and my stuff missing; open space
    - **Wheel indicator**
    - Online timetable teaching system
    - **Rotary dial with a pointer**
    - Wheel - poor; useless
    - e-mail - for me yes, for people outside of office - no
    - No system for indication
    - **Note in a diary or white board**
    - Enough
    - Yeah, effective enough
    - Wheel - no, not accurate reflection; have to use it; judgements whether working or not
    - Wheels
    - Phone, e-mail, receptionist
    - Yes, within my team
    - No - it will be useful
    - Works

6. Handles
    - Indicate if someone was in or not
    - **Recognition**
    - **Finger print**
    - Security
    - Touch to lock/unlock
    - **Not familiar**
    - **Notify if inside or not**
    - Fast evacuation
    - **Record in and out**
    - **Key-card system**
    - Don't need a key
    - Locks opening with phone app
    - **Switch appliances automatically**
    - Alert if someone opens your door

7. Problems with handles
    - **Card reader - would not open, jams**
    - Tend to work
    - **Have to pull very hard to lock it**
    - Round circulating doors waste time
    - Always has to be locked - no indication, so I unlock but

someone is in, so I actually lock
- Heavy door - security

- Longer

8. Grips
- **Strongly hold**
- **Full hand**
- Other body parts when hands busy
- **Push**
- Just a finger when full hands
- **Elbow**
- Thumb
- Open quietly
- Leg
- Right hand
- **Open hand**

- Couple of fingers
- Put foot down for support - back problems
- Forearm
- **Push**
- Ready
- Upside down - click
- **Full hand**
- Thumb
- Always full grip
- Thumb - more natural

9. Problems with grips
- **Agree with green - natural**
- **One finger - hard for small person when door heavy**
- Instructions
- Have to change how I open a door - not user friendly
- Natural
- **Time to remember**
- Most pressure at first part; red is awkward
- Forget to use them
- Hands too big - will touch two parts at once
- **Easy after you explain it**

- Orange is something I might use
- Unnatural
- **Effort to remember - will forget**
- Always open in the same way, so I will always forget
- Red - not comfortable
- Straight forward
- Red and orange are quite similar - confusing
- Confusing
- Secure

10. Solutions to grips
- Pressure sense instead of capacitive
- Swap yellow and green
- **Indication on door handle**
- Top and bottom grips
- **Use buttons instead**

- Texture for sensors
- Red sensor on the lock
- Actual door
- Test in a building

11. Lights
- Traffic light - immediately associate
- Green - positive; red - negative; orange - in between
- Time is precious
- See from distance
- Much simpler
- **Amber as 'do not disturb' or another light**

- Could have a phone or PC app, so that I don't have to get up
- **No difference**
- Well known simple message
- Good enough
- Helpful if you have an office that does not have glass windows
- Easier with three - more info

- 3 lights - like traffic light
- Clearer
- No more information

12. Problems with lights
    - Stronger lights
    - More distinguishable colours
    - Takes time to read text
    - Improve ease of use
    - Orange - much like red
    - Both red lights
    - Colour blind
    - Vertically
    - Eye level
    - Positioning is important for colour blind people
    - **After it's been explained**
    - **Vertical orientation**
    - Bad idea if the light not working
    - Vertical
13. Solutions to lights
    - Heat
    - Staff will feel easier when approaching an executive's office
    - Amber not needed
    - Click up for 'do not disturb'
    - Just two colours
    - One more light for 'do not disturb'
    - **Text beside lights**
    - **Small screen**
    - **Indication on the handle**
    - Sounds
    - Indicator for every person in an open office

# Appendix C Evaluation Questionnaire

## 19 INTRODUCTION

The aim of the experiment is to test the usability of and the need for a smart door handle. As to identify the usefulness of such a system, we ought to run experiments like this one. They would also help us in improving the comfort the door handle would bring to its users. Firstly, I will show you the prototype and explain how it works. Then I am going to ask you to perform several tasks and to answer a few questions. I will video record your hand when performing the experiment. I will use the data only for analysis in regards to this project. I will also observe you while you perform the tasks. Please ask questions if you need to.

