Energy Consumption and Light Interference Study for the Concept Smart Mirror

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Abstract

This thesis deals with the study of how the Smart Mirror fares compared to other information oriented devices in three areas: Energy consumption, light interference from the mirror foils and general performance of the computer system. The development of Smart Mirrors has mainly been focused on usability, whilst research in performance and light interference is lacking. The project, contains composing and building a Smart Mirror which is the system all testing is performed on.

The start of the thesis focuses on hardware and what choices that are possible to later describe why the mirror is designed the way as it is. It also explains the general structure of the program running the Smart Mirror and how it was built up. The programming structure shows one possible way to control the mirror and what possibilities this structure can lead to, but does not directly affect the later.

The result is derived from measuring energy in Watt (W) with an energy meter and light interference in illumination with a lux meter. When it comes to the light interference tests, they mainly focus on the Smart Mirror image and viewing capabilities in a completely dark room and an illuminated room to see how the background lighting disrupts the image brightness and instead goes over to use its reflecting capabilities.

The outcome of the project is that the Smart Mirrors greatest obstacle to truly be a commercial device is the lower image brightness derived from the coating material. The coating material is also one of the essential components as it otherwise looses its mirroring capabilities and thus does not work as a mirror. This is also the lead cause to the high energy consumption that puts the Smart Mirror well above the normal TV and also high-performance computers.

Popular Science Summary

One object that we face daily both in the homes, offices and in public space is the mirror. This arbitrary nonelectrical object takes up a large area, is used for only one purpose and is used usually while the individual is occupied with another task. People also tend to spend some time in front of it at the beginning and end of each day and also in short lapses in between. This would be a perfect place where to provide with information and interaction possibilities for that the day.

The concept that will be looked in to in this thesis is the Smart Mirror. It is a potentially good new platform, relatively unexploited and has a large variety of usage. It fit the profile for companies, personal use and, is yet not fully developed and does not have a large market base. The concept has been seen mostly in science-fiction movies but the technology for it already exists in other common devices, just not put together behind a mirror. It is a large possibility that this will be part of the near future and also the main reason for this thesis as this product still have parts that need to be researched and studied.

This device has the possibility to change how we receive information on a daily basis and also variations of the Smart Mirror can be implemented in a variety of stores and business areas. For example, it can occupy the store window and let by-passers interact and see what the store has to offer. Or be displayed in the store to be integrated into to the exterior as a normal mirror.

As this technology is on the rise and it can be applied in many different forms the biggest concern is the economic perspective and how well it performs compared to other devices. With flatter and cheaper screens or projection methods, the reality of the Smart Mirror is closer to be part of the society and probably something that will appear in just a few years. Some examples as the fitting room Smart Mirror by Oak Labs [33] or the smart shopping example at Heathrow Airport [34] is just indicators that this technology will try to find its place in society.

But to begin implementing the Smart Mirror it is important to have information about its performance and what obstacles it may approach along the way. Therefore this project conducts a study of energy consumption and light interference through the mirror glass for an affordable price to help be a base for further development in the area and also to pinpoint what in the hardware of the device that has to be improved.

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List of Acronyms

RPI	Raspberry Pi
LED	Light Emitting Diode
LCD	Liquid-Crystal Display
PCT	Projected Capacitance Technology
SCT	Surface Capacitance Technology
ITO	Indium-Tin Oxide
IR	Infrared
SBC	Single Board Computer
IO	Input Output
IRED	Infrared Diode
CPU	Central Processing Unit
GPU	Graphical Processing Unit
UWP	Universal Windows Platform
UWA	Universal Windows Application
XAML	Extensible Application Markup Language
WPF	Windows Presentation Foundation
API	Application Programming Interface
IoT	Internet of Things

Chapter 1

Introduction

Smart Mirror is a concept of using a mirror and making it do something more. It is intended to provide information to the user and while not in use blend into the environment. The technologies the product consists of are not revolutionary and have been around for some time, but this information age creates new possibilities for companies to bring information to the user. Together with the idea of IoT, the development of smart things are on the rise and the Smart Mirror is just one step on the way to the Smart Home. Therefore it becomes interesting to know how well the idea and concept fare in screening capabilities and energy consumption compared to other information channels, such as the computer, TV and digitalized kiosks that exist today.

1.1 Background for Thesis

This project was founded and started up with the help of the company Sitting In True Style AB (SITS) which is in the supplier market for furniture toward Swedish retailers. Today this market face a hard challenge to modernize as people buy furniture basically the same way as for 40-50 years ago but the demand for new interesting and fresh ways to brand and show the products is increasing. The most common way to show information about the merchandise in a store is still by paper catalogs and pamphlets in a time where everything is digitized [1].

Therefore SITS want to provide a new digitalized way to get information about the products to the customers. The product must be integrated into to the living room style and be something that does not take up too much space. It also has to have the ability to give information on demand and be a tool when virtually building the living room. By introducing the Smart Mirror to the stores the designated platform could easily be created, hidden in the exterior, and also function as a decoration while not in use. As the Smart Mirror concept is relatively new and does not have a customer or manufacturer base, the option to bring this technology towards a nontechnological business branch can be revolutionary.

1.2 Motivation and Concept

The intriguing concept of Smart Mirror can have a huge impact on how and where we receive information and not only as a marketing tool for companies. It can also be an interactive tool for the Smart Home to control and display information about the house itself and or be a news and connection platform in the home. The interaction possibilities are today mostly obstructed by programming capabilities as the hardware already exist in forms of thin monitors, see through mirror glass, small compact processors, touch and audio receiving technologies [2].

The biggest trend that can be seen today for Smart Mirrors is the change of the concept. As the research in Artificial Intelligence, monitoring systems and computer science evolve and the computers and screens get smaller and flatter the realization of a talking and/or interactive mirror are on the reach [7]. Hobbyists around the world have experimented with this concept for a time [10] and in later years the interest have reached companies that are creating versions of this display system. The company Mirrus is one that already has mirrors in production but those are merely used as display systems white out interaction [9]. It is also possible to buy versions of interactive smart mirrors through pre-ordering custom build systems and even some large company like Samsung have a version of their own [8].

The Smart Mirror label have however been around for some time. It has been used for various products and research areas from self-dimming mirrors, self-cleaning mirrors or protection coated mirrors. Today it is more on track with monitoring systems and digitalized evolved mirrors but historically any mirror with any function beyond reflecting light could be called a Smart Mirror [7]. To be able to compare this product to other devices a clear distinct definition has to be made. Even if there is no consensus or protected terminology around the Smart Mirror, the sake of this thesis the definition is set to the following:

A Smart Mirror is:

> A semi transparent and reflective surface with a monitor behind for screening. The device contains one or multiple interactive tools of the following kind: Touch control, display buttons (i.e. not remote control), audio control, voice control or gesticulates control. The mirror has to have some kind of processor and must be able to connect with the internet and/or have the ability for wireless connection to other devices.

This thesis deals with the concept of the Smart Mirror and looks on how this technology fares against other existing information channels like the computer, TV and digitalized kiosk. This will be looked in to in three categories which are energy consumption, screening possibilities, and general hardware performance. As Smart Mirrors are still in the development stage for most companies and that SITS wants to brand out with their own platform, this thesis also contains the building and development of the product. The main focus is on the hardware performance but also takes a look at software and program options.

Chapter 2

Project Goals and Main Challenges

2.1 Aim and Goal

This project aims to build a Smart Mirror out of existing components and hardware to an affordable price. The budget is 4000 SEK which will be part of the consideration when deciding upon hardware. Then programming a simple interface to show what can be achieved and also make the prototype operational. Thereafter conduct a study focusing on energy consumption and screening visibility to later be compared towards already existing information devices. The ultimate goal is to see if this prototype can be a platform for the company SITS to be used in their marketing. Because of the size of the budget, the final prototype will merely be a tool and template for future generations and therefore some quality limitations are allowed.

2.2 Questions

1. **How much energy does the Smart Mirror consume in Watts and what are the energy drivers of the system?**
2. **What is the light transparency, and reflectively of the Smart Mirror?**
3. **How well does the Smart Mirror system fare compared to other information channels in terms of energy and display efficiency?**

2.3 Main Challenges

This project faces three big challenges. The first one is the choice of hardware and program language. As this choice will set the direction of the whole prototype and also be reflected in the study result and end product. As the budget is only 4000 SEK it also determines what can be possible and hard to change choices that have been made. As the composition of hardware can be made in different ways the pre-work is utmost important.

The second challenge will be to build the prototype. Even when all hardware is fully compatible there will always be obstacles when using hardware from different manufacturers and make everything run smoothly. As mentioned in the first challenge the budget prohibits too much leeway.

The third challenge will be when conducting the study itself. Especially for measuring the transparency of the screen as it depends on different variables and also the environment the study is conducted in. The detection of the reflectiveness and transparency also changes depending on where the mirror is faced and how bright the light source is compared to the mirror.

Chapter 3

The Theory behind the Smart Mirror

This chapter focus on the theory behind the systems used in the Smart Mirror. It features Prior Work, Touch Technologies, Hardware, Software and Information for Energy Consumption. The section Prior Work look more on what devices have been created and studies conducted, in the field, prior to this thesis. Touch Technologies explain what different alternatives exist for touch technology and how they work. That is the base for what technology is used in the product. Hardware does go through the rest of the components used in the prototype like the computer, screen, and further components. The Software section shortly explains the different languages used and what special functions the platform can provide to the prototype.

The Information for Energy Consumption will be the base for the Energy study. It will list other devices and the energy performance of those to later be compared with this Smart Mirror prototype. The devices will be of three segments that exist today: Computers, Tv-Screens and Kiosks.

3.1 Prior Work and Scientific Basis

This section will handle both what commercially exists today on the market and also scientific basis and prior work. As the idea of Smart Mirror or Magic Mirror dates back to 1806 when mentioned in the Grim brother's saga Snow White and the Seven Dwarfs [6] people have had the idea to make the mirror do more and be intelligent. Some of the mirror inventions and the product do not fit the thesis concept of Smart Mirror as mentioned earlier but still is important for the development history. The section will also view the Kiosk system as it does relate to the Smart Mirror with similar interaction methods and display technology.

3.1.1 Devices on the Market

A device that has been on the market for some time and does share a lot of features with the Smart Mirror is the digitalized kiosk. It is mainly bought and used as a marketing tool in and outside of business stores and has also for some products interactive tools such as touch and speakers. The billboard type does have a slightly different purpose as it mainly screens advertisements and the information desk is more designed towards interactiveness to relay information such as map location [48] and store information. However, the kiosk model is limited and does not blend into the environment.

There do exist some Smart Mirror devices on the market. It is mainly for the house hold and private usage or for a very specified purpose only giving and operating around the specified information. One example is the Ralph Lauren dressing room mirror where the costumer can see other clothing items and accessories that fit the tested items [49]. The existing platforms are either specified information flow going to the digitalized kiosk model or specified towards flexibility and customization for interactive personal usage.

3.1.2 Scientific Basis

The most studies done in this area has been focused on how the Smart Mirror can help people and in what areas the touch screen could be applied. The scientific work is more on design level and investigation of usability and possibilities for the concept. Information about performance and how the problem with light interference from background light sources has not been found. This concept lacks that kind of studies or if they do exist it is under cooperate umbrellas for self-interest.

