T.C.
DOKUZ EYLÜL UNIVERSITY
ENGINEERING FACULTY
ELECTRICAL & ELECTRONICS ENGINEERING
DEPARTMENT

Methodology

Research Project Report

by

Rabia DOĞAN

Advisor

Ph.D. Özgür TAMER

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IZMIR

ABSTRACT

The project is that Vestel Elektronik A.Ş. Interactive Personalized Smart Mirror project carried out and supported by TEYDEB 3170688 code. It is aimed to give the Smart Mirror controllable features with gestures. In this way, the product will be able to appeal to the upper customer segments and increase its market share. The main goal here is to enable users to use most of the smart mirror applications with hand movements, to eliminate the need to touch the mirror, thus to eliminate the contamination in the touched parts of the mirrors and therefore to possible dissatisfaction with the product and to ensure that the product can be used even in cases where the users cannot touch the mirror with their hands for various reasons, such as the bathroom. Although camera-based systems are generally used for gesture recognition, it will not be welcomed by many users to have a camera in a personal use area such as the bathroom.Therefore, passive infrared sensor arrays will be preferred for gesture recognition in our project. They can be preferred in application areas where cameras are relatively weak because they work with the infrared radiation emitted by living creatures. We aim to detect ini and then the movement of the hand. In this way, gesture distinction can be made with a simpler electronic design with less processing load and lower cost than a standard camera.

ÖZET

Proje Vestel Elektronik A.Ş.taarafından TEYDEB 3170688 kodu ile yürütülen ve desteklenen Etkileşimli Kişiselleştirilmiş Akıllı Ayna projesine jest ile kontrol edilebilme özellikleri kazandırılması hedeflenmektedir. Bu sayede ürün üst müşteri segmentlerine de hitap edebilecek, pazar payını artırabilecektir.Burada temel hedef kullanıcıların akıllı ayna uygulamalarının birçoğunu el hareketleri ile kullanabilmesini sağlayarak, aynaya dokunma ihtiyacını ortadan kaldırmak böylece aynaların dokunulan bölgelerindeki kirlenmeyi ve dolayısıyla da ürün ile ilgili olası memnuniyetsizliği ortadan kaldırmak ve banyo gibi kullanıcıların çeşitli nedenler ile elleri ile aynaya dokunamayacakları durumlarda dahi ürünün kullanılabilmesini sağlamaktır.Jest tanıma için genellikle kamera temelli sistemler kullanılmakla beraber, banyo gibi kişisel kullanıma dönük bir alanda kamera bulunması birçok kullanıcı tarafından hoş karşılanmayacaktır.Bu nedenle projemizde jest tanımlama amacıyla pasif kızılötesi sensör dizileri tercih edilecektir.Bu tip sensörler oldukça düşük çözünürlüklerde görev yapmasına karşın, nesne ya da canlıların yaydığı kızılötesi ışıma ile çalıştıkları için kameraların görece zayıf kaldığı uygulama alanlarında tercih edilebilmektedirler.Pasif kızılötesi sensörler ile öncelikle kullanıcının elini ve sonrasında da elin hareketini algılamayı amaçlamaktayız.Bu sayede standart bir kameraya göre daha az işlem yükü ve daha düşük maliyet ve daha basit bir elektronik tasarım ile jest ayrımı yapılabilecektir.

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0.1 Introduction

The general purpose of the project is to add a gesture detection system to the Smart Mirror at the cheapest cost. In our project solution, the HTPA32x32d Thermopile Array sensor has been chosen to minimize the cost. It is a system that measures infrared radiation, developed with the thermocouple method dating back to 150 years. "A thermocouple consists of two different materials which are connected at one end, while the other two ends are attached to a voltage meter" [2]. Assuming we connect an absorber to the junction point and place it in the IR radiation from an object. As the absorber collects the incoming heat, the thermocouple junction will become hot due to the incoming radiation. [2] The thermocouple material in turn converts the temperature difference into a voltage indicated by the voltmeter. Hence, the voltmeter reading is a direct measure for object temperature. This method is basically simple, does not require any mechanics and can detect static signals accurately. [2]

Htpa32x32d sensor 32x32 pixel, operates between -10 and 70 degrees, provides I2C communication, has an internal EEPROM and provides an 8-bit data set. EEPROM data contains calibration data for each pixel of the sensor.