Please remember that it is the door handle, not you, that is being evaluated. You are welcome to withdraw from the experiment at any time without giving any reasons. Do you agree to take part in this evaluation? Do you have any questions before we start?

## 110 TESTING THE GRIPS

- The tasks were in a random order for every participant.
- Each task was performed 3 times by every participant.
- Three values were recorded for each task: the grip the participant used, the light that appeared on traffic light indication and the time it took a participant to perform the task (in seconds).

1. Perform the green grip.
   - Grip – 100% full grip
   - Light – 100% green light
   - Time – 80% 1 sec; 20% 2 sec
2. Perform the green grip.
   - Grip – 100% full grip
   - Light – 90% green light; 10% amber light
   - Time – 100% 1 sec
3. Perform the green grip.
   - Grip – 100% full grip
   - Light – 100% green light
   - Time – 70% 1 sec; 20% 2 sec; 10% 3 sec
4. Perform the amber grip.
   - Grip – 100% grip with thumb
   - Light – 100% amber light
   - Time – 80% 1 sec; 20% 2 sec
5. Perform the amber grip.
   - Grip – 100% grip with thumb
   - Light – 20% green light; 80% amber light
   - Time – 70% 1 sec; 30% 2 sec
6. Perform the amber grip.
   - Grip – 10% full grip; 90% grip with thumb
   - Light – 100 amber light
   - Time – 90% 1 sec; 10% 3 sec

7. Perform the red grip.
   - Grip – 100% finger on the lock
   - Light – 20% amber light; 80% red light
   - Time – 30% 1 sec; 40% 2 sec; 20% 3 sec; 10% 5 sec
8. Perform the red grip.
   - Grip – 100% finger on the lock
   - Light – 100% red light
   - Time – 80% 1 sec; 20% 2 sec
9. Perform the red grip.
   - Grip – 100% finger on the lock
   - Light – 10% green light; 90% red light
   - Time – 40% 1 sec; 20% 2 sec; 30% 3 sec; 10% 6 sec

## 111 NASA TLX GREEN, AMBER, RED

- The NASA TLX questions were always in the same order in each questionnaire (one for the green, one for the amber, and one for the red grip). Only the answers for question 7 were always randomised.
- A TLX questionnaire was given to every participant for each type of grip.
- The order of the TLX questionnaires was random for every participant.
- Every participant had to choose an answer on a scale from 1 to 20 for questions 1 to 6. 1 means Low and 20 is High. In question 4, 1 is Good and 20 is Poor.

1. Mental Demand: How mentally demanding was the task?
2. Physical Demand: How physically demanding was the task?
3. Temporal Demand: How hurried or rushed was the pace of the task?
4. Performance: How successful were you in performing what you were asked to do?
5. Effort: How hard did you have to work to accomplish your level of performance?
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?
7. Choose the scale which you think is the more important contributor to the workload of the task:
   - Temporal Demand or Effort
   - Physical Demand or Frustration
   - Physical Demand or Temporal Demand
   - Frustration or Mental Demand
   - Frustration or Effort
   - Effort or Physical Demand
   - Performance or Frustration
   - Physical Demand or Performance
   - Temporal Demand or Frustration
   - Effort or Performance
   - Mental Demand or Physical Demand
   - Mental Demand or Effort
   - Temporal Demand or Mental Demand
   - Performance or Mental Demand
   - Performance or Temporal Demand