3.2 Touch Technology

The touch technology has been around since the year 1965 and was developed at Cern, Schweiz. It is an input output device for communication with a computer, controlled by human touch where the user touch the surface at a certain coordinate on the screen and the controller will register that input [12]. During the 21-century the touch screen was starting to gain popularity and was adopted to many products. The first gaming product was the Nintendo DC in 2004 [13] and later on when Apple launched the product iPhone 3G [14][?] with multi touch system and after that the market grows rapidly. Today the touch technology is standard in tablets, mobile phones and also available for some computer screens[17]. Also most of the touch technology pattens where filed in 1970:s and 1980:s and thus have expired to be freely used by various developers .

This technology can be simplified as a grid that will detect when it comes in contact with human tissue or somtimes a stylus. More importantly, the grid can sense where it has been touched and send this information to a controller. The key attribute for the touch-screen is to interact directly with the screen instead of indirectly with a mouse and keyboard. Today the touch-screen can sense multiple objects and in some cases even sense how hard it is being pressed [17]. The different touch technologies are listed below.

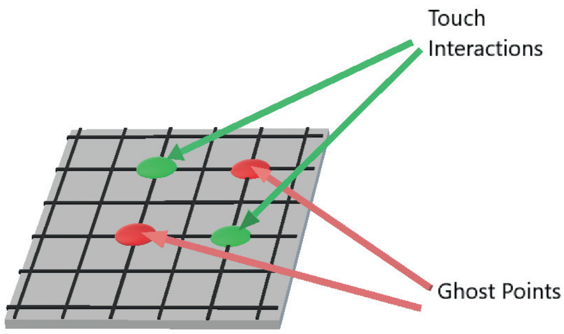
- Capacitive Touch-screen Technology
  - Surface Capacitance Technology
  - Projected Capacitance Technology
- Resistive Touch-screen technology

- Surface-Acoustic Technology
- Infra-red Touch-screen Technology

3.2.1 Ghost Points

Ghost points is a very important concept when talking about touch panels. It occurs when multiple touch inputs are detected by a grid as each input creates a touch shadow between the receiver and the transmitter. Therefore as figure 3.1 shows the two inputs marked with green check sign creates two ghost points and the controller can not decide which coordinates that is actually the real inputs.

Figure 3.1: Ghost Point occurrence



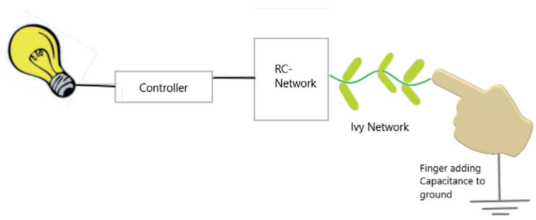
This is because both the two correct inputs give the same output to the receivers as the two ghost points and without a technique to counter this manifestation the panel must only allow a single input interface. The problem exists in all different touch technologies and each developer tackles the problem in different ways.

The method to eradicate the ghost points is called scanning and depending on which technology is used and the grid size, this scanning process varies. The basic idea is to look at each line of emitters and receivers one at the time and then measure the result with the opt (Zero Point) matrix. This is a matrix filled with no input entries and depending on how far from the receivers the intersection occurs it will give different results compared to the opt matrix [17].

By doing this way each input entry will have a designated fingerprint. This will create another problem as when the grid gets larger it requires more coordinates thus more transmitters and receivers which will lead to a more time-consuming scanning process. This is a large issue as the response time for a touch screen is vital and this is something to consider when choosing the technique. How the measurement is done and the consequences of different touch techniques are described in each section below.

3.2.2 Capacitive Touch

Figure 3.2: The lamp and plant figure example

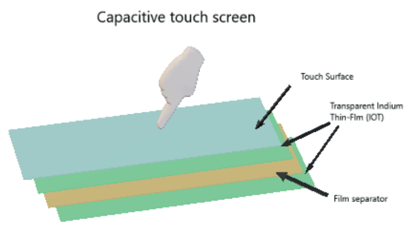


The capacitance sensing is the oldest method of using touch-screens [12] and was used a long time before the touch screen was invented. Due to the fact that the human body is an electrical conductor and when in contact or close enough to an electrical current it will interact and become a capacitor. One old and popular examples of how this method works is the lamp and plant example.

This is where a lamp connected up to a battery can be switched on with capacitance touch by holding a twig towards the touch area. The small current that flows through the touch panel gets distorted and detected by the micro controller that then redirect a bigger current through the lamp. This method is called self-capacitance where a single electrode senses the change to respect to ground. When an another capacitance, such as the human body, is near, the capacitance of the electrode will change and this change is what the micro controller detects.

Both version of capacitive touch, SCT and PCT, use the fact that the human body is a capacitance. It is created by sandwiching one isolating film between two conductors planes made of a glass substrate or plastic. The thin film separator is usually made of a thin non-conductive plastic sheet coating and the conductor planes are made from high conductive low resistance material, usually indium tin oxide (ITO) [16]. The ITO alloy is used because it has both high conductivity and high transparency which can be up to 90 %. The material only requires a thin layer and the latest conductor threads are only 10 microns thick. This alloy is printed out on the conductor plate as threads in a designated pattern. The pattern varies from manufacturers but has either an interlocking or row-based grid [18].

Figure 3.3: Capacitive touch layers



The touch surface can be of any material that is nonconductive and thin enough. The thickness varies from manufacturers but usually works up to the range of 10-12 mm. The thicker the glass the higher the voltage requirements. The reason touch panels have such high voltage is to limit power consumption and minimize the interaction from close by electrical components as a monitor screen. The touch surface is also usually bought separate from the touch screen and the installation is usually done by gluing the surface to the panel. As the touch panel is made of thin plastic and glass substrate, it is bendable and therefore does not need a flat surface. This is a huge advantage as many surfaces can easily be turned in to a touch area.

Scanning methods

The scanning method for capacitive touch consists of two kinds. The first one is Self Capacitance and is the simplest version of scanning. This technology can only recognize multiple touches on rows and columns but diagonally inputs are illegal because there is no way to eliminate the ghost points. This is a cheaper alternative and is usually used for small touch button panels like the one at the frames of a TV-screen. The reason for this is the grid pattern which is not interlocking and each electrode is scanned individually. This method is used with usually only one conductor plane and does not need an advanced micro controller which are the main cost drivers.

The second method is called Mutual Capacitance. It uses interlocking patterns in the ITO threading and when scanned it scans the electrode intersection instead of each electrode individually. This will allow multitouch in all directions and the limit of inputs is set to the controller and number of lines. The interlocking grid is built up through putting each conductor plane orthogonal to one another and measuring the difference in the electrode intersection when scanning [16].

Surface Capacitance Technology

The Surface Capacitance Technology does use the Self Capacitance scanning method. There are some touch panels with this technology but mostly used, as mentioned earlier in this section, in small button touch panels. The durability is higher than PCT but the resolution is limited. It is prone to giving ghost inputs which calls for calibration during the manufacturing. The main reason for using this technology is the price as it has fewer components, smaller controller and cheaper manufacturing [17].

Advantages:

- High resistance to touch surface contamination
- Scratch resistance
- Non image distortion from LCD and monitors
- Can be applied on curved surface

Disadvantages:

- Require bare skin or special gloves
- Can not trace ghostpoints
- Sensitive for Electro-Magnetic Interference
- Dust and grease can cause malfunction

Projected Capacitance Technology

The PCT uses mutual capacitance and thus also intersecting grids. The most common are the interlocking diamond pattern with one horizontal diamond row on one conductor plate and vertical on the other. The size usually is in the range of 4-8 mm. The biggest cost driver for this technology is the boarder layer as each row and column must be connected to the controller by its self. This can be around 40 or more connector lines each around 1 mm thick. This requires more ITO material and more cost and time-consuming manufacturing method compared to Surface capacitance that uses fewer lines and less intricate patterns. The purpose of the pattering and not using single line grids is to increase the sensor area and in that way increasing the resolution [16].

Advantages:

- High resolution and image clarity
- High resistance to touch surface contamination
- Scratch resistance
- Can be applied on curved surface

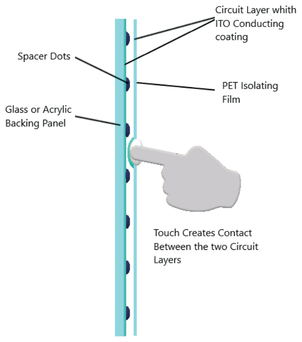
Disadvantages:

- Require bare skin or special gloves
- Sensitive for Electro-Magnetic Interference
- More costly then Surface Capacitance technology

3.2.3 Resistive Touch

The Resistive Touch technology consists basically of two electrically conductive panels with a small gap between them. When the touch surface is pressed the two layers will be pushed together and create an electric current from one panel to the other. The two panels are made of glass or plastic material and coated with ITO alloy threads. The two coated sides face one another and the gap between is made by adding small transparent insulation spacers. These, known as spacer dots, can be pushed together when a force is applied so the conductive panels will be able to get in contact of another [17].

Figure 3.4: Resistive Touch interaction



One layer of the conductive panels will have the x-coordinates wires and the other the y-coordinate wires. When they are pushed together the two x and y threads will come in contact and depend on where on the panel this appeared the voltage will vary. By this way, a precise location of the touch will be able to be calculated by the controller.

Due to the fact that this technology use force to recognize the inputs all kinds of pointing devices can be used. Does not matter if the user has gloves, styluses or other object and therefore it works in many different environments. The screen can also have dust, water and grease on it without interfering with the input control. But this also makes the panel unavailable for subtle touch as the force must be great enough for the two conductive panels to meet.

The Resistive Touch technology can detect a small number of multiple inputs. But if more than one input uses the same x-y-coordinate there is no way to scan for ghost points. The current always take the shortest path between the x-y threads and thus there is no way to get the voltage information from the second input. This limit this technology and therefore is usually used for smaller less advanced touch panels. It still has around 26 % of the market but is mainly used in ATMs, ticket booths, credit card machines and other similar machines.

One other disadvantage the Resistive touch have is the use of multiple layers. As each layer does not have 100 % transparency, the more layers the product use the less light can shine through. This leaves this kind of touch panels around 80 % transparency which can be a problem when the developer focus on higher screen resolution [20].

Advantages:

- Cheap technology
- Respond to any kind of input device
- Reliable and accurate

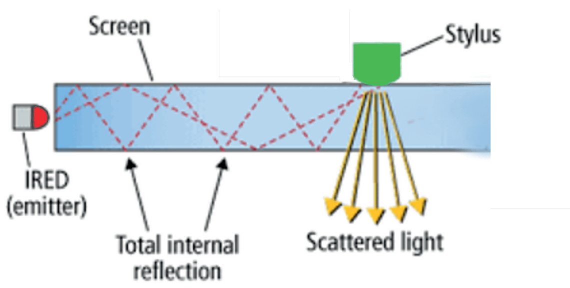
Disadvantages:

- No true multi-touch
- Low image resolution
- Vulnerable to dents and damage
- Hard to recognize lighter touch

3.2.4 Infra-Red Touch Screen

The IR touch screen, or optical touch screen as it sometimes is called, is based on light beam interruption technology instead of relying on electrical distortion. That technology works by sending a beam of light from a light source to a receiver and if the light signal is blocked in some way the detector will send a signal to a controller. By placing a horizontal and vertical row of IREDs and on each opposite side photo-transistors rows a matrix is created. Here the LEDs works as the light sources and the photo-transistors as the receivers. By obstructing the light beams from travailing to the designated receivers the controller can then calculate the x and y coordinates of the touched area.

