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PERSISTENCE OF VISION DISPLAYS

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ABSTRACT

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Persistence of vision displays are a relatively new display type. As time has gone by more applications are being made that are utilizing persistence of vision displays. These applications include for example advertising displays and propeller clocks. A typical persistence of vision display works by rapidly rotating a single strip of light-emitting diodes while a microcontroller is switching the diodes on and off. This creates an illusion of a picture that is floating in the air. The research problem was to find out where this display type is being used and what benefits it has compared to other display types.

A literary survey was conducted to find out about how to design persistence of vision displays, what are some of the applications where the display has been used, and how a cylindrical persistence of vision display is created. The results of the research are covered in chapters 2, 3 and 4.

The design process is showcased by explaining the operating principles of each of the most important parts for the operation of a persistence of vision display. The covered process is meant to be as general as possible to maximize the relevancy of the research. After covering the design choices, the work delves into the persistence of vision display applications. Persistence of vision has been used in the advertising system in Shanghai's metro tunnels where the display relies on a moving train instead of a rotating display. In addition, one more typical persistence of vision display application for advertising is covered. An application for gaming purposes and a three-dimensional persistence of vision display are highlighted as well. The final part of this thesis explains the design process and implementation of a cylindrical persistence of vision display.

Keywords: Persistence of vision, displays, three-dimensional, electronics

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POV-näyttö (eng. Persistence of vision, POV) on suhteellisen uusi näyttötyyppi. Ajan kuluessa POV-näytöt ovat alkaneet esiintymään lukuisissa sovelluksissa eri yhteiskunnan toiminnan alueilla. Tyypillisen POV-näytön toiminta perustuu LEDien (eng. Light-emitting diode, LED) nopeaan pyöritykseen, jonka aikana niitä sytytetään päälle ja pois mikrokontrollerin toimesta. Näin saadaan luotua illuusio ilmassa leijuvasta kuvasta. Tässä työssä esiteltävän tutkimuksen tarkoitus on kartoittaa, mihin kaikkiin tarkoituksiin tätä näyttötyyppiä käytetään sekä miksi sitä käytetään, eli mitä etuja sillä on kilpailijoihinsa nähden.

Tutkimus toteutettiin suorittamalla kirjallisuusselvitys aiheesta. Tutkimuksen keskeisimmät aiheet olivat POV-näytön suunnittelu, sen sovellukset ja käyttökohteet sekä sylinterin muotoisen POV-näytön suunnitteluprosessi. Tulokset esiteltiin vastaavasti kappaleissa kaksi, kolme ja neljä.

Yleinen suunnitteluprosessi on esitetty selittämällä tärkeimpien komponenttien keskeisimmät toimintaperiaatteet, sekä niiden käyttötarkoitukset käsiteltävässä näyttötyypissä. Suunnitteluprosessia käsitellään työssä mahdollisimman yleisesti, jotta tutkimus olisi relevantti enemmän kuin yhden sovellustyypin osalta. Suunnitteluprosessin avaamisen jälkeen työssä siirrytään POV-näytön käyttösovelluksiin. Tätä näyttötyyppiä on käytetty esimerkiksi Shanghain metron tunneleissa mainontaan, jossa junan nopea liike mahdollistaa näytön toiminnan ilman näytön ledien pyörittämistä toisin kuin tavallisessa POV-näytössä, jossa moottorin aiheuttama rotaatio aiheuttaa näytölle ominaisen kuvan illuusion. Lisäksi muita käyttökohteita, joita työssä esitellään, ovat tavallisempi POV-näyttö mainontaan, videopelien pelaamiseen käytettävänä monitori sekä kolmiulotteinen näyttö. Työn loppuosassa tarkastellaan vielä esimerkkinä projektia sylinterin muotoisen näytön rakennusprosessista. Tarkoituksena kyseisellä projektilla on vielä avata varsinkin kolmiulotteisen POV-näytön suunnitteluprosessia ja siihen liittyviä yksityiskohtia. Työn aivan viimeinen kappale toimii yhteenvetona, jossa tarkastellaan saatuja tutkimustuloksia sekä tuodaan esiin, millaisen jatkotutkimuksen voisi suorittaa myöhemmin.