## 112 COMMENTS ON THE GRIPS

1. Do you have any comments on the green grip?
   - Easy to choose. Feel natural.
   - Awesome.
   - It is natural, it doesn't require any elaborate thought to guess how to unlock the door, so that's good.
   - Works perfectly fine.
   - This one worked fine.
   - It would have been nice that instead of grips there was a button panel of some sort because it was confusing for me that controls were on the door handle.
2. Do you have any comments on the amber grip?
   - Need one more movement than green, it makes a lot of sense. It sometime goes back to green when removing my hand.
   - Had to be careful to not activate the green grip after the amber grip.
   - I find a tiny little bit "confusing" that keeping the hand on the green sensor does not stop from turning the amber light on when touching the yellow sensor; and at the same time, if one doesn't pay attention and puts their thumb on the yellow sensor while trying to unlock the door, then it will not work and that might be a bit frustrating (or if someone has a MASSIVE hand).
   - Little confusion, whether i can also touch the green part if I want it to go amber.
   - Need thinking a bit.
   - Sometimes it can cause issues and switch to the green grip.
3. Do you have any comments on the red grip?
   - Demands a bit more effort because the movement is less natural than the others. But it goes well with the idea that you are going to be away for a while.
   - It was a bit uncomfortable because the door wasn't fixed in place so moved back when you used the red grip.
   - If keeping the hand on the green sensor while touching the yellow sensor turns the amber light on, why isn't it the same when touching the red sensor while having the hand on the green one? I actually think that it is better not to be able to lock the door while the hand is on the green sensor, and for consistency, I would make it the same for the yellow sensor, or the other way around.
   - Red grip is more like a button than the other two which are grips. Although all are equal in usability.
   - The training door gave way to light push which made it a bit more difficult to push it.
   - had to press twice on one occasion to make it light
   - If the door's position fixed, that's easier to finish the tasks.
   - That was easy but the door was a bit flimsy so I had to be very gentle when pressing the button.

## 113 DEBRIEF

The main aim of the experiment was to test the usability of the smart door handle. However, I was particularly looking to see whether you made use of the three door grips and whether the light indication was responding properly. I wanted to know how easy the door handle is to use.

Do you have any comments or questions about the experiment? Please take a note of my email address and the email address of my co-ordinator, and please let us know if you have any further questions about this experiment. Thank you for your help.

**Ivan Katzarski:** 2163018K@student.gla.ac.uk

**Dr. Julie R. Williamson:** Julie.Williamson@glasgow.ac.uk

1. Comments.
    - Except for the slight issue where it goes back to green when removing the hand after selecting orange, the user experience was good. The design is solid and makes a lot of sense.
    - Overall I think it was pretty easy to use and seemed to work very well. Really cool.
    - It looks like a very interesting project to work on. It looks simple but well thought and well done. (For aesthetic reasons, is it possible to move the grey wire so that it is invisible to the user?)
    - I thought the system was very usable and responded correctly every time
    - da best
    - This was a cool experiment! :)
    - maybe you can add a speaker to tell the visitor the owner is not here and a mic so they leave a message as well.