Before Smart Mirror integration, it was decided to use an external microcontroller and it was designated as Raspberry pi. The sensor card to be developed is designed to allow the most efficient sensor to work. We can provide our sensor, which does not need an external communication protocol, to communicate directly with raspberry pi. For the development of the software part, we can read the sensor data using one of the python libraries, the I2C periphery library. [7] When we look at the image of the data read, all objects in the background and the human body emit infrared rays. For this reason, our sensor will detect these objects as well. It is mentioned under the name of thresholding in the literature. The Simple Thresholding method gives the same threshold value for each pixel. Pixel values smaller than the threshold value are changed to 0 . [7] Adaptive threshold, Threshold value becomes a global value. However, our action will not work when the system has different lighting points. Using this method for local regions will get us to the right point. [7] The most suitable method for our project is Otsu's method. The reason we chose this method is that we want the environment conditions to change and assign a different threshold value each time. [3]

After isolating the image from the background, we have reached the point of perceiving

the state of the image. We have divided the perception of gesture into two. These are static and dynamic gestures. There are several methods to make these two distinctions. With the Barycenter method, it is possible to adapt a similar situation of planetary movements for gestures. [12] Another method and our preferred method is MHI (memory History Image) and there are several studies in the literature using this method. [10]
8 Static and dynamic movements are now defined, the next step is to match the image to the motion of our desire. Some methods are as follows; Hybrid Method (combination of Haar-Like and HOG properties) [4], HOG(Histogram of Oriented Gradient) properties [5], CNN Classification [11] [9] [12], KNN (k-Nearest Neighbor Classifier) [6]. We decided to use that CNN. The reason is that the CNN transaction is very fast. Realization at this speed will minimize my propogation delay time.
All that remains is the communication between raspberry pi and the Smart Mirror. Due to the fact that it was a team dealing with the project before, the gesture detection system was worked on on the smart mirror side, but a problem occurred due to the sensor. Therefore, we do not have an extra workload on the smart mirror side, after the OTG connection settings between Raspberry pi and the Smart mirror, our system is expected to work properly.

0.2 Capture Thermopiles Image

The chip uses 7-bit I2C address 0x1A for configuration and sensor data and 7-bit I2C address 0x50 to access internal EEPROM. The address byte is followed by a W / R bit and an 8-bit command.
To read data from the chip first the address and read command must be sent. After the last ACK, a new start-bit (repeated start) and the address with a set read-flag initiates the read sequence. There can be bytes read as many as required. The last byte must be denoted by a not-acknowledge.

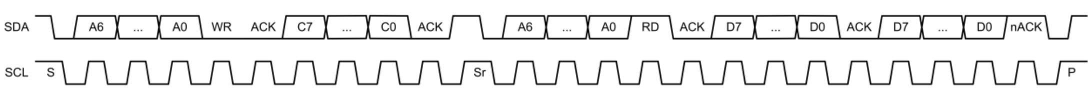


Figure 1: Read command

The sensor is divided into two parts (Top and Bottom Half), which are also divided into 4 blocks. The reading order is shown below for different blocks. When a conversion is initiated, the X Block of the upper and lower half are measured simultaneously. Each block consists of 128 Pixels sampled entirely in parallel. The reading order in the lower half is mirrored compared to the upper half so the center lines are always read last.

Table 1: Read Data 1 Command (Top Half of Array)

Addr/CMD	0x1A (7 Bit!) / 0x0A							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 1 MSB / LSB or Vdd 1 MSB / LSB							
3. Byte / 4. Byte	Pixel (0+BLOCK*128) MSB / LSB							
5. Byte / 6. Byte	Pixel (1+BLOCK*128) MSB / LSB							
...								
257. Byte / 258. Byte	Pixel (127+BLOCK*128) MSB / LSB							

Table 2: Read Data 2 Command (Bottom Half of Array)