Avainsanat: Persistence of vision, näytöt, kolmiulotteinen, elektroniikka

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SISÄLLYSLUETTELO

SYMBOLS AND ABBREVIATIONS

CPU	Central processing unit
FPGA	Field-programmable gate array
IR	Infrared
LED	light-emitting diodes
POV	Persistence of vision
RF	Radio frequency
RPM	Revolutions per minute
SVD	Swept volume display
3D	three-dimensional
DW	display width
f	frequency
h	thickness of the LEDs
r	radius of the rotary part
T	period

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1. INTRODUCTION

Displays play a huge role in forming an interface between software and end users. Many different types of displays have been made using differing approaches and technologies. This thesis will be focusing on Persistence of vision displays.

Persistence of vision (POV) refers to a natural occurrence that happens when eyes see single images that change at a rapid rate [1]. The human eye can retain an image for about $1/16^{\mathrm{th}}$ of a second [1]. If the images are being displayed at a faster rate than the human eye can retain them for, then the images converge together into a single object. In POV-displays, this phenomenon is utilized to form an illusion of images floating in the air. This is achieved by blinking light-emitting diodes (LEDs) while the display is being rapidly rotated. Typical images that can be portrayed this way are for example warning signs or well wishes. Figure 1 portrays a POV-display.

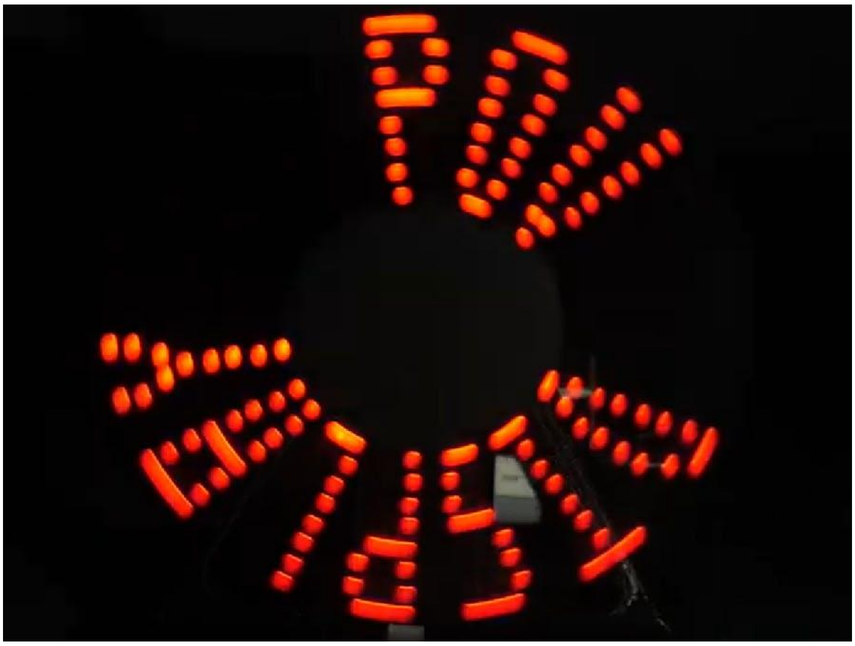

***Figure 1**.* A functional POV-display depicting the message “POV DISPLAY” [2].

In this thesis the research problem is to find out whether POV-displays have actual applications, and what strengths typical POV-displays have compared to other display types. POV-displays are relatively new and as such these questions are essential to answer in order to get a grasp of this new technology and its place in the world.

The hardware for a typical POV-display is examined in chapter 2. Chapter 3 focuses on POV-display applications and gives insight on another kind of POV-display found in the subway tunnels of Shanghai. A cylindrical three-dimensional (3D) POV-display is later showcased in chapter 4 and the thesis is concluded in chapter 5.

2. HARDWARE CONSIDERATIONS FOR A PERSISTENCE OF VISION DISPLAY

The typical POV display has a framework, a motor, LEDs, a power supply, a microcontroller and often a sensor as seen for example in works [1, 3, 4]. Other than the sensor, the parts can be seen in Figure 2, where the parts have been highlighted as follows: 1. Framework, 2. Motor, 3. LEDs, 4. The connections leading to the power supply, 5. Microcontroller.