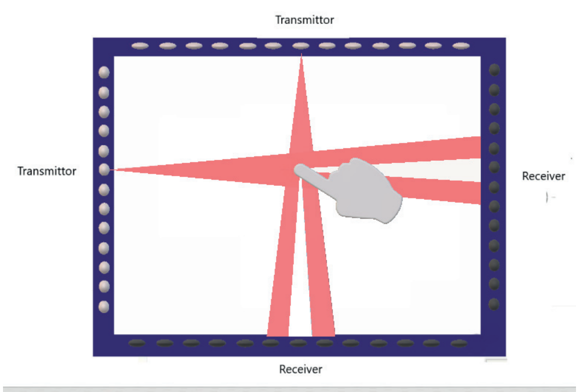
Figure 3.5: Interruption of IR light



The whole touch screen is created from a glass screen fixated into the frame and the IR grid is mounted into the bezel. There is some controller often hidden inside the frame and regulating the LED and receiving information from the photo-transistors. The glass works as an IR barrier to contain the transmitted IR light which has total internal reflection. When a stylus or finger is pressed against the surface this will create a scattering of the light beam and thus is can be detected 3.5.

The light beam traveled from the IREDs will scatter more and deactivate more of the photo transistors if the intersection is closer to the light source [21]. But because each light beam has some divergent effect 3.6 each photo transistor will get input from more than one IRED transmitter.

Figure 3.6: IR grid with single touch input



This will give the grid more accurate position determination and also why IR touch screens have a high resolution. When scanning for ghost points the matrix created from the inputs will be compared with the opt matrix to calculate the x-y positions one row at the time. The IREDs can pulse at a very high speed and with each pulse, a new comparable matrix composition can be registered by the controller. The update speed is therefore restricted by the micro controller instead of the touch matrix itself.

Even if image resolution and high speed there are some disadvantages to the IR touch screen. It is costly to produce this technology as it requires a lot of IREDs

and photo transistors and the installation
as these must be integrated into to the bezel which requires high precision. The disturbance from outside lights in the right spectrum and angle of approach can affect the screen to create ghost touches. One example can be when a finger is hovering very closely over the screen but not touching the surface and still send an active touch input. Hovever this only effects IReds mounted above the touch surface which is the occation for some displays. Also, oil and grease on the glass can create anomalies in the internal reflection and create dead touch areas or standing ghost touch inputs. On the other hand does the touch system fair well to dents and scratches [22].

Advantages:

- High resolution and image clarity
- Long life due do no internal cables
- Resistant to scratches and bumps

Disadvantages:

- Expensive technology
- Does require a frame
- Sensitive to ambient light interference
- Dust and grease can cause malfunction

3.3 Processor and Controller, Monitoring Systems, Mirror Glass and Further Components

3.3.1 Processor and Controller

In this project, due to budget, accessibility, size, and usability only single board controllers will be investigated. There are plenty of options on the market but many scopes towards the industry with high performance which increases the cost and the complexity. The options that are narrowed down in this section are Raspberry Pi, BeagleBoard and Asus Tinker Board.

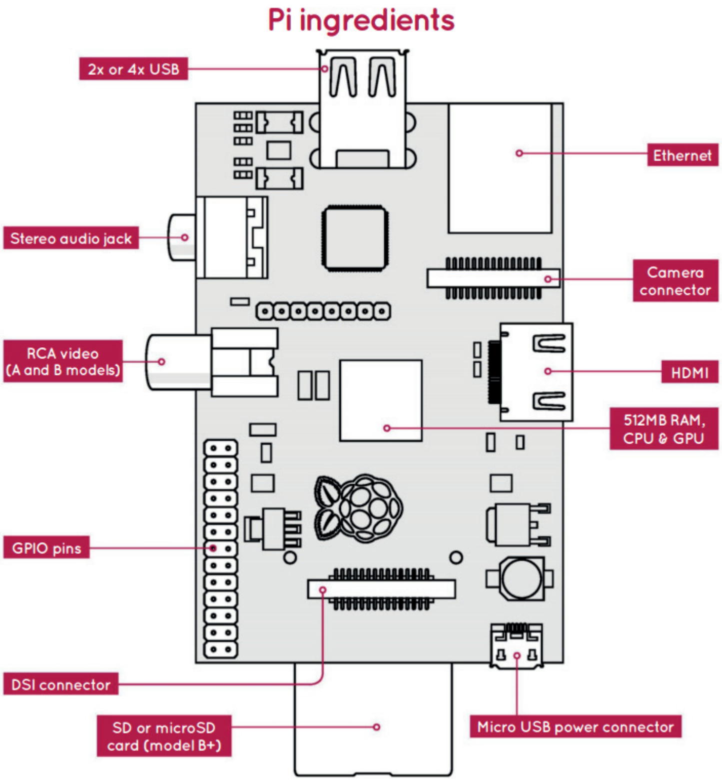
Raspberry Pi 3B

The Raspberry Pi (RPI) is a SBC system created by the Raspberry Pi Foundation. The main idea of the foundation is to have an open hardware platform with open software programs. It was created for a teaching purpose toward computer science classes. The original version, the RPI 1 model B came out February 2012 and by November 2016 the foundation had distributed over 11 million units. Under its umbrella the foundation has a couple of versions in the RPI series. The mini computer is today a well-known brand over the world and acts like supplements rather a competitor to the computer market. The whole idea with the RPI is to create an affordable unit enabling a starting platform for new developers.

The system supports multiple operating systems, free to download from the Raspberry Pi foundation website that also has a huge forum based knowledge distribution. The community created for RPI users have the solemn purpose to educate and help people learn to use and program their device. This makes the RPI system flexible for many types of smaller devices and is used widely for prototyping when the developer seeks an affordable platform to run its process [23].

Figure 3.7: Raspberry Pi

Figure 3.8: Raspberry PI board and ingredients



The single CPU & GPU ship contains the ram memory of 1 gigabit and processing power for the whole device. It is created by ARM and runs the architecture ARMv8-A 64 bit with a quad core CPU clocking at 1.2 GHz. The device also provides 100 Mbits Ethernet port, On-board 802 11n wireless network and Bluetooth generation 4.1. Due to its high processing power the device uses a 300 mA (1.5 W) on average with a peak on 1.34 A (6.7 W). The average may increase if multiple devices as a keyboard, mouse or touch screen use USB line power from the board and this can also lead to heating problems. The generation 3 model B is the first RPI to sometimes require a heating sink when pulling heavy duty [24].

ASUS Tinker Board

Asus Tinker model is the next level step from the RPI system. It does have a slightly higher CPU and also provides with an additional 1 GB RAM. The system provides with the same IO ports and a 40 pin header for more specified usage. The system targets Android specially and is sold with that OS pre-installed which is also the main difference from the RPI. The Tinker board has only two alternatives to run either Android or the specially made TinkerOS which is a derivative of Debian Linux [50].

BeagleBoard

BeagleBoard is similar to the Raspberry Pi models. It is also an SBC but focuses more on generic output options and the x15 model which is the newest board from BeagleBoard was released in September 2016. It is equipped with a Dual ARM processor clocking at 1.5 GHz and also builds in micro SSD memory of 4 GB with a micro SSD memory slot extension. Due to its higher performance than the RPI system it has a higher power consumption, up to 5 A, that also can power up to 4 USB 2.0 and 3 USB 3.0 ports. It also provides with an inbuilt SDRAM of 2024 MB to increase the overall performance and computational options. The system is more expensive than the RPI and costs around 1500 -SEK with few distributes and none of them located in Sweden.

The system is built for gaming development and systems requiring many sensors and IO options. The board supports Ubuntu, Arc and Android as its base but can also be direct booted with other Linux options. The high computational speed also helps the processor process lots of data and information which is crucial for real-time operational programs. This makes BeagleBoard a good option when the RPI system is not enough and also works in a lightweight desktop computer environment.

There are also other cheaper Beagle Board options like the BeagleBone Black that is more like the RPI with slower CPU and GPU and also fewer IO channels. They are still more expensive than the RPI and retails at staring price of 700:-SEK [51].

3.3.2 Monitor system

For the monitoring and flat panel displays there are three possible options: Liquid Crystal Display (LCD), Plasma panels, and different form of Light-Emitting Diodes (LED). The Plasma panel is basically two plates with a narrow gap between them. The two plates have electrodes on them facing each other and the gap is filled with a gas, usually neon. When a voltage is applied to two electrodes the gas between them will start to glow. Depending on the voltage the neon will emit light with different weave length and in that way the image is controlled.

However, since the year 2010 many manufactures discontinued their production of Plasma screens as the technology is outperformed by the LCD and LED screens.

The LCD uses, instead of neon gas, liquid crystals between two plates packed with electrodes. The same principle, as for Plasma, to charge the crystals to create an image is used. When a voltage is applied to a crystal the diffusion properties change. By illuminating the back panel the white light can be diffused in a controlled way to create the desired picture. This technology is cheaper, more durable, more reliable and compact than the Plasma screen. Usually this type of flat panel is used for smaller electronic displays and also popular for laptops and computer-screens[52].

The LED is standard for today's TV-screen market. It is also used for laptop-screens and desktop computers. The diodes in a LED use the same technology as the LCD but instead of controlling the whole plane each diode is controlled separately. These diodes are placed in arrays over the whole screen and by controlling each element by itself it produces a higher image clarity. It still uses a background lighting but the quality of the image is directly linked to the number of pixels, i.e. the number of diodes. The LED is slightly more expensive to produce than the LCD screen but the high demand of image clarity has made this technology dominant on the market [11].

3.3.3 2 Way Mirror Glass

A normal mirror is made by adding a reflective coating to a transparent substrate. This substrate is normally glass but can basically be any sort of transparent material. The reflective coating is made from Tin(II) Chloride or silver which both have a very good reflecting capabilities. To make sure no light can go through the mirror the backside is covered with a protecting panel with a black painted surfaced facing the coating. By doing this way nearly 100 % of the light will be reflected back from the mirror and the small part that is absorbed is not noticeable [25].

All known material has some reflective capabilities. Even transparent glass plates will reflect some of the incoming light. This might not be noticeable due to the fact that the light on the opposite side shines through and the difference from the reflecting light and the shine through light is so large that the reflective light can be disregarded. But if there were no light source on the opposite side of the glass the small reflection will be quite noticeable. This is a phenomenon that occurs for normal glass windows when it is dark outside and even if most of the light will go through the glass, some will reflect. As this reflecting light is much more than the lack of light source that the darkness will shine through the glass the window will be perceived as a mirror.

The idea of two-way mirrors works in the same fashion as the glass window in the example above. When the incoming light intensity is greater than the background lighting a reflection will appear but when the opposite is true the background lighting is dominant and it will be seen. The reflection will still be there but just not or less noticeable. To create as good 2-way mirror as possible the reflective capabilities are increased in the glass. This can be done by coating one side with a very thin metal layer so only part of the light will reflect [26].

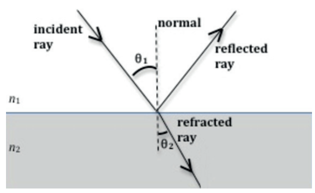
Another way to do this is to tint the glass in a darker color and or have a polarized coating. By tinting the back side glass then the front side the mirror will have more reflecting capabilities from one side and more transparency capabilities from the other. The polarization will let 50 % of the light through and the other 50 % will reflect. By using these two techniques the manufacturers can produce a glass (or plastic) window that has a good reflective property on one side and a good transparent property on the other.

The method for making nonconductive (i.e. not using metal coating) is more expensive than the conductive version but when used combined with some electronics a nonconductive plate is required. There are cheaper versions of the 2-way mirror which usually is made of only a thin film with reflecting property. This is laminated on to the plane and is far less expensive than acquiring a true 2-way mirror. The problem with using a mirror-film is that some of the background light transparency is lost [27].