Addr/CMD	0x1A (7 Bit!) / 0x0B							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 2 MSB / LSB or Vdd 2 MSB / LSB							
3. Byte / 4. Byte	Pixel (992-BLOCK*128) MSB / LSB							
5. Byte / 6. Byte	Pixel (993-BLOCK*128) MSB / LSB							
...								
65. Byte / 66. Byte	Pixel (1023-BLOCK*128) MSB / LSB							
65. Byte / 66. Byte	Pixel (1023-BLOCK*128) MSB / LSB							
67. Byte / 68. Byte	Pixel (960-BLOCK*128) MSB / LSB							
69. Byte / 70. Byte	Pixel (961-BLOCK*128) MSB / LSB							
...								
129. Byte / 130. Byte	Pixel (991-BLOCK*128) MSB / LSB							
131. Byte / 132. Byte	Pixel (928-BLOCK*128) MSB / LSB							
...								
257. Byte / 258. Bytes	Pixel (927-BLOCK*128) MSB / LSB							

Complete sensor data must be read at once. If communication falls somewhere in between, all successive data will be corrupted. Reading can be stopped anywhere by pausing the clock. A newly started reading progress through this stopped byte, continuing the clock, but the index is reset when a new conversion is started. If the bit for electrical offsets (Bit 1 in Config 0x01) is set, the electrical offsets are sampled and can be read similar to the active pixel.

After reading the data in blocks, there are a few more steps we need to take.Object and ambient temperature can be calculated from sensor output and stored calibration data. The figure below shows an overview of the EEPROM in Figure 2.2.

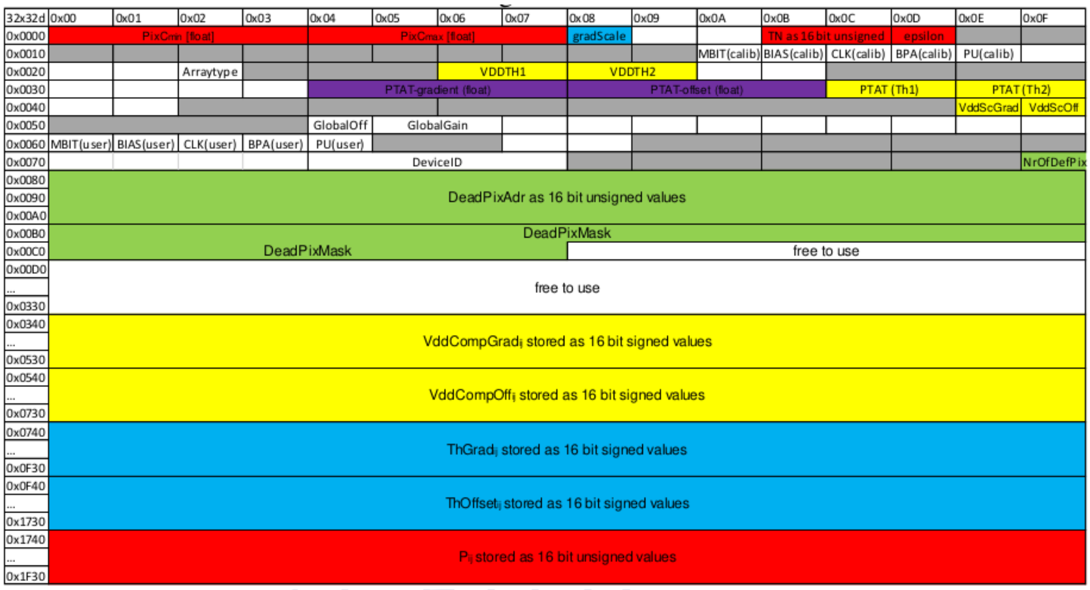


Figure 2: EEPROM overview 32x32d

Unless otherwise specified, all values are stored as unsigned 8-bit values. Small endian format is used for larger values. Fields marked in gray are used during calibration or for future use and the Heimann Sensor is reserved.

The ambient temperature (Ta) is calculated from equation 2.1

$$Ta = PTATav \cdot PTATgradient + PTAT_offset \tag{1}$$

where:

PTATav $= \frac{\sum_{i=0}^{7} PTATi}{8}$ is the average measured PTAT value.

PTATgradient and **PTAToffset** are from EEPROM.

The thermal offset of sensor has to be subtracted for each pixel to compensate for any thermal deviation.

$$Vij_Comp = Vij - \frac{ThGradij \cdot Ta}{2^{gradscale}} - ThOffsetij \tag{2}$$

where:

ij represents the row (i) and column (j) of the pixel.

VijComp is the thermal offset compensated voltage.

Vij is the raw pixel data (digital), readout from the RAM.

ThGradij is the thermal gradient, stored in the EEPROM from 0x740 to 0xF3F.