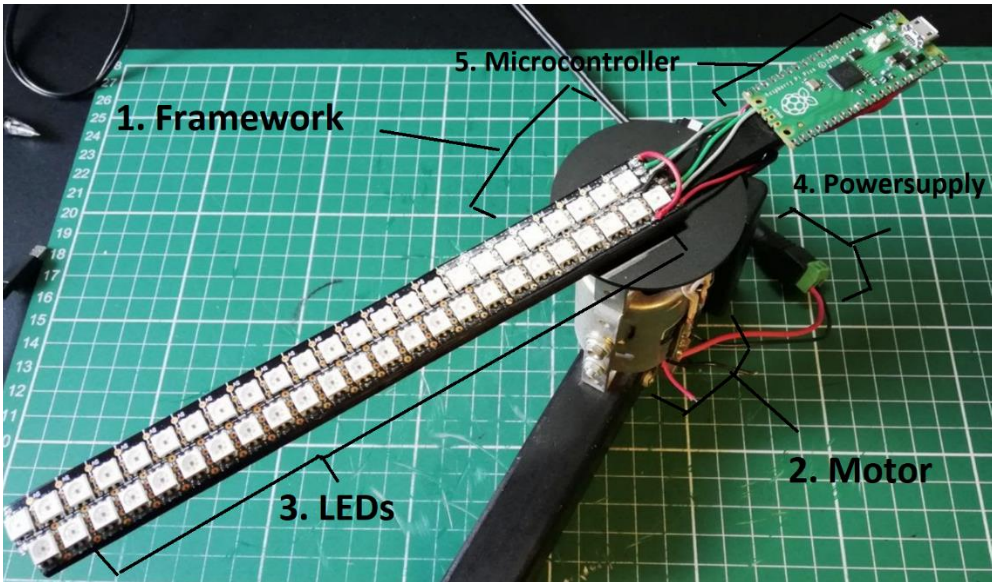

Figure 2. Common POV display parts [5].

The technical limitations are largely based on the way in which the human visual system processes information. Human vision is generated by retinal photoreceptor cells, which release photo-pigment. The released photo-pigment excites the sight neural currents [6]. Since the entire imaging process includes many biochemical reactions that take time, the temporary hold-up time of vision memory causes persistence of vision to be around 50 – 200 ms. Imaging can thus be realised by subsequentially illuminating pixels or LEDs that reach this target frequency [7]. The target frequency can be calculated by $\boldsymbol{f} = \frac{\mathbf{1}}{\mathbf{T}}$ [8]. It can then be calculated that $\boldsymbol{f_{target}} = \frac{\mathbf{1}}{\mathbf{50\ ms}}$ = 20 HZ. Our POV display system needs to be able to produce a frequency over 20 HZ for the LEDs. Another thing that needs to be taken care of is the revolutions per minute (RPM) with which the illusion is good enough. This is system specific but a typical value for the RPM varies between 1800 to 3000 depending on the LED flickering frequency [3].

2.1 MOTOR

The display needs something to provide the needed RPM. A typical solution is a DC motor [1]. The two motor types that are most used are the brushless- and the brushed DC motor.

The brushed DC motor is an electric motor that is internally commutated and designed to work with a direct current source [9]. The biggest advantages of brushed DC motors are low initial cost as well as uncomplicated control of the motor speed. Disadvantages are short lifespan and frequent maintenance for high intensity uses, such as a POV display. Maintenance involves replacing the carbon brushes which are used to carry the electric current. It also involves cleaning or in some cases replacing the commutator. [10]

A typical brushless DC motor uses one or multiple permanent magnets in the rotor and electromagnets on the motor casing for the stator. The motor-controlled converter inside a brushless DC motor converts DC to AC. This design is mechanically simpler than the brushed DC motor design. Brushless DC motors eliminate the complicated process of transferring power to the spinning rotor from outside the motor. Hall effect sensors or other similar devices can be used by the motor controller to sense the rotor's position. This gives the controller the ability to precisely control the system's many elements such as the phase or timing. Advantages of brushless motors include for example: long lifespan and little or in some cases no maintenance. Disadvantages include relatively high initial cost and more complex motor speed controllers. [10]

AC motors have also been used [3]. They are generally more powerful than DC motors, have high durability and lifespan, and controllable starting current levels and acceleration [11]. AC motors have problems though: Usually all the electronic elements on the circuit work with DC power so a rectifier bridge must be added to the circuit which in turn complicates the design and adds to the costs.

The motor needs to be picked so that it makes the product most valuable for the end user. For a typical POV display the motor must fulfil a set of demands: It must be low maintenance, relatively low noise, and it must have a long lifespan [1].

2.2 Framework

Typical framework consists of a solid base on which the entire setup is placed on and a bar serving as the axis for the rotating LEDs [1,3]. The framework must be rigid enough so that it withstands the vibration that the rotation causes at high RPM. This is a reliability concern that must be taken into consideration and tested properly before finishing the development of the product. The size of the framework varies based on the application.