3.4 Transparency and Reflectiveness of Materials

When light hits a medium two thing will happen, some of the light will be reflected and some will be refracted into the medium. Depending if the density of the two mediums, the angle of transmission will change [43]. If light travels from a more dense to a less dense medium, the light will refract away from the normal. This happens because the light travels at different speeds depending on the material. This unit is called the Index of Refraction. For example as acrylic plastic the index is between 1.489 to 1.498 depending on the light wavelength [42] and the index for air is around 1, that means if light travels from the acrylic material into the air the angle of refraction will be bigger then the angle of incidence. And if the angle exceeds around 42 degrees, total internal reflection will occur.

Figure 3.9: Reflection and Refraction



The light can also be absorbed when passing from one medium to another which is mostly what happens for shaded glass or other shaded optical materials. The clearer the material is, the lesser the absorption will be. Due to these two facts the light clarity will be different depending on where the observer is compared to the screen. The amount of light that will be emitted through can be measured in Lux (lx), which is the SI unit for luminous flux. For comparison, full daylight is around 10 000 lux and background light in a normal home around 150 lux [44].

3.5 Information about Energy Consumption of Known Devices

This section shows a list of other devices that can be found on the market. It is two or three devices from each device family that are modern and up to date, showing the energy consumption of that device as seen in 3.1. This is to be compared with the Smart Mirror to see how well it performs in the energy study.

Device	**Brand**	**Model**	**screen size**	**Power Consumption**		
				Sleep	Normal	Max
Computer	Lenovo	ThinkCenter M93z	23 Inch	$<$0.3 W	70 W	150 W [39]
Computer	Apple	IMac 2015	21.5 Inch	$<$0.2 W	63 W	240 W [45]
TV	Samsung	UF43M	40 Inch	$<$0.3 W	54 W [36]	
TV	Samsung	QLED E497F	49 Inch	$<$0.3 W	124 W [35]	
TV	LG	UH603	43 Inch	0.3 W	53 W [38]	
Kiosk	ViewSonic	EP5520T	55 Inch	5 W	115 W [46]	
Kiosk	ViewSonic	CDM5500T	50 Inch	5 W	70 W	130 [47] W

Table 3.1: Energy Consumption List

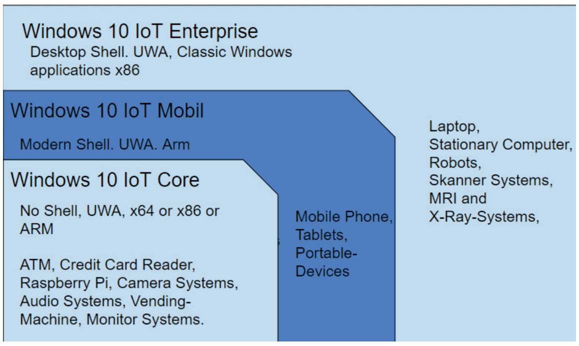
3.6 Programming Language

The program was written as a Universal Windows Application in C# and XAML for the UWP. C# was released in the year 2000 and has in its 17 years lifespan been through six major releases. Today it is one of the most popular and wide spread programming languages. It is designed under the .Net framework and has from the launch been mostly compared to Java. It is an object orientated language but has over its releases diverged to its own path to include generics, lambda extension, anonymous types and asynchronous methods [3].

XAML stands for Extensible Application Markup Language. It is a declarative language also developed by Microsoft and is an extension of the WPF. This language is used a lot in the .Net framework and everything that is developed in the XAML can also be produced in a more traditional .Net languages like C#. The main idea for this language is to use it as a declarative definition of the UI instead of having the procedural code to generate a graphical interface. In this way, the developer can see how the interface will look without compiling the code [4].

The idea with UWP is for Microsoft to have a cross platform architecture for developers to create one application that will work with many devices. Today the UWP is supported on all new Microsoft platforms as the Windows 10, XBox One, Windows Phone and Windows 10 IoT. It can use multiple languages like JavaScript C#, XAML and more in the same program which makes the development possibilities very flexible but also with set boundaries. One problem the UWA have is that it operates in a close to a sand-boxed mode which will make it hard or near impossible to change features outside of the application. The reason for this is that all the devices work in a different way and to protect the operating system from harm this safety measure is required [37].

Figure 3.10: Windows IoT Family



Windows 10 IoT is a operating system made for small devices and supported by platforms running Arm or x86x64 architecture [29]. It is part of the Windows 10 IoT Enterprise family and provides an IoT base for a lot of different purposes. The normal Windows 10 window format has been scaled away to make the OS more lightweight and basically only contains the basic drive routines to manage images and screen, sound, networks, memory and input devices. The rest of the capabilities must be handled by the program which means that the developer has to create everything from scratch. This allows the IoT foundation to basically run what the developer desires. Most importantly it is easy to set up and easy to handle, the restraints lay mostly on the device itself and the program executed on the device [28].

Chapter 4

Components List, Approach, Programming and Study

This chapter handles the approach and decision behind the materials and how the prototype was built. It also discusses the program structure and how the program works in the background. Some documentation and references will also be discussed in the Programming and Language section.

4.1 Material List

Item	model	Brand	Price
Raspberry Pi 3	Model B	Raspberry Pi Foundation	379 SEK
Charger	2.4A USB	DELTACO	99 SEK
USB Kable	USB 2.0	DELTACO	89 SEK
RPI Casing	Model B	Raspberry Pi Foundation	129 SEK
Micro SD	MICRO SDHC 16 GB, 80 MB/s	Sandisk	149 SEK
Screen	42LD450 42-Inch	LG	0 SEK
Mirror 1	Mirrorfilm silver Reflectivity: 75 %	MDP	58 SEK
Mirror 2	Solarfilm 55 Transparancy: 69 %	MDP	54 SEK
Plastic Scrape	006935045	MDP	29 SEK
Acrylc Plate	Clear 3x1000x750 mm	Plexiglas	249 SEK
Touch Panel	42 inch USB touch screen foil film 10 point multitouch	Shenzhen Smart New Tech	2299 SEK
Energy Meter	EMT707CTl 16A, 230V; 50 Hz Sertenty to 1 Watt	COITECH	150 SEK
Camera	Dual 12 MP 8 MP, HDR 60 fps	Huawei	0 SEK
Screw kit	M2.5	Electrokit	59 SEK
Total Cost:			3743 SEK

Table 4.1: Component and material list

4.2 Decision of Materials and Hardware

The prototype uses a Raspberry Pi as the micro computer and processor for the Smart Mirror. It is very affordable and also powerful enough for minor operations. The reason for not going with the Tinker Board SBC is mainly for the possibility to have a more open system not only targeting towards Android and the BeadleBord is to expensive for the budget. It is also one of the most well known systems with the largest developer forum to help find information and solutions for the system. The RPI contains all necessary IO ports and supports HD screen, WiFi and Bluetooth network. The OS for the system is also free of charge and the system can be connected to cameras and also general output pins for a more specialized purpose.

The display was donated by SITS to this project which did not impact the budget. It is a 42-inch LED-TV bought 2012 with HDMI port. This did set the size of the mirror and touch panel and also the thickness of the frame.

For the touch control, the decision was grounded on size, multitouch, cost and accessibility. As the display was 42 inch the touch panel had to be that big. With that width and multitouch in consideration, this ruled out both Resistive Touch as those products are not generally built in that size and SCT as true multitouch had to be acquired. Both CPT and IR-Touch have screens in the right size but the IR-Touch is harder to fit into the mirror as it has its own frame and also there where slightly better offers for the CPT. This however puts a lot of restraints on the mirror coating as it can not be of any conducting material.

The choice to go with a coating material in acryl plastic had mostly to do with economy and accessibility. The charge for a glass mirror was about 2000 SEK [40] which would mean that the project did not fit the budget. The acrylic coating was bought in two different examples with different transparency level. This to create a more viable study for the light measurement. Coating instead of glass also meant that an acrylic transparent panel also had to be bought. The reason for that was so the touch panel and coating foil had to be coated on a surface.

4.3 Construction of Prototype

First the chassis was taken off the TV-screen and unimportant buttons and unnecessary components were removed. Thereafter the acrylic panel was cut in the right dimensions with a laser cutter. The touch screen was a little bit bigger than the 550 by 970 mm. The reason for it to be bigger than the 530 by 940 mm as normal 42-inch screens are is for the ATO wires to feed back to the controller and about 1-2 cm extra material at the edges. This made the touch screen too big and after careful consideration and a discussion with the manufacturer about 1 cm on each edge could be cut off.

To be able to mount the touch screen on the acrylic plate first the plate was thoroughly washed with a soft sponge. After removing the protective plastic sheet from the touch screen a blend with about 1 drop of soap to a half liter of water was sprayed on to the both the touch screens both sides and the acrylic plate. The reason for doing this is to make the mount easier as the glue took longer before it stuck. To remove all the water a plastic scraper was carefully used from the middle of the board towards the edges. This pushed all the water between the touch screen and the acrylic plate away to not leave any bubbles.

Thereafter the touch output was connected to the controller and the screen sandwiched between the frame and the TV screen. To minimize the cost the screen was made from the original TV chassis. But to fit in the screen and the controller card cables going from the front to the back of the mirror some adjustments to the interior of the plastic chassis had to be made. A small part of a bearing wall inside had to be cut off and also a part of the back to be able to fit in the RPI.

4.4 Programming

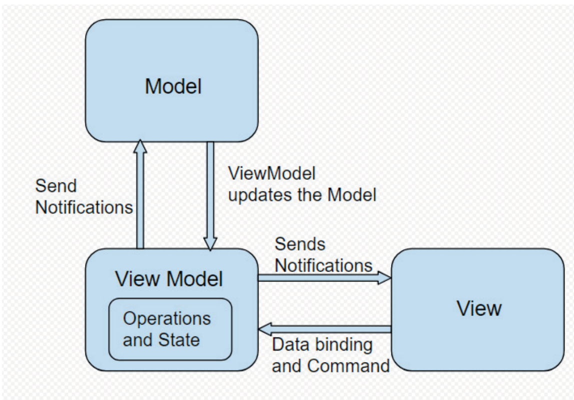
This section contains the basic information about the program, the basic structure and how it is developed. It also features how the main functions and interfaces.

4.4.1 MVVM

MVVM stands for Model-View-ViewModel and is a separation of graphical user interface and the back end logic of the program. The MVVM-system is composed of three parts. First we have the model which represents real state content. The content has an object-oriented approach. Second comes the view, which is graphical structure, layout and appearance of what the user will see. It is the user interface and is handling all graphical content. The last part is the ViewModel. It is the abstraction of the view and is responsible for converting data objects from the Model to the View. To simplify the explanation, The view is what the user sees, the ViewModel makes the operations and the Model stores the values.

The reason for using this type of structure is when using Windows Forms, like XAML, the program can grow quite rapidly. To manage the size each new graphical function is fitted to the MVVM model to create a good over view of the program. It also makes the maintenance issues easier for tracking and debugging error as each structure is contained to only a part of the bigger program. The key for the pattern to work well is the clear separation between the UI and the application logic together with the rich data binding stack provided by the Windows Form.

Figure 4.1: MVVM Pattern



To be able to communicate between the Model-View-ViewModel the system uses binding. The binder for the MVVM is created in the XAML language and with use of a function called NotifyPropertyChanged the system can control and change parameters globally throughout the system. This is the most crucial communicating tool when using the MVVM pattern. The NotifyPropertyChanged method is used to control properties adeptly in the model and notify when these are changed. An example is the Clock application in the program. Here the model has all the clock parameters as date and time. Then the ViewModel contains the changing of the clock parameters and the view displays the clock. The ViewModel is then programmed to change the time each second which will fire an event to the Model changing the parameters, that will notify the ViewModel that the parameters are changed and then in return through data-binding give the control to the view to change the correct parameters [30].