ThOffsetij is the thermal offset, stored in the EEPROM from 0xF40 to 0x173F.

gradScale is the scaling coefficient for the thermal gradient stored in the EEPROM.

Electrical stabilization is used to compensate for changes in supply voltage. This compensation is only one subtraction, so it can be done before or after thermal offset compensation. We chose to do it later.
The compensation for the top half is done by using the following formula:

$$VijComp^{*} = VijComp - elOffset[(j + i \cdot 32)]\%128] \tag{3}$$

The bottom half analogue with this formula:

$$VijComp^{*} = VijComp - elOffset[(j + i \cdot 32)]\%128 + 128] \tag{4}$$

where:
ij represents the row (i) and column (j) of the pixel and electrical offset.
VijComp* is the thermal and electrical offset compensated voltage.
VijComp is the **elOffset[ij]** thermal offset compensated voltage.
elOffset[ij] is the electrical offset belonging to Pixel ij.
A supply voltage compensation called VddComp is used to provide supply voltage changes. To use this compensation, the sensor's supply voltage (Vdd) must be measured by the sensor, adjusting the configuration record and averaging from time to time. Vdd_1 and Vdd_2 result in Vdd.Average Voltage is calculated by equation 2.5.

$$VDDav = \frac{\sum_{i=0}^{7} VDDi}{8} \tag{5}$$

Compensation for the Top half is done using the formula:

$$V_{ij-VDDComp} = V^{*}_{ij-VDDComp} - \frac{\frac{VddCompGrad[(j+i\cdot 32)\%128]\cdot PTATav}{2^{VddScGrad}} + V_{ddCompoff}[(j+i\cdot 32)\%128]}{2^{VddScOff}} \cdot (VDDav - VDD_{TH1} - (\frac{VDD_{TH2} - VDD_{TH1}}{PTAT_{TH2} - PTAT_{TH1}}) \cdot (PTATav - PTAT_{TH1})) \tag{6}$$

The bottom half analogue with this formula:

$$V_{ij-VDDComp} = V^*_{ij-VDDComp} - \frac{\frac{VddCompGrad[(j+i\cdot 32)\%128+128]\cdot PTATav}{2^{VddScGrad}} + V_{ddCompoff}[(j+i\cdot 32)\%128+128]}{2^{VddScOff}} \cdot (VDDav - VDD_{TH1} - (\frac{VDD_{TH2} - VDD_{TH1}}{PTAT_{TH2} - PTAT_{TH1}}) \cdot (PTATav - PTAT_{TH1})) \quad (7)$$

where:

ij represents the row (i) and column (j) of the pixel.

$\mathbf{V_{ij-VDDComp}}$ is the Vdd compensated voltage.

$\mathbf{V_{ij-VDDComp}}^*$ is the thermal and electrical offset compensated voltage.

VddCompGrad[ij] is the VddComp gradient belonging to Pixel ij.

VddCompOff[**ij**] is the VddComp belonging to Pixel ij.

VDDav is the average measured supply voltage of the sensor in Digits.

VddScGrad is a scaling coefficient and stored in the EEPROM 0x4E.

VddScoff is a scaling coefficient and stored in the EEPROM 0x4F.

$\mathbf{VDD_{TH1}}$ is the supply voltage during calibration 1 stored in the EEPROM 0x26, 0x27.

$\mathbf{VDD_{TH2}}$ is the supply voltage during calibration 2 stored in the EEPROM 0x28, 0x29.

$\mathbf{PTAT_{TH1}}$ is the PTAT value of calibration 1 stored in the EEPROM 0x3C, 0x3D.

$\mathbf{PTAT_{TH2}}$ is the PTAT value of calibration 2 stored in the EEPROM 0x3E, 0x3F.

All we need to do to get the thermal image and separate it is to do the above given mathematical operations and steps. For this we will use a python library periphery-python. After reading the data from our sensor, after applying the steps of thermal offset, electrical offset and Vdd Compensation, the data will appear in all its simplicity.

0.3 Hand Thermal Image Isolation

Our biggest advantage in the project is that our sensor is infrared, so only the objects that emit heat are detected. The main purpose in this section is to separate the hand from the back body. The hand is in front of the body will cause us to perceive the hand warmer. For this reason, the body with hand will appear as two different objects. The second step is to pull the hand off the background. There are many methods for this today. Among these methods, we decided to use OTSU's Method. According to

this method, "it approaches the feasibility of directly evaluating the "goodness" of the threshold and automatically selecting the most suitable threshold". [1]
You can see an example of an image with Otsu's method applied in the figure 4.1.