Furthermore, the size can be reduced by placing the power supply elsewhere than in the base of the system or by using wireless power transfer [3].

POV displays are often used in advertisements and message displaying systems. Therefore, the framework is often designed to fit the wanted aesthetic of the end product. A fitting aesthetic can cause a more complicated and costly frame for the device and may thus affect the price of the display.

2.3 Light-emitting diodes

A light-emitting diode is a p-n junction diode that emits light when current flows through it [12]. The current source must give enough current for the LEDs to turn on.

The LED type is application dependent. For example, if the application requires colours to be presented then according to the RGB colour model RGB LEDs would have to be chosen [13]. Because brighter LEDs generally require a higher amount of current running through them it might affect the decision on which power source to use. It is apparent that if the display is meant to be used indoors, the LEDs don't have to be as bright as when placed outside where there is more sunlight. The effect of persistence of vision is better for brighter LEDs [14]. When determining which LEDs to use for a project one should keep these design aspects in mind.

2.4 Power supply

In a POV display application the power supply is often used to give two different voltages for the motor as well as the micro controller and LED circuitry [1]. LEDs require relatively low power. Thanks to the persistence of vision effect the amount of power the LEDs need is minimized even further since there is no need to fill an entire display area with LEDs.

Typical value for the microcontroller is 5 V because the popular microcontroller boards such as Arduino nano and Arduino uno as well as Raspberry Pi boards run on the 5 V supply voltage [15,16,17].

2.5 Microcontroller

The microcontroller is the core of the system. It controls which LEDs are illuminated and when. Many projects such as [1] and [3] use popular microcontroller boards because they are simple to program and to connect with other parts. A microcontroller system consists of one or more central processing units (CPUs) along with memory and programmable input/output devices. The executable code must fit in the system's memory.

Therefore, the memory size must be taken into account when designing code for a POV display system.

For the proper operation of the device the microcontroller is often fed information from outside sensors. A positional sensor is used in many POV displays for example [1, 3, 18]. The microcontroller receives a signal from the positional sensor and thus gets the information on the angular position.

2.6 Sensors

As mentioned earlier many POV displays use positional sensors to guarantee a more robust performance. Two good sensor types for tracking the position of the LED strip are the Hall-effect sensor and the Infrared (IR) sensor. Both sensor types have their pros and cons. [19]

The infrared sensor contains two parts, an infrared emitter and an infrared receiver. One of the parts is placed on the rotating side of the device and the other part would be on the stationary side. When the emitter and the receiver cross each other, it results in a “hit”, which can then be used to calculate the optimal RPM value. IR sensors are highly usable. They can be used with any motor type and they are unaffected by the use of a gearbox. The biggest concern for this sensor method is its accuracy. The use of an IR sensor inherently results in a possibility for some fall trips or even failed trips. This means that the number of samples must be increased to prevent these errors. One such way is to add for example two or four sets of IR sensors. [19]

The Hall-effect sensor is relatively inexpensive and easy to implement. It has two major limitations though. The first one is that this method is limited to motors that have a rotating magnetic pole within. This means that the sensor isn’t as generic and is a better fit for AC motors and certain DC motors. The most obvious DC type motor for this sensor is the brushless DC motor. This isn’t really a problem as explained in chapter 2.2 since the brushless DC motor is a good fit for a POV display anyway. The second limitation is that because these sensors require a moving magnetic pole to measure it would be difficult to implement the sensor with a gearbox design. This is because a moving magnetic pole would have to be created on the rotating apparatus side that would cross the Hall-effect sensor during its rotation. A design such as this is possible, but it complicates the design and could cause some unforeseen issues. [19]

3. POV DISPLAY APPLICATIONS

The POV display is a display device so it has applications in advertising, education, entertainment, animation, toys and games, malls, 3D displays, and it can also be used as a propeller clock [20].

3.1 POV displays in advertising

A bigger portion of advertising is going digital [21]. This is constantly driving the technology behind it to evolve and to separate from the rest so that the advertisement works better [22]. POV displays have been used as marketing tools because of their unique qualities.