4.4.2 Structure

The program first contains an application file-set called App.xaml and App.cs. This is the launch file that will operate on how the program will launch and the basic settings for that. The (.xaml) file will bind all global variables and each MVVM properties. The C# (.cs) file handles all the initiations of each MVVM structure and binds the initiations to the bindings made in the Xaml file. Thereafter it will navigate to the MainPage file.

The MainPage contains the main view for the program. This view is essentially just a blank page with empty frames which can navigate to other views. When one frame navigates to a View this view only exists in the frame specified by the MainWindow. The MainWindow is also tied to a MainModel path with the dedicated purpose to control what MVVM models that are active and what applications that are turned on. This is vital for the possibilities of interaction between some MVVM structures and operating interaction interfaces like the virtual keyboard. For example, when an application is active the MainModel must know what text blocks are active direct the keyboard inputs to the right path. The execution of commands is still handled by each MVVM model and the MainWindow and MainModel does not change that. The reason for this cross interaction model that essentially steps outside of the MVVM pattern is the need to simplify the program for a smooth use.

To the structure there are a few style documents that are tied to the UI. This so the programming style will look and activate in the right graphical fashion. It also helps to minimize the amount of code as the style documents can be used multiple times for a lot of actions. For instance when activating a button, the visual interaction is drawn from the style dictionary as a resource and the code only has to be written once and thereafter referenced to it. The figure 4.2 shows how the whole program is built up. In short terms this is what happens step by step:

1. App is launched
2. App creates the MVVM structures and navigates to the MainWindow
3. MainWindow initiates frames in to the MainWindow
4. MainWindow navigates each frame to each MVVM structure
5. The program is fully initiated
6. When operating, each MVVM structure sends global information to MainWindow
7. MainWindow sends information to MainModel and navigation
8. Navigation navigate each frame to containing the right MVVM structure
9. MainModel holds global information to provide to the MainWindow and communicates with Keyboard and gives the path to the active textbox
10. Keyboard sends information to active textbox

4.4.3 Variable management and notification

All important and global variables are bounded in the Xaml to the designated path. The necessary properties that will act on change are routed through the

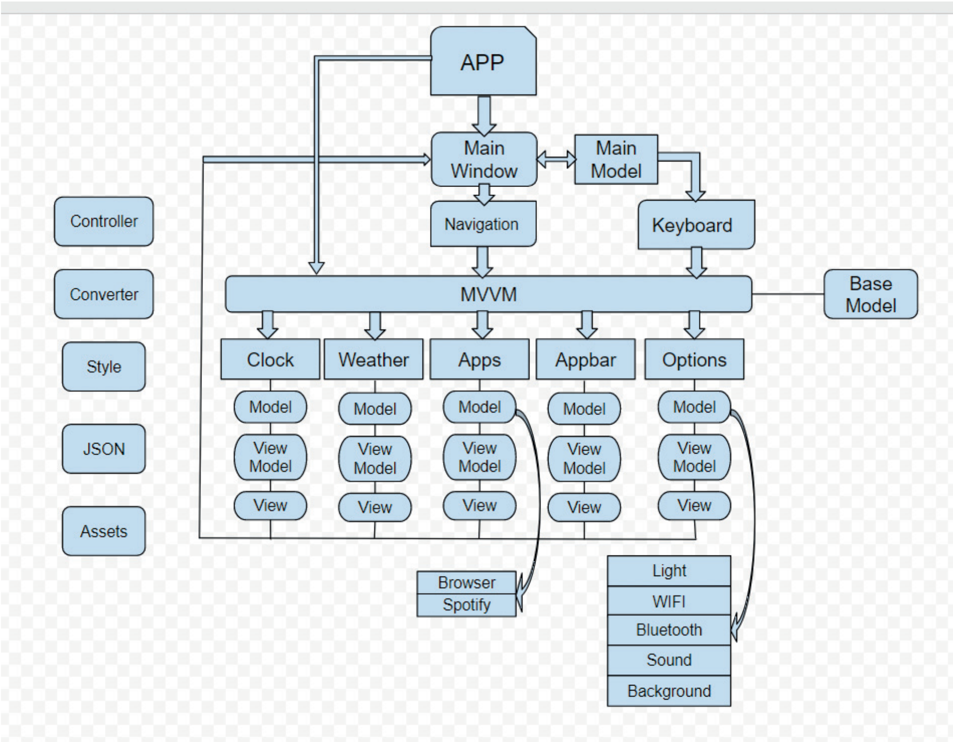


Figure 4.2: The general program structure and base functions.

INotifyPropertyChanged Interface. Each model in the MVVM structure will be in charge of its properties and the MainModel is in charge when cross model interaction is needed.

The Notifications are of two kinds. Either it is an active notification from a user input or data input, or it is a background notification that the program handles independently from what the user is doing. Examples of the active notification can be button clicks, global touch commands, keystrokes from the virtual keyboard or local touch commands. These notifications are handled directly by the currently active view and the ViewModel tied to that view. Here the path is direct and in the first level from the child view.

The background notifications can be notifications like the clock and date state changed, data streams from the weather station or an inactivated application sending sound. These only use the INotifyPropertyChanged interface to handle the change and the PropertyChanged is picked up by the right ViewModel and the correct code path is executed. The background notifications therefore does not work on first level and the code path can usually include second or in some cases even third level.

Level means the number of steps or directions from the notification to the execution part. By sending information from one state to be executed in another part of the program, the execution have gone to one higher order level. To have too many levels can be very dysfunctional and creates an intricate program. This can lead to a slow processing of that thread and levels above third state should be avoided if there is no good reason for it. For example, The MVVM pattern use a second level execution, the notification is created from viewModel and the data is changed in the model which the view taps its information from. A button click on the other hand is usually on one level as when the button is pressed the action is picked up and immediately the designated code path is executed by the same program class.

4.5 Functions and Packages

4.5.1 INotifyPropertyChanged

This function when tied to a property will send a notification to the client when the property value has been changed. This is typically binding clients for nondirect interactions that happen in the background. It can also be used for direct interaction to handle variable managements but instead of a direct path from the interaction the client listener will catch the designated property changed and in the background execute the direct order [31].

4.5.2 Navigate

The navigate function is the C# version to choose what the screen will view. It is used in the API of Windows.UI.Xaml class and used by the Control.Frame, Control.Page and Navigation classes. A frame or page can have siblings or children to multiple frames and pages and this method is the bridge to go between these. It can be through a button click or with generated input methods. [32]

4.5.3 JSON Newtonsoft

JSON stands for JavaScript Object Notation and is a data interchange format. It is used to send and store data in an easy to read for humans format and one client that use it a lot is the HTTP. This means that whenever the program retrieves data from the web it is likely to come as a JSON string which needs to be decrypted and converted to C# manageable data sets. Because UWP is a cross platform supporting many languages and JavaScript is one of them this format is easy to handle. The Jason string can handle integers, doubles, strings, chars and booleans [41] which can be seen in the example below.

```
{
        "People" :
        [
                {
                        Student : "True",
                        Name : "Albin",
                        Age : 25,
                        Affiliation : "Electroteknik"
                }
                {
                        "Student" : "Ture or False"
                        "Name" : "Some Name"
                        "Age" : Some Age
                        Affiliation : "Something"
                }
        ]
}
```

4.6 Study

Energy Measurement

The energy measurement was conducted with a standardized energy meter available in most hardware stores4.1. The measurement was divided into three categories: Sleep Mode, Low Activity Mode and High Activity Mode. Because the Raspberry Pi is only connected to the display by HDMI port a true sleep mode for the screen when the mirror is inactive is not possible. Therefore when conducting the Sleep Mode test the screen is set to sleep mode externally. However for the long term test going from high activity to automatic sleep the screen never goes to true Sleep Mode.

The Low Activity Mode reflects when the Smart Mirror is not in use but still powered on. This means that the screen is projecting the base image where it is possible to see the time and date and the Smart Mirror is ready for interactions. Only the basic background processes are running and no touch inputs have interacted.

The High Activity Mode reflects when the processor is running heavy duty and the mirror is fully active. The most CPU processor capacity is used when the Mirror is displaying online videos and that also activates most of the screen. Therefore High Activity Mode will be processing daylight bright videos from youtube.com. During each mode test the highest light and color-intensity and image sharpness was selected on the monitor.

1. True Sleep Mode over 5 minutes

2. Low Activity Mode over 5 minutes

3. High Activity Mode over 5 minutes

4. Long Term Alternating Test 4 hours

For each five minute test the measurement was taken each minute and each test was conducted five times. Then the average for each test was calculated and thereafter the average over all five tests. During the tests the current watt was recorded for both the screen and the RPI to see the energy cost drivers but because the study only used one measuring device the total was first read and then the power cord to the screen taken out so the RPI power consumption could be read.

For the Long Term Alternating Test of four hours the energy meter was cleared so the total energy used over the whole time span could be measured. During this test only the total energy consumption of the whole device was recorded. During this test the Sleep Mode, as said before, was not true Sleep Mode as the screen during sleep mode only showed a black screen and the background light was not turned off. Also when the Smart Mirror went from active to sleep it took 60 seconds, as the sleep timer is programmed.

With the data from the earlier energy tests, the Sleep, Low and High Activity Mode, two calculated version of the Long Term Alternating Test was done. The first one used Low Activity Mode as sleep to see how well those results were compared to the Long Term Test and the second calculation used true sleep mode. The second calculations purpose was to create a version more likely to fit the reality for a final product. During the Long Term Alternating Test and the calculated version a 30 % activity rate was used.

The effect that light intensity and background light on the display had on the energy consumption was also measured. This was done by feeding the monitor with a black or white image covering the whole screen and then adjusting the background light and pixel brightness. The pixel brightness was changed by changing the parameters light-and color-intensity and image sharpness from 100 % to 50 %. The watt measured with the energy meter from each adjustment for each screen image was then recorded.

4.6.1 Hardware Performance

For the hardware performance the results were recorded by the program Visual Studio which is the IDE that the program was programmed in. During the launch in debug mode, both the memory and the processor activity of the RPI could be measured. This test was done by setting the Smart Mirror in the Sleep, Low-and High-Activity Mode each over five minutes and then note the result. Also another mode, Normal Mode, was introduced which was an active mode doing less CPU demanding things as browsing the web and activating different applications on the device. During the test the Normal Mode tried to mimic actual usage of the mirror with similar task each time. This test was done five times and in between each time the device was shot off to clear the memory stack and eventual background processes. For each test the same consecutive order was done.

1. Starting up the device waiting 5 minutes for all background processes to clear off and let the device go to sleep.

2. 5 minutes in Sleep Mode.

3. 5 minutes in Low Activity Mode.

4. 5 minutes in Normal Activity Mode.

5. 5 minutes in High Activity Mode.

6. The device was turned off.

4.6.2 Light Interference in Mirror Material

The first Light Interference test was to measure the amount of illumination that would pass through the mirror material. This was done by using a camera4.1 and pointing it towards the screen. For the measurement to be accurate and not take in other reflections from external light sources the room which in the test was conducted was completely dark where the lux meter in that room gave zero output. The lux meter measured visible light in the range of 400-700 nanometres to capture the entire spectrum of white light. To this study a completely white background was screened on the monitor and all test was conducted on the bare screen for reference and thereafter the two mirror materials. This was done by placing the camera at 20, 40, and 50 centimetres from the display and for each distance the camera was placed with a 0, 10, 20, 30 and 40-degree angle towards the screen pointing towards the center 4.3.