Formuluzation: the gray level histogram is normalized and regarded as a probability distribution:

$$p_i = \frac{n_i}{N}, p_i \geq 0, \sum_{i=1}^{L} p_i \tag{8}$$

Where:
$N = n_1 + n_2 + ...n_{1024}$ total number of pixel

Let's divide the pixels into two class as CO and C1 with a threshold, where CO represents the background while C1 represents the foreground. Suppose we call our Threshold Value k.The set C0 implies the background pixels with a gray level of [1, ...,k], and C1 means those pixels of foreground object with a gray level of [k + 1, . . . , L]. The probabilities of gray level distributions for the two class are the following: $\omega_0$is the probability of the background and ω_1 is the probability of the object [8]

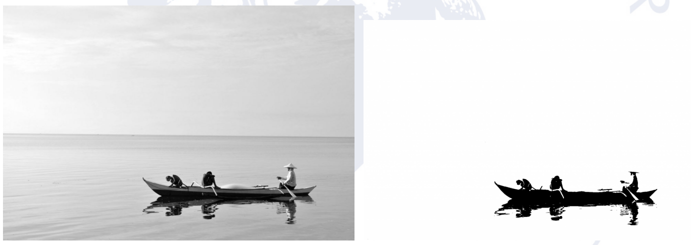


Figure 3: Application of Otsu's method

$${}_0 = P_r(C_0) = \sum_{i=1}^{k} p_i = \omega(k) \tag{9}$$

$$\omega_1 = P_r(C_1) = \sum_{i=k+1}^{L} p_i = 1 - \omega(k) \tag{10}$$

and

$$\mu_0 = \sum_{i=1}^{k} iP_r(i|C_0) = \sum_{i=1}^{k} \frac{ip_i}{\omega_0} = \frac{\mu(k)}{\omega(k)} \tag{11}$$

$$\mu_1 = \sum_{i=k+1}^{L} iP_r(i|C_1) = \sum_{i=k+1}^{L} \frac{ip_i}{\omega_1} = \frac{\mu_r - \mu(k)}{1 - \omega(k)} \tag{12}$$

where:

$$\omega_k = \sum_{i=1}^{k} p_i \tag{13}$$

$$\mu_k = \sum_{i=1}^{k} i p_i \tag{14}$$

cumulative of the zeroth- and first-order cumulative moments of the histogram:

$$\mu_T = \mu(L) = \sum_{i=1}^{L} i p_i \tag{15}$$

is the total average level of the original picture. For any choice of k, we can easily verify the following relationship: [1]

$$\omega_0\mu_0 + \omega_1 + \mu_1 = \mu_T, \qquad \omega_0 + \omega_1 = 1 \tag{16}$$

calculated the class variance:

$$\sigma_0^2 = \sum_{i=1}^{k} (i-\mu_0)^2 P_r(i|C_0) = \sum_{i=1}^{k} (i-\mu_0)^2 \frac{p_i}{\omega_0} \tag{17}$$

$$\sigma_1^2 = \sum_{i=k+1}^{L} (i-\mu_1)^2 P_r(i|C_1) = \sum_{i=k+1}^{L} (i-\mu_1)^2 \frac{p_i}{\omega_1} \tag{18}$$

Between-class variance is:

$$\sigma_B^2 = \omega_0(\mu_0-\mu_T)^2 + \omega_1(\mu_1-\mu_T)^2 = \omega_0\omega_1(\mu_0-\mu_1)^2 \tag{19}$$

Within class Variance is:

$$\sigma_W^2 = \omega_0\mu_0^2 + \omega_1\mu_1^2 \tag{20}$$

Total Varience:

$$\sigma_T^2 = \sigma_W^2 + \sigma_B^2 \tag{21}$$

Calculated Otsu threshold:

$$\sigma_B^2 k = \frac{[\mu_T\omega(k) - \mu(k)]^2}{\omega(k)[1-\omega(k)]} \tag{22}$$

and optimal threshold k^* is:

$$\sigma_B^2(k^*) = \max_{1\le k<L} \sigma_B^2(k) \tag{23}$$

After these procedures, we have a threshold value. When we ignore the parts below this threshold and take the parts above, we will see a clear hand shape.
If we cannot perceive the hand clearly as a result of the Otsu method, then the Using the Neighbor contour detection algorithm, we can make the image what we want. [8]