Metro tunnels in Shanghai, China have adopted the LED POV display principle and made it into an advertising channel for passengers traveling on the train [23, 24]. There are two different types of techniques being used for advertising in the metro tunnels relating to persistence of vision. First method is to use LED screens. The images of an advertisement are placed one by one on a long screen panel that extends from beginning of the tunnel to the end. The passengers on the train see the images as if they were moving due to persistence of vision. For the illusion to work the train must move fast enough. [24] The trains in Shanghai move at the speed of 35-40 km/h [25]. The second method is to place RGB LED pillars on the walls with sufficient distance from each other. In Shanghai's case the LED strip system is implemented by the Jinri Group [24]. Their system specifications for the LED system require the LED pillars to be placed 600 mm from each other [26]. Given that the lowest speed for a metro train in Shanghai is 35 km/h which is about 9,72 m/s the amount of LEDs that would fit into the timespan of a second would be $\frac{\mathbf{9{,}72}\ \boldsymbol{m/s}}{\mathbf{0{,}6}\ \boldsymbol{m}} \approx \mathbf{16{,}2}\ \boldsymbol{pc/s}$. This translates to $\mathbf{16{,}2}$ HZ which is on the border of being an acceptable frequency for persistence of vision. Of course, for the higher speeds the illusion works better. Other relevant technical parameters are that the LED pillars must be placed less than 10 cm from the wall, it has a 25 W/LED pillar power consumption and the color depth is 8 bits [26]. The system is shown in Figure 3.

Figure 3. LED pillars on the wall of Shanghai's metro tunnel [26].

LED POV displays are also used in advertising in a smaller scale than metro tunnel long systems of LED image panels or LED pillars. LED fan displays use the principle of persistence of vision to create the effect of an image or animation in air. The advertisement can include text, pictures or even animation. One such display is the FY3D-Z1 by Utorch. The display can be used for advertising for a shopping mall, clothing store, restaurant, or any other display area according to the company's statement. The fan supports many file formats ranging from JPG and PNG to MP4 and AVI. The fan uses one single strip of RGB LEDs, and the persistence of vision effect is generated by rotating the fan while the microcontroller lights the correct LEDs. For the FY3D-Z1 the manufacturer gives a power consumption of 10-15 W and a lifespan of 11 years. [27] The display is shown in figure 4.

Figure 4: Utorch FY3D-Z1 POV display [28].

3.2 POV displays in games and entertainment

In 2016 on hackaday.io a team of French and Taiwanese engineers created a project called SPINO. It was a POV display with 32 RGB LEDs that would connect to a smartphone via Bluetooth. The purpose of the display was to be a transparent display device to play retro games with. The team found that displaying games on the POV screen posed its own set of problems. Importing Space Invaders which was an old game from 1978 [29] required the team to change the coordinate system from cartesian to polar coordinates. This changed the nature of the game quite a bit and was eventually declared as too awkward. Another challenge they had was related to porting Doom on SPINO. Doom is a first-person shooter game developed in 1993 [30]. Porting it on the SPINO resulted in the team creating an algorithm to transform the games graphics into a cel-shaded form. [31] Cel-shading makes the outlines easier to see, which can improve the visibility of what is happening on the screen [32].

As seen, there are problems in porting games to POV display. It is easy to understand why the technology hasn't been picked up in gaming. Figure 5 shows SPINO.

Figure 5. A game being played on SPINO [33]

3.3 3D POV displays

The POV displays this far have presented the images in a 2D space by the use of LEDs. However there have also been attempts to have POV displays working in three dimensions [3]. These stereoscopic or Multiview display systems are considered better than the two-dimensional displays because such systems can provide important cues for the human brain to process three dimensional objects, in particular depth [34]. Stereoscopic displays often come with limitations though. Inconsistencies in the 3D information cause visual confusion and fatigue. This is undesirable because it leads to a more uncomfortable end user experience. The inability to provide full 360 ° angles of view without requiring special head gear or glasses generally is another hinderance. Volumetric displays are a subgroup of stereoscopic displays and 3D POV displays are subgroup of volumetric displays. POV displays answer many of the typical problems. They can render 3D images without the need to use any kind of head gear or glasses. Volumetric displays can roughly be divided into two groups of display devices: Static volumetric displays and swept-volume displays. Both kinds have been used in order to create 3D POV displays. [35]

A Chinese team created an 8x8x8 LED cube in 2018. The project was created to bring a completely new entertainment experience for outdoors or indoors. [36] The system is a POV display system in the sense that it attempts to trick the human eye with fast lighting of the LEDs, but the LEDs are placed in a cube formation with no moving parts. The system is therefore a static volumetric display. The problem with static volumetric display such as this, is that it includes complex image addressing optics and the field of view is restricted to 90 ° because the display is not unidirectional. [35]