# Appendix D  Code for Prototype 2

```
#include <CapacitiveSensor.h>     // Capacitive Sense library.

/*
 * 3 CAPACITIVE SENSORS CONTROLLING 3 LEDs.
 * Using capacitive touch to switch between 3 LEDs.
 * Uses 1M resistors between the send pin (2) and the receive/sensor (3, 5, and 7)
   pins.
 * The 1M resistor requires absolute touch to activate. Larger resistor values yield
   larger sensor values.
 */


// Variables:
const int RED_LED = 13;       // The number of the RED_LED pin.
const int AMBER_LED = 11;     // The number of the AMBER_LED pin.
const int GREEN_LED = 9;      // The number of the GREEN_LED pin.
const int THRESHOLD = 150;    // The minimum value a sensor needs to reach to turn an
                              // LED on.

CapacitiveSensor cs_2_3 = CapacitiveSensor(2,3);  // 1M resistor between pins 2 & 3,
                                                  // pin 3 is sensor/receive pin.
CapacitiveSensor cs_2_5 = CapacitiveSensor(2,5);  // 1M resistor between pins 2 & 5,
                                                  // pin 5 is sensor/receive pin.
CapacitiveSensor cs_2_7 = CapacitiveSensor(2,7);  // 1M resistor between pins 2 & 7,
                                                  // pin 7 is sensor/receive pin.

void setup()
{
   Serial.begin(9600);      // Starts a serial port needed for the communication
                            // between the Arduino and the computer.

   pinMode(RED_LED, OUTPUT);        // Set digital pin 13 as OUTPUT.
   pinMode(AMBER_LED, OUTPUT);      // Set digital pin 11 as OUTPUT.
   pinMode(GREEN_LED, OUTPUT);      // Set digital pin 9 as OUTPUT.
}

void loop()
{
    long start = millis();  // Keeps track of the lowest (baseline) capacitance.

   // The three longs contain the sensed capacitance when a sensor has been
   // touched. The capacitance is in arbitrary units. The value in the brackets
   // (30) is in bytes and it adjusts the sensitivity of the sensor.
    long greenSensor = cs_2_3.capacitiveSensor(30);
    long amberSensor = cs_2_5.capacitiveSensor(30);
    long redSensor = cs_2_7.capacitiveSensor(30);

    // All data is printed on the Serial Monitor.
    Serial.print(millis() - start);     // Check on performance in milliseconds.
    Serial.print("\t");                 // Tab character for debug windown spacing.

    Serial.print(greenSensor);          // Print the output of the greenSensor.
    Serial.print("\t");                 // Print space.
    Serial.print(amberSensor);          // Print the output of the amberSensor.
    Serial.print("\t");                 // Print space.
    Serial.println(redSensor);          // Print the output of the redSensor.


    if (amberSensor > THRESHOLD) {      // If amberSENSOR is higher than the minimum
      digitalWrite(RED_LED, LOW);       // value (THRESHOLD), only the AMBER_LED will
      digitalWrite(GREEN_LED, LOW);     // light up.
```

```
      digitalWrite(AMBER_LED, HIGH);
    } else if (greenSensor > THRESHOLD) {     // If greenSensor is higher than the
      digitalWrite(RED_LED, LOW);             // minimum value, only the GREEN_LED
      digitalWrite(AMBER_LED, LOW);           // will light up.
      digitalWrite(GREEN_LED, HIGH);
    } else if (redSensor > THRESHOLD) {       // If redSensor is higher than the
      digitalWrite(AMBER_LED, LOW);           // minimum value, only the RED_LED
      digitalWrite(GREEN_LED, LOW);           // will light up.
      digitalWrite(RED_LED, HIGH);
    }

    delay(500);    // Arbitrary delay to limit data to serial port.
}
```

# Appendix E Project Log

**WEEK 1**

- Improving knowledge of basic electronics - Basics: Ohm's law, electronic components, resistors, circuits, breadboards.
- Enhance understanding of capacitive touch technologies.

**WEEK 2**

- Improving knowledge of basic electronics - measuring current and voltage and multi-meters.
- Creating the first Arduino Sketches.
- Finding examples of capacitive touch technologies already in use.

**WEEK 3**

- Improving knowledge of basic electronics - capacitors.
- Creating the first Arduino Sketch using capacitive touch and the Arduino Capacitive Touch Library.
- Deciding on a project environment - closed environment.
- Generating 10 examples of possible capacitive touch implementations.

**WEEK 4**

- Improving knowledge of basic electronics - integrated circuits, oscillator, filters, and LEDs.
- Choosing an idea (a chair sensing the correct sitting posture) and realising a mistake - the idea requires pressure sensing, not capacitive touch.
- Choosing a more specific project environment - the office space.
- Choosing an idea - creating a door handle which could sense how a user is touching it.

**WEEK 5**

- Improving knowledge of basic electronics - diodes.
- Finding examples similar to the chosen idea; they could be the basis for comparisons in the evaluation and conclusion.
- Creating the first sample prototype which uses only one point of touch and the already created Arduino Sketch.
- Deciding that there could be two points of touch; touching just one would result in locking the door and turning on an orange LED (BACK SOON); touching both of them would result in locking the door and turning on a red LED (OUT); touching any of them after any of the previous two cases would unlock the door and turn on a green LED (AVAILABLE).
- A questionnaire has to be prepared to find out how the user feels about the different parts of the project.

**WEEK 6**

- Improving knowledge of basic electronics - Transistors.

- The questionnaire is finished and approved.
- Changing the light indication. Touching the sensor on the outer part of the door handle would result in an orange light. Touching the sensor on the inner part of the door handle would turn on the red light. Touching both sensors would turn on the green light.
- First prototype ready - no interactive components installed yet.
- First prototype ready - with interactive sensors.

**WEEK 7**

- Improving knowledge of basic electronics - more on integrated circuits.
- Interviews have been started. They would be recorded and the data would be used in Grounded Theory.
- 10 interviews have been completed and audio recorded.