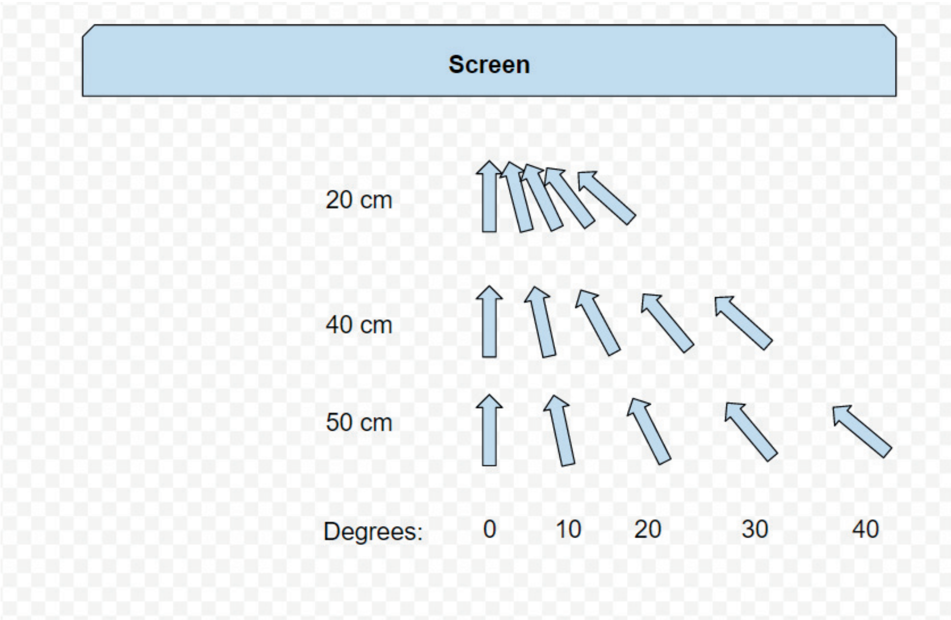


Figure 4.3: Light interference test set-up

Then test for 50 cm away from the screen was conducted again but with a 35 and 55 W lamp two meters away and one meter above the mirror. The result was recorded and then the same experiment was conducted for each of the mirror coating materials. For this to be possible, first the chassis of the mirror was removed and then the material stretched over the screen with the edges taped so the material would remain flat. Then the chassis was put together again and the measurement started.

Chapter 5

Measurement and Result from Study

This chapter presents the results found in the various studies. Some of the displayed results are derived from the measurements in Appendix A and also some minor calculations of percentage and calculated cases for easier cross comparability of the results.

5.1 Energy Measurement

5.1.1 Sleep Mode

The result displayed in this section is from the Sleep Mode test that was conducted on the Smart Mirror system. The table below, 5.1, are the result from five different Sleep Mode tests that can be found in Appendix A A.1 to A.5. The result is displayed by showing the energy consumption in watt for each energy cost driver for each conducted test. This is then presented as an overall average with the percentage of the contribution from the cost drivers.

Test	**Screen**	**RPI**	**Total**
1	1 W	2 W	3 W
2	1 W	3 W	4 W
3	1 W	2 W	3 W
4	1 W	2 W	3 W
5	1 W	3 W	4 W
Average	1 W	2 W	3 W
Percentage	33 %	67%	

Table 5.1: Result of Sleep Mode test 1-5

5.1.2 Low Activity Mode

The result displayed in this section is from the Low Activity Mode test that also was conducted on the Smart Mirror. The table below, 5.2, shows the energy consumption for each of the five tests and also the average over all tests with the combination of the percentage of contribution from the cost drivers. The measurement from each of the Low Activity Mode tests can be found in Appendix A A.6 to A.10.

Test	Screen	RPI	Total
1	99 W	2 W	102 W
2	99 W	2 W	101 W
3	100 W	3 W	102 W
4	100 W	3 W	103 W
5	99 W	2 W	102 W
Average	99	2	102
Percentage	97 %	2%	

Table 5.2: Result of Low Activity Mode test 1-5

5.1.3 High Activity Mode

This section displays the result for the High Activity Mode in the same way as for the Sleep and Low Activity modes. The result is displayed in the table below, 5.3, and derives from A.11 to A.15 that also can be found in Appendix A. During this test the strain on the computer was close to maximum to get values for maximum energy consumption.

Test	Screen	RPI	Total
1	101 W	4 W	105 W
2	100 W	5 W	105 W
3	101 W	6 W	107 W
4	101 W	5 W	106 W
5	102 W	5 W	107 W
Average	101 W	5 W	106 W
Percentage	95 %	5 %	

Table 5.3: Result of High Activity Mode test 1-5

5.1.4 Long Term Alternating Test and calculated versions

The long Term Alternating Test was conducted over a period of four hours where each fifth minute a measurement was recorded. The table below, 5.4, displays only the result for each hour and all measurements can be found in Appendix A A.16. The test alternated between High Active mode and artificial Sleep mode which meant that no true Sleep mode was acquired. That meant that the RPI system went into a programmed sleep mode but the display showed only a black screen with full background lighting.

Time	Active Mode	kW
1 h	33 %	0.10 kW
2 h	25 %	0.21 kW
3 h	33 %	0.31 kW
4 h	33 %	0.41 kW
Average:	30 % Active	0.103 kW per h

Table 5.4: Result for Long Term Alternating Test during 4 Hours

For comparability of the result in Long Term Alternating Test a calculated version of the same test was conducted. This is shown in the table below, 5.5, and the figures used in this calculation was derived from the result of Low Activity Mode and High Activity Mode. During this calculation Low Activity Mode was used for both artificial Sleep mode and for Low Activity Mode.

Mode	Time	W	kW
Sleep	2 h 49 min	102 W	0.287 kW
Low Activity	11 min	102 W	0.019 kW
High Activity	1 h	106 W	0.106 kW
Average:		103 W	0.103 kW per h

Table 5.5: Calculated version based on each mode test without true sleep.

Another calculation of a Long Term Test was calculated but instead of using Low Activity mode as Sleep mode this time the result from the Sleep Mode test was used to see how the system would work with true Sleep Mode. The result is displayed in the table below, 5.6.

Mode	Time	W	kW
Sleep	2 h 49 min	3 W	0.008 kW
Low Activity	11 min	102 W	0.019 kW
High Activity	1 h	106 W	0.106 kW
Average:		33 W	0.033 kW per h

Table 5.6: Calculated version with true sleep mode

5.1.5 Screen brightness

To see the change in energy consumption when changing the background lighting combined with the pixel brightness an energy test for just the screen was conducted. The result is displayed in the table below, 5.7, which show the energy consumption when screening a solemnly white or black background screen.

Background Light:	Low	Medium	High
		Dark Screen	
100% Pixel brightness:	65 W	82 W	97 W
50% Pixel brightness:	65 W	82 W	97 W
		White Screen	
100% Pixel brightness:	72 W	89 W	105 W
50% Pixel brightness:	70 W	87 W	103 W

Table 5.7: Screen Brightness with Different Light Settings

5.2 Hardware Performance

In the Hardware Performance test some new acronyms were introduced. Here, CPUA, CPUT, CPUL stand for CPU usage Average, Top Value and Lowest Value. The result is displayed in the table below, 5.8, and show the strain on the RPI in four different modes and also the memory usage for each category.

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	6%	<1%	9.6 MB
Low	<1 %	10%	<1%	11.2 MB
Normal	10 %	49 %	<1 %	52.0 MB
High	62 %	100 %	4 %	215 MB

Table 5.8: RPI Performance Average for test 1-5

5.3 Light Interference Measurement

Table, 5.9, 5.10, 5.11, that is displayed below show the light measurement result of no coating, mirror material 1 and mirror material 2. This test was conducted in a completely dark room and all three tests were conducted in the same way. The Lux meter measured the light at different distances with different angles from the screen center which is shown by figure 4.3.

20 cm	0	10	20	30	40
Screen	328	253	244	222	141
Mirror 1	97	74	64	62	44
	29.57 %	29.24 %	26.23 %	27.93 %	31.21 %
Mirror 2	39	34	29	24	17
	11.89 %	13.44 %	11.89 %	10.81 %	12.06 %

Table 5.9: Light Measurement 20 cm Distance

40 cm	0	10	20	30	40
Screen	298	238	206	171	106
Mirror 1	87	67	57	42	22
	29.19 %	28.15 %	27.67 %	24.56 %	20.75 %
Mirror 2	32	27	22	19	14
	10.74 %	11.34 %	10.68 %	11.11 %	13.21 %

Table 5.10: Light Measurement 40 cm Distance

50 cm	0	10	20	30	40
Screen	278	221	199	163	104
Mirror 1	82	54	42	37	17
	29.50 %	24.43 %	21.11 %	22.70 %	16.35 %
Mirror 2	28	24	19	17	9
	10.07 %	10.86 %	9.55 %	10.43 %	8.65 %

Table 5.11: Light Measurement 50 cm Distance

The table, 5.12, show the light measurement with adding outside light sources of 35 and 55 watt light bulbs in front of the Mirror. This was recorded by a Lux meter that was stationed with different distances at different angles from the center of the screen. The result with no mirror coating is displayed to give a better overview of the change in Lux when coating the Screen.

50 cm	0	10	20	30	40
	No mirror coating				
Screen	278	221	199	163	104
35 W	261	211	193	169	108
55 W	256	204	187	164	107
	Mirror material 1				
Dark	82	54	42	37	17
35 W	71	49	41	37	18
55 W	69	48	40	35	17
	Mirror material 2				
Dark	28	24	19	17	9
35 W	22	19	19	18	9
55 W	19	16	18	17	11

Table 5.12: Light Measurement with background lights

Table, 5.13, displays the result from table 5.12 but in percentage instead of Lux, The result was calculated by using the dark room result as the maximum value compared to the result when the light source was turned on.

50 cm	0	10	20	30	40
			No mirror coating		
Screen	278	221	199	163	104
35 W	93.88 %	95.48 %	96.98 %	103.68 %	103.84 %
55 W	92.08 %	92.30 %	93.96	100.61 %	102.88 %
			Mirror material 1		
Dark	82	54	42	37	17
35 W	86.59 %	90.74 %	97.62 %	100 %	105.88 %
55 W	84.15 %	88.89 %	95.24 %	94.59 %	100 %
			Mirror material 2		
Dark	28	24	19	17	9
35 W	78.57 %	79.17 %	89.47	105.88 %	11.11 %
55 W	67.85 %	66.67 %	94.74	100.00 %	122.22 %

Table 5.13: Result from table 5.12 in %

Chapter 6

Discussion and Conclusion

This chapter deals with the conclusions that can be drawn from the result and discuss the end product and the benefits and problems regarding the platform. It also looks at what future the Smart Mirror have as a commercial tool for companies and what the future obstacle that has to bee overcome.

6.1 Conclusion from Energy Study

The energy study relied on an energy meter with the accuracy of 1 Watt. This gives a high uncertainty when measuring low watts like the output of the RPI and the True Sleep Mode. Some values also vary between two values like in A.6 when the screen is outputting between 99 and 100 W but nothing major is changing on the screen. The reason for this might be that the true value is around 99.5 W which would give the appearance that the energy value is unstable. A mere infraction of a change could lead to a change in results and for low watts that is a huge difference.

Another uncertainty is the measurement itself as it is taken each minute but in the meantime it is not regarded. There is a possibility that the recorded value not truly represent the consumption over time and also the reason why the Long Term Alternating Test was conducted. There the total consumption was recorded which gives a more true value over time. It can be argued that the activation rate of 30 % does not represent real time usage, but this value was chosen with in mind that the product will be placed in a store environment.