0.4 Detecting Hand Movement

0.4.1 Static Gesture

0.4.2 Dynamic Gesture

0.5 Matching Gesture to Commands of Smart Mirror

A number of scenarios have been prepared for command mapping for smart mirror. The scenarios prepared are as follows;
For Static Gestures:
We have 4 fixed gestures. It is the ability to Open, Close, Touch and Return to the Home Page.

Figure 4: Gestures of Open,Close,Touch,Return to the Home Page

For Dynamic Gestures:
There are two mobile situations. Down-Up, Right-Left properties.

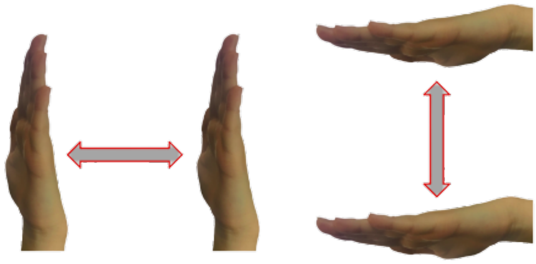


Figure 5: Gestures ofDown-up,Right-Left

In total, we activated 8 features of the smart mirror with gesture.Afterthat, by activating the Raspberry pi OTG communication channel, intelligent Mirror and MCU communication is provided.

0.6 Sensor and MCU Communication Card Design

A sensor card design will be made with the selection and supply of the passive infrared sensor. In the card design in question, a schematic design will be made first and the necessary components and connections will be made schematically. After this part, the schematic design will be turned into a printed circuit. In the design of the printed circuit board, along with the schematic design, the physical properties of the place where the sensor will be mounted will be taken into consideration in the current smart mirror design. After this part, the designed sensor card will be produced in an external company and its assembly will be carried out in the company.
The pcb and schematic drawings of the communication card are as shown in the figures below. Schematic and PCB design will be done using KiCad EDA - Schematic Capture & PCB Design Software. In the next step, support will be received for printed circuit operations. After soldering the printed cards, our sensor communication card will be ready and the test phase will begin.