Swept volume displays (SVD) were created in [3] and [35]. The SVD in [35] consisted of multiple panels; each panel rotates and has various image panes. Each of the image panes contain a field-programmable gate array (FPGA) that controls how the LEDs operate. This SVD is a class of auto-stereoscopic display devices, that can render 3D images without having to use special headgear. Because of the active LED emission, it can also display 3D opaque objects over other systems. [35] In [3] the SVD created was a cylindrical POV display. The LEDs are rotated in a circular motion along the axis of the cylinder. Since the LEDs are moving in three dimensions this creates the wanted 3D effect. The advantage in [3] compared to [35] is that the design requires less LEDs and FPGAs. However, there are resolution constraints when the number of LEDs is small. The team was able to create a resolution good enough to display distinguishable characters that can be used in warning signs, advertisements, billboards etc. [3]

4. EXAMPLE PROJECT: DESIGN AND IMPLEMENTATION OF A CYLINDRICAL PERSISTENCE OF VISION DISPLAY

I chose the example project to be the design and implementation of cylindrical Persistence of Vision Displays. The main source where the project was created is [3]. The choice to focus the rest of this chapter on this project was made because it covers the design process of creating a 3D POV display and it also focuses on wireless power transformation.

As covered earlier in chapter 3.3 the project consisted of creating a cylindrical POV display. The display is on the circumference of a cylinder and thus viewable from any direction around it. The goal was to create a display that has sufficient resolution to let viewers clearly distinguish different symbols, numbers, and letters. The cylindrical display is shown below in Figure 6.

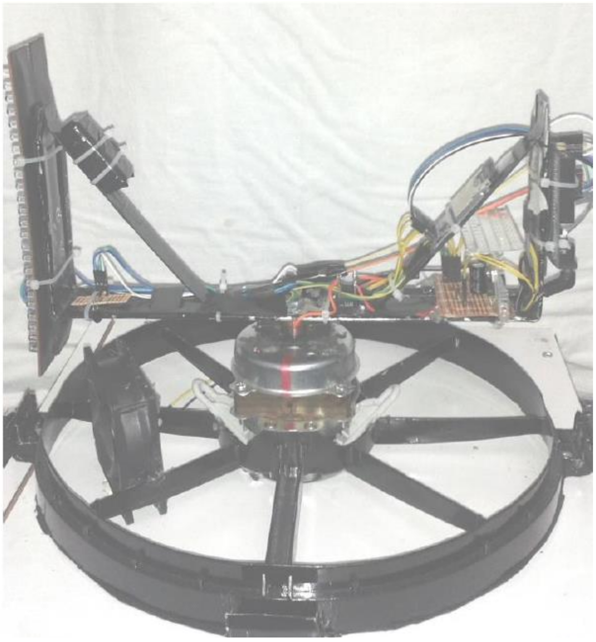

Figure 6. *Final prototype of the cylindrical POV screen* [3].

4.1 Example project: Mechanical components for cylindrical persistence of vision display

The design process starts from creating the framework. As established earlier in chapter 2.3, the framework must withstand the vibrations caused by rotation. In this project a mechanical framework was created with this matter in mind. The framework is built of two parts: A stationary part that holds the motor and other parts that can be placed on it, and a part that rotates that supports the LEDs, the microcontroller, and the related electronic circuitry. The rotary part is made such that it covers the whole surrounding area. This part forms the rotating display screen. [3]

A see-through cover can be added if safety regarding the rotary part is a concern. Since the safety cover is see-through it doesn't hinder the POV effect. [3]

The motor shaft is designed so that it can support the rotary load without loss in its performance. In addition, the motor shaft and the rotary part are designed so that they have the same centre of mass to remove fatigue on the shaft. The solution also reduces vibrations and stresses. [3]

4.2 Example project: Electrical components for cylindrical persistence of vision display

The POV display system contains many electrical components. The components define the system's electrical operation.

For the microcontroller Arduino UNO is chosen. It controls the operation of the system. It is simple to program the device and to connect it to the rest of the parts. The wanted characters are displayed by using LEDs. 24 red LEDs are used to form the POV screen. The LEDs are driven by three shift-registers to convey images with the resolution of 24×77. To attain the wanted RPM an AC motor is used. Brushes and commutator supply the power to the rotating screen. An infrared sensor is used to monitor the position of the rotating part. Voltage regulators and a rectifier are introduced to the system to provide direct current without power disconnections. Arduino MEGA is used for controlling when the display starts and stops its operation. It has three relays and two push buttons for starting and stopping the POV display. A computer hosts the software that controls and runs the system. Bluetooth is then used for transferring the images from the computer to the POV display. The images received from the Bluetooth are stored on a MultimediaCard that has a 1 GB storage capacity. Electrical power supply is required for feeding power to the many parts of the system. Two supplies are chosen to be used in this design. One is for the control circuit and the other is to feed the display with 24V/3A. For the rotary part of the screen no batteries are required because the brushes supply its power. Lastly a cooling fan is used to lower the operation temperature of the AC motor. [3]