The Sleep Mode of the RPI is also just a programmable sleep mode as the UWP does not support true sleep mode. This has to do with the fact that the platform is recently new to the market and this part has not yet been implemented into the software of the OS. That is most likely the reason for the RPI to output more energy than the screen during this Mode and is generally outputting the same energy level as in Low Active Mode.

The High Activity Mode also is symbolizing the worst case scenario. For the sake of the measurement, it was important to have a stable and close to same level output during the whole 5 min test. When using the system as intendant and not just trying to reach maximum energy output the result would vary a lot more as the processor spikes with each command and when that is processed it goes back to less consumption.

6.1.1 Discussion of Result

Even if there are some uncertainties with the energy meter the many tests hopefully eradicate that. This can be shown in the calculated version using normal mode as sleep mode for the Long Term Alternating Test 5.5 which use the results of the short term tests and end up with the same result as in the long term study. This gives a more weight to the result in the short term tests and a likelihood that those numbers fit the reality.

The biggest energy cost driver for the Smart Mirror is the screen. Even if the true Sleep Mode of the screen never is in use while it is operational the output while active is about 30-50 times that of the RPI which means that trying to improve the energy consumption of the processor would do very little to the total energy consumption. It is also interesting to see how the background lighting and the brightness levels of the screen affect the energy consumption. Because the smart mirror needs the coating to be preceded as a mirror this will automatically lower the brightness of the screen which can be seen in the Light study 5.11. To create a bright enough view the background lighting has to be amplified to the maximum which will increase the energy consumption.

The consumption goes down to around 70-72 W 5.7 for a white screen which then puts the energy levels just a little above a new normal 24 inch TV-screen. Another factor that has to be calculated into the picture is that the screen is from an old TV-screen and with the presumption that newer TV-screens have a lower Energy Consumption over all the Mirror is Actually performing a lot better than the Kiosks. The comparison to the computer can also be a little miss guided as the screen for the mirror is much larger than in the computer models and as the screen is the main cost driver for them as well the Mirror is not performing that badly.

When the estimated consumption for a fully integrated screen with true sleep mode and a 30 % activity rate was done the total consumption would be about 70 % less. And even then the activity level was quite high as the mirror was put in a stable High Activity Mode. This would probably not be the occasion for most of the time as it is built like a tool for information and not film viewings. The general usage purpose is product information and image display which does not take that large activity on the RPI.

It can be argued that the estimation of 30 % usage might not be an accurate number. The number has no real basis in reality and is just a probable guess when in discussion with SITS. However, that figure will vary quite a lot from customer to customer and how they choose to use the Smart Mirror. But with the idea that the device should blend into the exterior of the store and not be used as a constant information display, only active when interacted with, the 30 % figure is not that unlikely.

6.1.2 Comparison to Other Devices

The consumption goes down to around 70-72 W 5.7 for a white screen which then puts the energy levels a little above normal TV-screens. Another factor that has to be calculated into the process is that the screen is from an old TV-screen and with the presumption that newer TV-screens have a lower Energy Consumption over all then older ones, the Mirror is Actually performing fairly well. The PRI does not contribute largely to the energy consumption and restraints comes mostly from the screen itself. By using a more modern screen the device would have a significantly lower energy consumption.

When in comparison to the computer the study can be a little miss-leading as the screen for the mirror is much larger than in the computer models and as the screen is the main cost driver for them as well it is hard to actually see how well the prototype performs. A better option would be to compare it towards the digitalized kiosk models. Here the mirror does have a slightly smaller screen but performs better than the modern kiosks. The true sleep mode also puts them in the same consumption and this is important as that mode will be the most common one.

The estimated consumption for a fully integrated screen with true sleep mode would lower the total consumption with about 70 % when calculating that the mirror is only active 30 % of the time. And even then the activity level was quite high as the mirror was put in a stable High Activity Mode. This would probably not be the occasion for most of the time as it is built like a tool for information and not film viewings. The general usage purpose is product information and image display which does not take that large activity on the RPI.

6.1.3 Improvement in the Energy Study

As mentioned before the biggest improvement would be if the screen was fully integrated into to the system and thus true Sleep Mode could be required. This is only calculated with help from the different Mode tests but might varies a little from reality. Another test that can be done would be to place the prototype out in a store and be used as it is intended. This would allow costumers to integrate with the device and use the relevant applications. The biggest improvement this would give is the activity rate and also a normal usage energy consumption.

The simulations of normal behavior done in this project are just estimations of what different behavior can look like and how it is used in the real world. If a study was done in a real store it would not only provide with more data also gives feedback on how to optimize the system to fit the customer need. But as this prototype is just the first platform and an application containing all necessary information about the company and the products this was not available. The reason for not implementing that information in the application was a question of time.

6.2 Conclusion from Hardware Performance study

A lot of the performance of the prototype is due to the OS it runs on and the program behind the platform. The high Activity Mode was created mainly from viewing videos on in the internet browser. This is not fully compatible with the UWP as it does not contain background processes as Adobe to handle that kind of performance. Therefore it did over activate the system and thus around 100 % computing power was sometimes needed. For programs to run smooth and not lag the processing should not be too high as the High Activity Mode. But as that mode was intended to show the maximum stress on the computer it did its job.

The Normal Mode tried to view a more true picture of how the system works when operated. In that mode, it did almost everything except playing online videos and the result as seen in 5.8 is quite low. Mainly the reason for this is that the program does not run multiple programs in the background as a normal computer with multi threading might do. It does run some clock timers and update values for managing the MVVM patterns but that does not require so much processor power and can be seen in the result of Low Activity mode where only those background processes are active. This means that the RPI basically only works with one main program on the processor at the time.

When looking only at the memory stack of the RAM it increases every time when going from Sleep Mode to Low Activity Mode. Why the stack varies from one Sleep Mode test to another Sleep Mode test is hard to explain. What is contained in the stack is not displayed in the Visual Studio debug machine but the variation is very little and thus not affect the system at the whole. If a larger quantity of memory was obtained it might point to a programming error but this is not the case.

The conclusion to draw from the Hardware Performance test is that the RPI is able to handle the Smart Mirror concept. As long as this platform does not run multiple application at the time. This will probably not be a problem in the store environment as the usage will be short and new for each customer and thus not the need to have multiple applications active at the same time. It might however run into obstacles in forms of processing power if the mirror would be developed towards the household environment to work as a controller for the household.

6.3 Conclusion from Light study

To be able to compare the result with other devices and how much light they let through the lux meter have to be calibrated towards a real licensed lux meter. This does not however affect the result when doing this study because the interest is to see the decrease in transparency. The bare screen might not emit exactly 278 lux at 50 centimeters but is more as a reference for the study. The decrease when coating the mirror will be the same even if the measured lux is off compared to a standardized lux meter.

6.3.1 Discussion of Result

The light study shows that the transparency is about 30 % of all light for mirror material 1 and around 10 % for the mirror material 2. This is a huge decrease and also the reason why the screen must be in maximum background lighting. It also shows a slight decrease when the viewing angle increases especially for the distance of 50 cm. One reason for it to show almost the same result closer to the screen is that the screen is too wide and the lux meter actually detects the illumination at around 0 degrees angle. The test on 50 cm however is further from the center and thus have a greater true angel to the light source.

For both mirror materials at the angle of 40 degrees the lux was a lot lower then then the transparency level measured from 0 degrees. This fact has probably to do with the fact that the angel gets close to the critical angle where all light gets reflected. The reason this value is that high as it was can have to do with that the light source is not just a single point but the whole screen and thus not all pixels have the same angle towards the lux meter.

The measurement when the background light was turned on was conclusive. In the measurement the amount of illumination decreased for both 35 and 55 W light sources and more when measuring from zero degrees angle then measuring from a grater angle. This probably has to do with the background light being placed directly behind the the 0 degree point of view and thus giving a worse result. For the values for the tests from 20-40 angle however is so slight that it is hard to determine if the change actually comes from the background lighting or just a small irregularity in the conduction of the measurement.

The result from tests with background light might be a little surprising as the lux meter sensed lower values even if the amount of light sources was just added without changing settings on the screen. The suspected result was that the lux meter would give a higher output and the image would be perceived as darker compared to the rest of the room. This was however not the case. To back up this measurement the same test was done without any mirror coatings which also gave a lower value.

It seems that the transparency level does not fit what was declared when purchasing the mirror materials. Those values was a lot higher then what the study shows but as seen transparency and reflection does depend in what lighting condition the material is in. In a dark room there is no problem to see the screen image and even with a 55 W lamp close by the clarity is enough. But for brighter environments the mirror coating lead to a problem.

6.3.2 Improvement and uncertainty

The uncertainty when measuring the screen at an increased angle is higher as the light does not have the right angle towards the lux meter. Therefore the only possible conclusion to draw is that the amount of illumination has decreased but the quantity is harder to specify. This is especially true when looking at the result from mirror material 2 as the result varies a lot more than the result from both mirror material 1 and test with no coating. The reason for this might be as the lux values are so small and smaller variations in the set up gives a lot higher variations. To rule out those variations and get a more reliable result would be to repeat the test a couple of times and in between take down and then up the equipment. This would in a better way counter out the small align problems in the conduction of the test. This is however very time consuming but can be something for future experiments.

The measurement for the increasing degrees also meant increasing distance to the center of the screen. This also affects the result and decreases the lux levels as the measuring device is further away from the source. The reasoning behind using this set-up was that the with the same distance to the center it would actually put the measuring device closer to the screen and that would affect the result.

One way to counter this would be to narrow the picture on the monitor to just a white dot in the center representing a single light source. But the problem that approach would be that the lux levels automatically would be lower and that also increases the uncertainty.

One problem that still exists is to quantify how much background lights lower the image clarity. The tests conducted proves more that the illumination from the screen decreases but not gives the whole picture of at what levels no image from the screen at given screen brightness can be detected. The equipment for this was not available for this project but something interesting to look in to in the future.

6.4 Conclusion from Program and platform

The UWP platform is great for single usage and will be able to fit the requirement for SITS. As long as the device is used for a purpose and not allow flexibility outside of the working area. It works well when gathering information from a pre decided HTTP source or connecting to devices with a purpose predefined in the program. The problems start to stack up when a greater flexibility is needed. This is the case when designing the Smart Mirror towards personal usage or the household environment. In the home, people have different needs and use the mirror for different tasks and use different applications and this is hard to pre-program in the UWP environment.

The UWP has also another disadvantage when reaching a more flexible program base. The applications created for the platform is closed and not easy to control programs outside of the main application. That would make it close to impossible to download another application from another developer and run it inside of the mirror program. The reason for that is because UWP is created as a universal platform and to protect the devices running the OS the applications has to be regulated harder than applications written for a single device.

For the household and personal Smart Mirror, it might be better to run something like Android or IOS that already have customization build into the OS and have a huge app base available to download via respective purchase applications. That is however not possible when using the RPIs CPU as it does not support those IOSs but might be in the future.

One of the most positive outcomes of using the UWP is the easy deployment with the Visual Studio and how changes are experienced on the device directly in debug mode. This allows to see and quickly change the interface to fit the desired profile. The UWP also have a great support for visual GUI programming with the WPF and Xaml.

Chapter 7

Questions Answered

7.1 Question 1: How much energy does the system consume?

As seen from the result the biggest energy driver is the screen. Because the need of bright setting the consumption is little higher than for a normal screen but the general consumption is a little above 100 W and the sleep mode consumption around 3 W. The screen is about 97 % of the total consumption and the rest is consumed by the RPI. This varies however a little dependent on the tasks and how large the processing duty is.