**WEEK 8**

- 10 interviews have been transcribed.
- The interviews have been coded and the key words have been grouped according to Grounded Theory.

**WEEK 9**

- The key words from the previous week have been regrouped two more times.
- The evaluation questionnaire has been prepared using NASA TLX.
- Door handle improvements have been made (3 indicators used now; the lights have been modified to simulate an actual traffic light).

**WEEK 10**

- 10 surveys have been completed.
- The hands of the interviewees have been video recorded.
- The data has been gathered using Survey Monkey.
- A synopsis of the dissertation has been prepared and approved.

**WEEK 11**

- Writing the dissertation.

**WEEK 12**

- Writing the dissertation.

**WEEK 13**

- Submission.

# Appendix F Ethics

**School of Computing Science**

**University of Glasgow**

## Ethics checklist for 3rd year, 4th year, MSci, MRes, and taught MSc projects

*This form is only applicable for projects that use other people ('participants') for the collection of information, typically in getting comments about a system or a system design, getting information about how a system could be used, or evaluating a working system.*

***If no other people have been involved in the collection of information, then you do not need to complete this form.***

*If your evaluation does not comply with any one or more of the points below, please submit an ethics approval form to the Department Ethics Committee.*

*If your evaluation does comply with all the points below, please sign this form and submit it with your project.*

---

1. Participants were not exposed to any risks greater than those encountered in their normal working life.

   *Investigators have a responsibility to protect participants from physical and mental harm during the investigation. The risk of harm must be no greater than in ordinary life. Areas of potential risk that require ethical approval include, but are not limited to, investigations that occur outside usual laboratory areas, or that require participant mobility (e.g. walking, running, use of public transport), unusual or repetitive activity or movement, that use sensory deprivation (e.g. ear plugs or blindfolds), bright or flashing lights, loud or disorienting noises, smell, taste, vibration, or force feedback*

2. The experimental materials were paper-based, or comprised software running on standard hardware.

   *Participants should not be exposed to any risks associated with the use of non-standard equipment: anything other than pen-and-paper, standard PCs, mobile phones, and PDAs is considered non-standard.*

3. All participants explicitly stated that they agreed to take part, and that their data could be used in the project.

*If the results of the evaluation are likely to be used beyond the term of the project (for example, the software is to be deployed, or the data is to be published), then signed consent is necessary. A separate consent form should be signed by each participant.*

*Otherwise, verbal consent is sufficient, and should be explicitly requested in the introductory script.*

4. No incentives were offered to the participants.

    *The payment of participants must not be used to induce them to risk harm beyond that which they risk without payment in their normal lifestyle.*

5. No information about the evaluation or materials was intentionally withheld from the participants.

    *Withholding information or misleading participants is unacceptable if participants are likely to object or show unease when debriefed.*

6. No participant was under the age of 16.

    *Parental consent is required for participants under the age of 16.*

7. No participant has an impairment that may limit their understanding or communication.

    *Additional consent is required for participants with impairments.*

8. Neither I nor my supervisor is in a position of authority or influence over any of the participants.

    *A position of authority or influence over any participant must not be allowed to pressurise participants to take part in, or remain in, any experiment.*

9. All participants were informed that they could withdraw at any time.

    *All participants have the right to withdraw at any time during the investigation. They should be told this in the introductory script.*

10. All participants have been informed of my contact details.

    *All participants must be able to contact the investigator after the investigation. They should be given the details of both student and module co-ordinator or supervisor as part of the debriefing.*

11. The evaluation was discussed with all the participants at the end of the session, and all participants had the opportunity to ask questions.

    *The student must provide the participants with sufficient information in the debriefing to enable them to understand the nature of the investigation.*

12. All the data collected from the participants is stored in an anonymous form.

    *All participant data (hard-copy and soft-copy) should be stored securely, and in anonymous form.*

---

**Project title:** Capacitive Touch in Interactive Systems

**Student's Name:** Ivan Katzarski

**Student's Registration Number:** 2163018K

**Student's Signature:** Ivan Katzarski

**Supervisor's Signature:** Julie R. Williamson

**Date:** 19/07/2015