4.3 Example project: Image processing and control design for cylindrical persistence of vision display

The operation begins with the PC transmitting images to the microcontroller. This triggers the LEDs to show the wanted numbers, pictures, or messages. The microcontroller stays in a waiting state until it gets a signal from the infrared sensor that tells the angular position of the LEDs. Then it starts its operation according to the images received from the PC. [3]

If the motor is not operating at a sufficient speed to display the images correctly, the microcontroller halts sending signals to the LEDs to save energy. This saved energy can then be used to increase the speed of the motor. In order to convert the used images into matrices that the microcontroller can easily operate with, image processing is used. [3]

4.4 Example project: Synchronization of cylindrical persistence of vision display

Synchronization is achieved by utilizing the infrared sensor. It gives a reference point that serves as the starting point for image displaying. Arduino is connected to the infrared sensor so that it gets the information. This serves as an information link between the microcontroller and the rotary part. It is important to relay the information between the microcontroller and the motor so that the motor speed and microcontroller frequency are the same. This results in a smooth display and visible flickering is avoided. [3]

For this project a minimum frequency is twenty-five frames per second. This means that the motor must have the speed of around 1500 RPM or higher. To ensure a better performance in practice, a design choice is made that the project will operate with 30-50 HZ because that is an optimal frequency for this type of display. Therefore, the motor needs to have the speed of 1800 to 3000 RPM to work properly [3].

4.5 Example project: Resolution of the cylindrical persistence of vision display

The resolution of a display is the number of pixels in each dimension that can be displayed [37]. In two dimensional displays it is expressed as the number of pixels arranged horizontally and vertically on the display. For example, $1280 \times 720 = 921\,600$ pixels. The resolution for cylindrical persistence of vision displays depends on the number of LEDs, radius of the rotary part and the thickness of the LEDs. The latter two form the width resolution according to the following formula:

$$\mathbf{DW} = \frac{\boldsymbol{2\pi r}}{\boldsymbol{h}} \tag{1}$$

where DW is the width of the display in pixels, h is the thickness of LEDs and r is the radius of the rotary part. The display resolution is mainly dependent on the number of LEDs that are used. A better resolution is achieved by using more LEDs. However, because Arduino's number of input and output pins are limited and not enough to control the number of LEDs used in this project, LED drivers must be added to the design. The drivers also supply the needed output current that exceeds that of the common microcontrollers'. [5] For example, Arduino UNO uses ATmega328P microcontroller which has the maximum output current of 200 mA [16,38].

Synchronizing a POV display relates directly to the resolution of the display. They must be compatible so that images of high enough quality can be obtained. When the speed of the motor increases, the microcontroller has to decrease the speed with which it is sending the images, so that the aspect ratio and resolution remain unaffected. If the motor speed decreases, then the microcontroller increases the speed rate of image sending.[5]

4.6 Example project: Power considerations

The power considerations of the project can be divided into two groups: Microcontroller power supply and motor power supply [3].

The used microcontroller board Arduino Uno operates at 5V. The power could be supplied with a standard 9 V battery for instance, but it would have a relatively short lifetime. So instead a rotary transformer, which is a wireless DC power supply, is implemented. It is built of two coils: a receiver and a transmitter. There are no metal cores in the coils. This method has an acceptable range of transmitting and receiving, but it has low efficiency. As distance between the coils increases, the efficiency decreases more. Therefore, the separating distance must be set with care. [3]

The system operates using a brushless AC motor. It requires 220 V and 1.5 A for its operation. A commutator is added to the design so that it inverts the DC input into AC power. A rectifier bridge with a large capacitor to eliminate ripple voltages is added because all the electronic elements that are on the rotating part work with DC power. [3] The circuit is shown in Figure 7.