7.2 Question 2: What is the light transparency?

Depending on the mirror material the transparency varies. To obtain a mirror effect the transparency goes down to around 30 % depending on the background lighting. The lighter the background lights are the more transparency is needed. Depending on the reflectiveness of the material this figure is about 15-30 % compared to 5-10 % which is obtained when no mirror material is used when the background light is 35 to 55 W light bulb. It is therefore important to choose the right mirror coating for the right environment.

7.3 Question 3: How well does the system fare compared to other devices?

When it comes to the energy consumption the system consumes more than a TV with the same size and even newer OLED screening devices. This derives from the bright light settings that are required due to the mirror coatings. Compared to a modern computer the consumption is higher for the Smart Mirror as well during normal load but the computer has a higher max consumption when operating heavy duty. If compared with a laptop the consumption is highly dependent on the screen size which makes the computer consume less energy than the Smart Mirror. For kiosk models the consumptions are about the same. The models compared with in this thesis do have a little bigger screen but also a little bigger consumption on a whole.

Chapter 8

Continued Work

8.1 Hardware and Programming

The main goal in the future is to fully integrate the screen and make the basic screen adjustments manageable from the RPi and the program interface. This would most importantly allow full sleep mode and therefore also lower the energy consumption on a total. Especially when having in mind that the goal of the prototype is only to be active under store hours which means about 8-10 hours a day. The rest of the time the device would be in true sleep mode and thus unnecessarily consume around 101 W instead of around 3 W as measured in table 5.2 and 5.1.

It would also be possible to integrate a microphone in the device to allow speech control and for the household environment also messages and online phone calls. This would make the device more flexible and have a bigger impact on the interaction. The microphone would also open up the possibility to integrate the current version of AI as Apples SIRI or Microsoft Cortana. Cortana is especially interesting when running on UWP as it is fully supported by the OS.

To integrate a camera would also be some things that have a lot of use. This for taking pictures or sending videos for the personal Smart Mirror or to integrate sign control for the mirror. This would also allow the device to activate when someone is approaching it and for a more flexible usage. It can even be used with facial recognition software to be used as identification but probably something also for the personal usage.

8.2 Future Studies

It would be interesting to see what saturation light levels that the mirror materials can allow as that figure sets restrictions on where the device can be used. It will never be as bright as a normal display because of the mirror quality but with the known saturation levels of different mirror materials, the display can be coated after the use it is intended for. For example, a Smart Mirror in a store environment does not have to use the same coating as a device used in a brighter area but to choose right this has to be quantified.

It would also be interesting to conduct a study of how the mirror is used in the store. This would be more of a field study but would help with the development of the software to be optimized for the store environment. It would also help in the hardware development and better locate what issues might derive from using the build of this device. Even if this device has a lot common with the digitalized kiosk the possibilities for this platform derives from the integration into the environment and then also comes with its own problems. These are not covered in this study and but have to be investigated for this platform to have a future and be viable to invest in.

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Appendix A

Measurement from Study

A.1 Sleep Mode

Minute	Screen	RPI	Total
1	1 W	3 W	4 W
2	1 W	2 W	3 W
3	1 W	2 W	3 W
4	1 W	3 W	4 W
5	1 W	2 W	3 W
Average	1	2	3

Table A.1: Sleep Mode test 1

Minute	Screen	RPI	Total
1	1 W	2 W	3 W
2	1 W	3 W	4 W
3	1 W	3 W	4 W
4	1 W	2 W	3 W
5	1 W	3 W	4 W
Average	1	3	4

Table A.2: Sleep Mode test 2

Minute	Screen	RPI	Total
1	1 W	2 W	3 W
2	1 W	2 W	3 W
3	1 W	2 W	3 W
4	1 W	2 W	3 W
5	1 W	3 W	4 W
Average	1	2	3

Table A.3: Sleep Mode test 3

Minute	Screen	RPI	Total
1	1 W	2 W	3 W
2	1 W	3 W	4 W
3	1 W	2 W	3 W
4	1 W	2 W	3 W
5	1 W	2 W	3 W
Average	1	2	3

Table A.4: Sleep Mode test 4

Minute	Screen	RPI	Total
1	1 W	2 W	3 W
2	1 W	3 W	4 W
3	1 W	2 W	3 W
4	1 W	2 W	3 W
5	1 W	3 W	4 W
Average	1	2	3

Table A.5: Sleep Mode test 5

A.2 Low Activity Mode

Minute	Screen	RPI	Total
1	99 W	2 W	101 W
2	99 W	2 W	101 W
3	100 W	2 W	102 W
4	100 W	3 W	103 W
5	99 W	2 W	101 W
Average	99 W	2 W	102 W

Table A.6: Low Activity Mode test 1

Minute	Screen	RPI	Total
1	99 W	2 W	101 W
2	100 W	3 W	103 W
3	99 W	2 W	101 W
4	99 W	2 W	101 W
5	99 W	2 W	101 W
Average	99 W	2 W	101 W

Table A.7: Low Activity Mode test 2

Minute	Screen	RPI	Total
1	100 W	3 W	103 W
2	99 W	2 W	101 W
3	100 W	3 W	103 W
4	100 W	2 W	102 W
5	99 W	2 W	101 W
Average	100 W	3 W	102 W

Table A.8: Low Activity Mode test 3

Minute	Screen	RPI	Total
1	99 W	2 W	101 W
2	100 W	3 W	103 W
3	100 W	3 W	103 W
4	99 W	2 W	101 W
5	100 W	3 W	103 W
Average	100 W	3 W	102 W

Table A.9: Low Activity Mode test 4

Minute	Screen	RPI	Total
1	99 W	2 W	101 W
2	100 W	2 W	102 W
3	99 W	2 W	101 W
4	99 W	2 W	101 W
5	100 W	3 W	103 W
Average	99	2	102

Table A.10: Low Activity Mode test 5

A.3 High Activity Mode

Minute	Screen	RPI	Total
1	101 W	3 W	104 W
2	101 W	4 W	105 W
3	100 W	4 W	104 W
4	101 W	3 W	104 W
5	101 W	5 W	106 W
Average	101 W	4 W	105 W

Table A.11: High Activity Mode test 1

Minute	Screen	RPI	Total
1	100 W	3 W	103 W
2	100 W	4 W	104 W
3	101 W	5 W	106 W
4	100 W	5 W	105 W
5	101 W	6 W	107 W
Average	100 W	5 W	105 W

Table A.12: High Activity Mode test 2

Minute	Screen	RPI	Total
1	100 W	5 W	105 W
2	102 W	5 W	107 W
3	101 W	6 W	107 W
4	102 W	6 W	108 W
5	101 W	6 W	107 W
Average	101 W	6 W	107 W

Table A.13: High Activity Mode test 3

Minute	Screen	RPI	Total
1	100 W	3 W	103 W
2	101 W	4 W	105 W
3	102 W	5 W	107 W
4	101 W	3 W	104 W
5	103 W	6 W	109 W
Average	101 W	5 W	106 W

Table A.14: High Activity Mode test 4

Minute	Screen	RPI	Total
1	101 W	4 W	105 W
2	102 W	6 W	108 W
3	102 W	5 W	107 W
4	101 W	5 W	106 W
5	102 W	5 W	107 W
Average	102 W	5 W	107 W

Table A.15: High Activity Mode test 5

A.4 Long Term Alternating Test and calculated versions

Time	Mode	W	kW
0 h 5 min	Sleep	101 W	0.01 kW
0 h 10 min	Sleep	101 W	0.02 kW
0 h 15 min	Sleep	102 W	0.03 kW
0 h 20 min	Sleep	102 W	0.03 kW
0 h 25 min	Active	104 W	0.04 kW
0 h 30 min	Active	105 W	0.05 kW
0 h 35 min	Sleep	101 W	0.06 kW
0 h 40 min	Sleep	102 W	0.07 kW
0 h 45 min	Sleep	102 W	0.08 kW
0 h 50 min	Active	106 W	0.09 kW
0 h 55 min	Active	105 W	0.10 kW
1 h 0 min	Sleep	101 W	0.10 kW
1 h 5 min	Active	105 W	0.11 kW
1 h 10 min	Sleep	102 W	0.12 kW
1 h 15 min	Sleep	101 W	0.13 kW
1 h 20 min	Sleep	103 W	0.14 kW
1 h 25 min	Sleep	102 W	0.15 kW
1 h 30 min	Sleep	101 W	0.16 kW
1 h 35 min	Active	104 W	0.16 kW
1 h 40 min	Sleep	102 W	0.17 kW
1 h 45 min	Sleep	101 W	0.18 kW
1 h 50 min	Sleep	102 W	0.19 kW
1 h 55 min	Active	105 W	0.20 kW
2 h 0 min	Sleep	102 W	0.21 kW
2 h 5 min	Sleep	101 W	0.22 kW
2 h 10 min	Active	106 W	0.23 kW
2 h 15 min	Sleep	101 W	0.23 kW
2 h 20 min	Sleep	102 W	0.24 kW
2 h 25 min	Active	105 W	0.25 kW
2 h 30 min	Active	106 W	0.26 kW
2 h 35 min	Sleep	101 W	0.27 kW
2 h 40 min	Sleep	101 W	0.28 kW
2 h 45 min	Sleep	103 W	0.29 kW
2 h 50 min	Sleep	102 W	0.30 kW
2 h 55 min	Active	104 W	0.30 kW
3 h 0 min	Sleep	102 W	0.31 kW
3 h 5 min	Active	106 W	0.32 kW
3 h 10 min	Sleep	101 W	0.33 kW
3 h 15 min	Sleep	102 W	0.34 kW
3 h 20 min	Sleep	102 W	0.35 kW
3 h 25 min	Sleep	101 W	0.36 kW
3 h 30 min	Active	105 W	0.36 kW
3 h 35 min	Sleep	102 W	0.37 kW
3 h 40 min	Sleep	102 W	0.38 kW
3 h 45 min	Sleep	102 W	0.39 kW
3 h 50 min	Active	107 W	0.39 kW
3 h 55 min	Sleep	101 W	0.40 kW
4 h 0 min	Active	104 W	0.41 kW
Average:	30 % Active	103 W	0.103 kW per h

Table A.16: Long Term Alternating Test over 4 Hours

A.5 Hardware Performance

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	7%	<1%	9.1 MB
Low	<1 %	11%	<1%	10.0 MB
Normal	6 %	50 %	<1 %	41.1 MB
High	69 %	100 %	4 %	223 MB

Table A.17: RPI Performance test 1

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	6%	<1%	9.5 MB
Low	<1 %	10%	<1%	10.6 MB
Normal	8 %	37 %	<1 %	53.7 MB
High	63 %	100 %	7 %	198 MB

Table A.18: RPI Performance test 2

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	8%	<1%	9.0 MB
Low	<1 %	11%	<1%	10.4 MB
Normal	11 %	61 %	<1%	57.2 MB
High	68 %	100 %	<1 %	252 MB

Table A.19: RPI Performance test 3

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	6%	<1 %	10.9 MB
Low	<1 %	7%	<1%	13.1 MB
Normal	10 %	43 %	<1 %	47.8 MB
High	46 %	100 %	<1 %	184 MB

Table A.20: RPI Performance test 4

Mode	CPUA	CPUT	CPUL	RAM
Sleep	<1 %	4%	<1%	9.7 MB
Low	<1 %	9%	<1%	11.9 MB
Normal	13 %	53 %	1< %	60.1 MB
High	65 %	100 %	3 %	217 MB

Table A.21: RPI Performance test 5

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