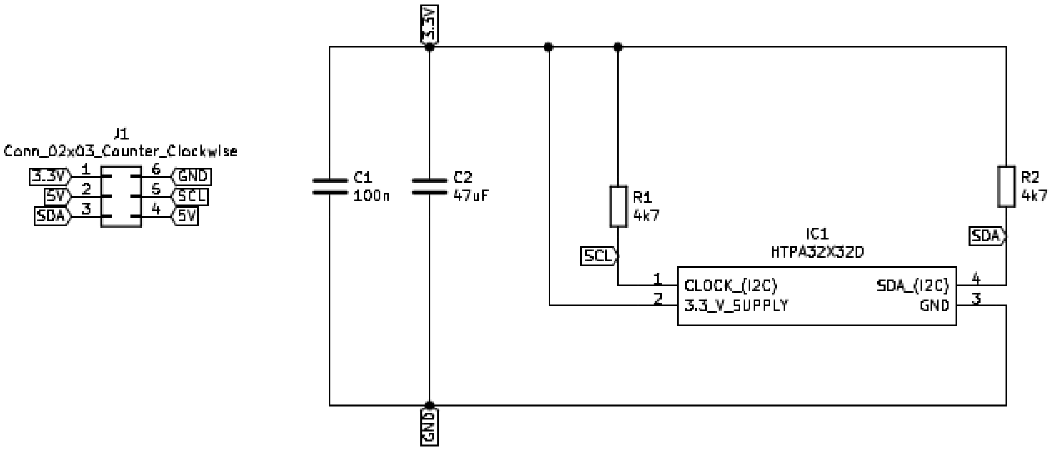


Figure 6: Schematic Design of Communication Card

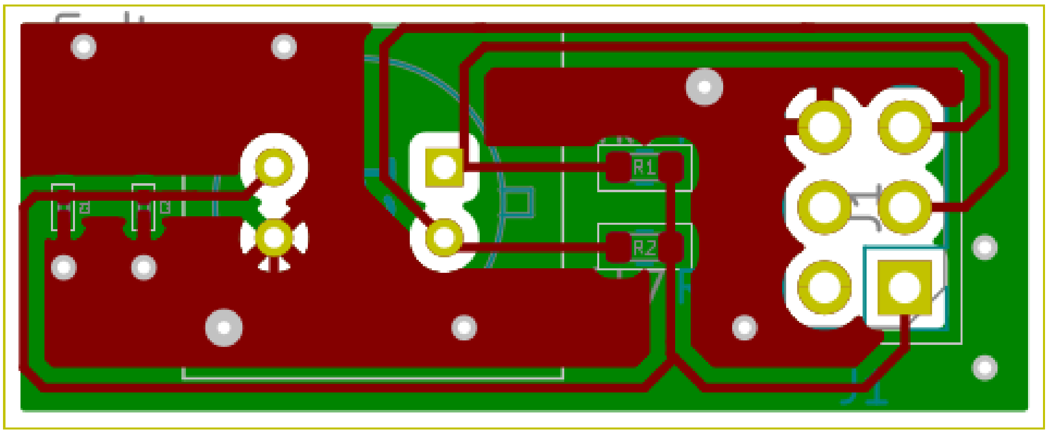


Figure 7: PCB Design of Communication Card

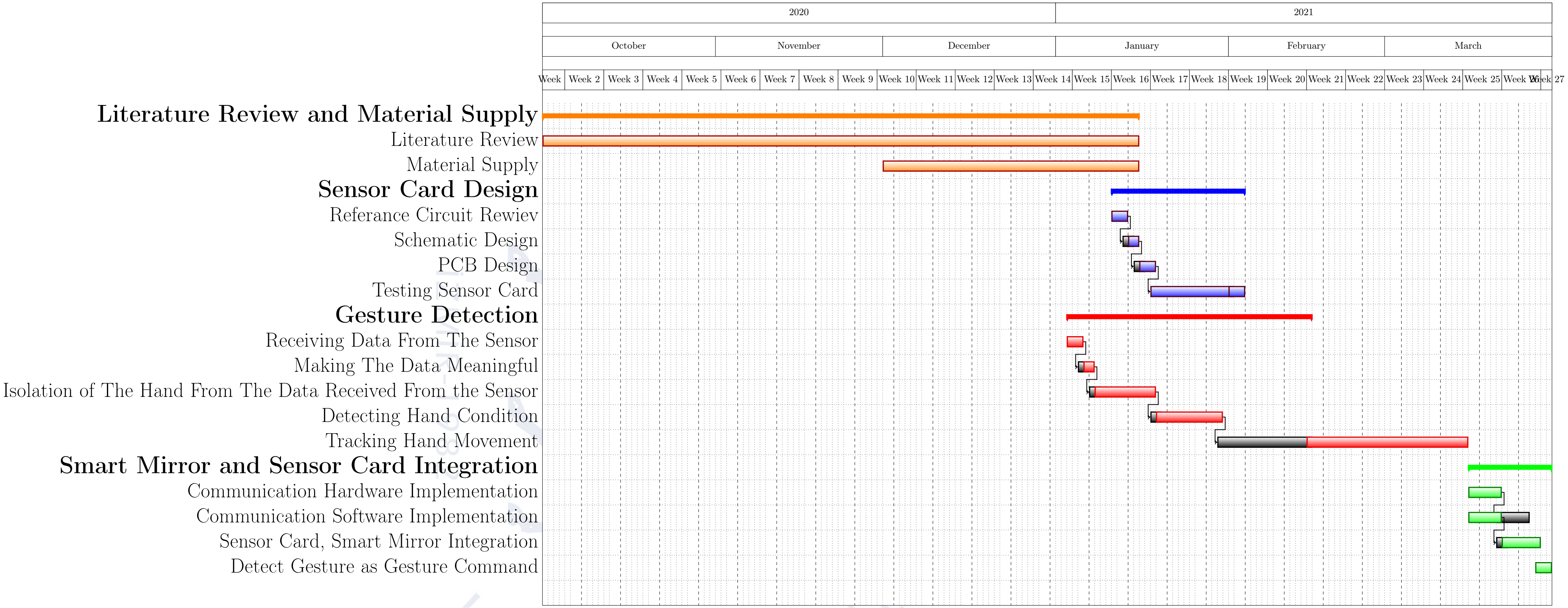
0.7 WORK PLAN AND WORK PACKAGES

Worker:Rabia DOĞAN	Time: 7 Weeks (2020.10.01-2021.01.15)
Work Package Name:Literature Review and Material Supply	
Inputs: • Past studies. • Articles on internet. • Thesis on internet. • Books.	
Steps:• Searching for articles Gesture Recognition with Infrared array sensor. •Searching the OpenCV library and Python programming language. •Searching convenential neural network for gesture recognition •Searching Thermopil Array sensors •	
Outputs: •Determining Thermopil Array Sensor. •Determining methods to be used.	
Status:Complated.	

Worker:Rabia DOĞAN	Time: 3 Weeks (2021.01.11-2021.02.03)
Work Package Name:Sensor Card Design	
Inputs: •HTPA32x32d Application Notes	
Steps : •Drawing Schematic Design •Drawing PCB Design •Testing Sensor Card	
Outputs: •Schematic and PCB Design of Sensor Card.	
Status:In Progress	

Worker:Rabia DOĞAN	Time: 9 Weeks (2021.01.03-2021.03.15)
Work Package Name:Gesture Detection	
Inputs: •Methods of Gesture Recognition •HTPA32x32d Datasheet •Books about of Image Processing	
Steps : •Reading sensor data with the help of the python-periphery library. •Making calibrations with EEPROM calibration data. •Removing the hand from the background with the Herbaceous Method. •Hand condition detection with Motion History Image method. •Defining gesture with CNN Outputs: • Capture sensor Image •Detected Gesture Types •Tracking Gesture Recognition •Matching Gesture to Commands of Smart Mirror •	
Status:In Progress	

Worker:Rabia DOĞAN	Time: 3 Weeks (2021.03.16-22.03.30)
Work Package Name:Smart Mirror and Sensor Card Integration	
Inputs: •WP1,WP2,WP3 outputs	
Steps : •Connectting Raspberry pi and Smart Mirror with OTG Communication	
Outputs: •Complated the project	
Status:In Progress	


2020
2021
October
November
December
January
February
March
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
Week 13
Week 14
Week 15
Week 16
Week 17
Week 18
Week 19
Week 20
Week 21
Week 22
Week 23
Week 24
Week 25
Week 26
Week 27
Literature Review and Material Supply
Literature Review
Material Supply
Sensor Card Design
Referance Circuit Rewiev
Schematic Design
PCB Design