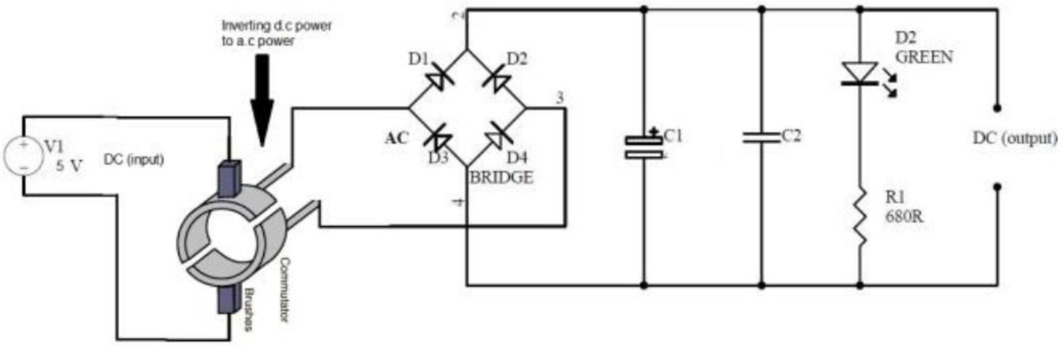

Figure 7. Schematic for the commutation circuit [3].

4.7 Example project: Data storage and communication

Arduino contains quite little memory capacity. Therefore, images are kept on a personal computer and transmitted to the screen or saved on MultiMedia card which is connected to the controller device. Storing images on a personal computer and wirelessly sending them to the board one at a time is a convenient way to show images of larger sizes.[3]

Bluetooth is one such technology that enables data exchanging over small distances. It is designed to work at a distance between 10 and 100 meters [39]. Bluetooth usage in this project has several benefits, which make it a desirable data exchange technology. Bluetooth has a faster data transfer rate than its radio frequency (RF) counterparts, it is fast and almost effortless to connect wirelessly, it doesn't use a lot of power, and the receiver as well as the transmitter are on the same module which reduces complexity [40].

The MultiMedia card is a memory card that is used for solid-state data storage. The MultiMedia card doesn't require much space since its size is comparable to that of a postage stamp. It is used as a data storage device for portable devices and it is easy to remove it for access by a personal computer. MultiMedia cards are available in different storage capacities, the largest being 512 GB [41]. The MultiMedia card is used as a backup storage device in the cylindrical persistence of vision display. It is used in the case of not being able to connect the device to the personal computer. [3]

4.8 Example project: Programming and testing procedure

As a proof of concept, the word “ICEEE 19” was chosen to be shown on the designed POV display. The microcontroller programming begins with transforming images to matrices. The microcontroller can read the pictures as matrices of ones and zeroes. The image implementation for the microcontroller is thus straight forward. [3]

The wanted symbols, in this case “ICEEE 19”, are reformed as a two-dimensional matrix of 24×77 elements. Then this matrix is converted into triggering signals that form the wanted picture by switching LEDs off and on. The LEDs are controlled by binary signals. A value of 0 is assigned to represent the LED being off and a value of 1 is assigned to represent the LED being on. The matrix can be thought of as combined column vectors. The microcontroller takes each column individually and sends trigger signals in parallel to the LEDs. After that there is a waiting break of 1-2 milliseconds to avert the column vectors from interfering with each other and takes the next vector column wise until the wanted picture is formed entirely. [3]

The software with which this POV display works was created with Visual Basic programming language. The application can process any picture with a legal Bitmap format and 24×77 resolution. The created software is called POV-screen manager. It works on Windows XP/Vista/7/8/8.1. To start the program POV screen must be connected to the personal computer by Bluetooth, after which POV-screen manager can be opened by simply clicking on it. There are five main blocks on the main screen: Picture preview to preview pictures before sending them to the device, an open button to open images that are chosen to be transmitted to the device, a send button to send the wanted information to the device, a sharpness adjustment tool that can be used to adjust the sharpness of the picture, and lastly a status bar that shows whether the system is connected, sending or disconnected. The system can thus be operated by using these functions. [3]

5. CONCLUSIONS

Persistence of vision displays are a display type that offers something different. It is a unique visual experience and as seen in the thesis it can be used in a variety of different applications. For gaming and entertainment purposes it isn't as general and robust as its competitors but for something that requires a new visual experience such as advertisements, the display has taken some ground from the other more regular displays. It can also be used to view pictures three-dimensionally without any other gear which can be useful for certain applications.

For a future study it would be fruitful to compare build costs and performance in different tasks between a POV display and for example a liquid-crystal display. This would provide more scientific data on how well POV displays can compete. Right now, there aren't many studies where POV displays have been explicitly compared to other display types.

All in all, this literary survey managed to answer the research questions and to clarify the current state of POV displays. The design process was also covered to clarify why the typical POV display has the parts that it does.

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