Testing Sensor Card
Gesture Detection
Receiving Data From The Sensor
Making The Data Meaningful
Isolation of The Hand From The Data Received From the Sensor
Detecting Hand Condition
Tracking Hand Movement
Smart Mirror and Sensor Card Integration
Communication Hardware Implementation
Communication Software Implementation
Sensor Card, Smart Mirror Integration
Detect Gesture as Gesture Command

0.8 Cost Analysis

0.9 Economical Costs

In this project, the economic cost is only in the hardware part. A Raspberry Pi 4B and Thermopil array sensor are used in our project. The market price of Raspberry pi 4B is $55. The thermopil array sensor, on the other hand, has been chosen the most suitable for our project and has been researched for the market. The price of the HEIMANN HTPA32x32d Thermopil array sensor is $87. There is currently no separate cost in the software part. Because using opensource software.

0.9.1 Environmental,Political and Social Costs

Infrared sensor arrays have emerged in recent years and are products that allow the application of thermal imaging technologies to consumer electronics. With the introduction of Covid-19 into our lives, it is frequently encountered in the field of thermal imaging. Since a consumer electronics product using these products has not been produced in Turkey yet, it is considered to contribute to the national knowledge. In the project where privacy is prioritized, the privacy of the person will be ensured by using a thermopile array sensor. Also, the project is executed by Vestel A.Ş. so the project is expected to inspire different projects within Vestel. The fact that these sensors are newly introduced to the market will pave the way for innovative applications in many fields and thus method changes that can turn into patents. For example, although gesture recognition is performed with cameras conventionally, it offers a significant innovation in methodology, using passive infrared arrays. Smart mirrors that can be controlled with gesture recognition can have a positive effect on the preference of the products in question by the consumers. In doing so, using a technology that does not impair personal privacy will ensure that the users put the product into their lives safely and the applications related to the product become widespread.

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