TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

http://www.tekstilvemuhendis.org.tr

GÜNEŞ ENERJİSİ İLE ÇALIŞAN STOR PERDE YÜZEYİNDE ALARM ÖZELLİKLİ ESNEK SENSÖR YAPILARININ GELİŞTİRİLMESİ

DEVELOPMENT OF FLEXIBLE SENSOR STRUCTURES WITH ALERT FEATURE ON ROLLER BLIND SURFACE WORKING WITH SOLAR ENERGY

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Online Erişime Açıldığı Tarih (Available online):30 Aralık 2022 (30 December 2022)

Bu makaleye atıf yapmak için (To cite this article):

Berin HACIOĞLU, Murat YILDIRIM, Hafız ALISOY (2022): Development of Flexible Sensor Structures With Alert Feature On Roller Blind Surface Working With Solar Energy, Tekstil ve Mühendis, 29:128, 272-279.

For online version of the article: https://doi.org/10.7216/teksmuh.1222512

Araştırma Makalesi / Research Article

DEVELOPMENT OF FLEXIBLE SENSOR STRUCTURES WITH ALERT FEATURE ON ROLLER BLIND SURFACE WORKING WITH SOLAR ENERGY

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Gönderilme Tarihi / Received: 01.09.2022
Kabul Tarihi / Accepted: 01.12.2022

***ABSTRACT*:** In the project, roller blinds with alarm sensors working with solar energy were developed. It is aimed to develop the alarm system, which is a security system product that has become the need of every house, on the curtain surface by designing flexible sensor structures. Lightweight fabric design, sensor design, system design and mobile application studies were carried out. User tests of the product with optimum values were carried out. As a result of the evaluations, it was seen that the lightweight fabric rate was 34% and the capacitive sensing distance of the selected pattern was 15 cm.

Keywords: *flexible sensor, conductive yarn selection, solar energy, roller blind, alarm feature*

GÜNEŞ ENERJİSİ İLE ÇALIŞAN STOR PERDE YÜZEYİNDE ALARM ÖZELLİKLİ ESNEK SENSÖR YAPILARININ GELİŞTİRİLMESİ

ÖZ: Projede, güneş enerjisi ile çalışan alarm sensörlü stor perde geliştirilmiştir. Her evin ihtiyacı haline gelen bir güvenlik sistemi ürünü olan alarm sisteminin esnek sensör yapıları tasarlanarak perde yüzeyinde geliştirilmesi amaçlanmıştır. Kumaş hafifletme, sensör tasarımı, sistem tasarımı ve mobil uygulama çalışmaları gerçekleştirilmiştir. Optimum değerlere sahip ürünün kullanıcı testleri gerçekleştirilmiştir. Değerlendirmeler sonucunda kumaş hafifletme oranı %34, seçilen desenin kapasitif algılama mesafesi 15 cm olarak çalıştığı görülmüştür.

Anahtar kelimeler: *esnek sensör, iletken iplik seçimi, güneş enerjisi, stor perde, alarm özelliği*

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DOI: *https://doi.org/10.7216/teksmuh.1222512*   *www.tekstilvemuhendis.org.tr*

This study was presented at "3rd International Congress of Innovative Textiles (ICONTEX2022)", May 18-19, 2022 Çorlu, Turkey. Peer review procedure of the Journal was also carried out for the selected papers before publication.

1. INTRODUCTION

Smart home systems is a term used for homes that enable remote monitoring and management of various appliances and systems such as lighting and heating. Smart home systems provide users with comfort, security, energy efficiency (low operating cost) and convenience [1]. For this reason, the demand for motorized roller blinds is increasing with the developing technology and the need for comfort. The electrical energy required for the operation of the motors of these curtains is generally obtained from non-renewable energy sources. Today, the use of renewable energy sources in the production of electrical energy is increasing rapidly. One of the most striking among renewable and clean energy technologies is photovoltaic technology, which enables the production of electrical energy by using unlimited solar energy. The word ‘photovoltaic’ is formed by the combination of the words ‘photo’ meaning light and ‘voltaic’ meaning electricity [2].

In addition to smart home systems, smart textiles have entered our lives with the developments in textile technologies and raw materials used (fibers and polymers). Electronic/smart textiles are electronic components that form systems that can sense, illuminate or transmit data [3]. Fabrics with sensing features, called (Smart Fabric Sensor- SFS), are sensitive to multiple physical and chemical stimuli such as temperature, pressure, force and changes in electrical current [4]. The word sensor refers to the detection of something with a specific target stimulus. A device that detects a signal (stimulus) and converts this stimulus into a signal that can be measured electronically is called a sensor [5].

As well parameters such as temperature, pressure, and force, sensors also detect the approach. The proximity sensor is a contactless sensor that detects the presence of an object. This object can be a conductive or non-conductive surface, depending on the sending mechanism of the proximity sensor. Proximity sensors can be optical, ultrasonic, inductive, capacitive, etc. implemented using different mechanisms. Capacitive sensors are proximity sensors that detect both metals and non-metals. Therefore, it is suitable for detecting people and objects [6].

Wijiesiriwardana et al. (2005), using capacitive sensing techniques, developed electronic/smart textiles with weaving and approximation features. Using the knitting technique, electrodes with different patterns and symbols were designed with conductive fibers and metallic fibers. In their study, they developed electrodes faster than piezoresistive materials with good washing resistance and thermal properties [7].

On the other hand, Ojuroye et al. (2019) developed approach and weaving sensitive flexible circuit systems using NXP semiconductor and commercial capacitive sensing chip (PCF8883US). As a result of the study, it was seen that a square-shaped electrode provides a 58.3% increase in approach detection distance compared to multiple electrodes in the same area [8].

The purpose of this project, flexible sensor structures with alarm features have been developed on the surface of the motorized roller blind, which provides its movement with the energy it receives from the sun. These sensor structures offers a practical solution to protect against possible theft from windows and balcony/terrace doors.

2. MATERIALS AND METHODS

2.1. Material

In this study, conductive yarns used for sensor design Bekinox VN 12.1.2.100Z and Bekinox VN 12.3.2.175S conductive yarns supplied from Bekinox company were used. Shiledex 235/36 dtex 4-ply HC+B and Shieldex 235/36 dtex 2-ply HC+B conductive yarns supplied from Shieldex company were used. AM 25 curtain motor and AC601-01 photovoltaic panels supplied from A-OK company were used.

2.2. Method

In this project, studies on construction studies, conductor yarn selection, pattern studies, sensor studies, photovoltaic panels and battery charging time were carried out. The experiment plan is given in Table 1. First of all, the weight of the fabric has been reduced in order not to experience any decrease in the running speed of the engine to be used. For the sensor, a raw material and pattern with suitable conductivity and/or data acquisition will be selected. Then system design and mobile application were developed.

User tests given in Table 2 will be performed for the final product to be produced. Curtain up/down movement numbers, battery charge time of the photovoltaic panel and alarm system tests will be conducted for a month.

2.2.1. Lightweight fabric design

In order to lighten the fabric weight, firstly, weft density values and weft yarn count were changed. The construction features to be developed were given in Table 3.

Additionally to the lightening studies in the weaving department, coating recipe studies were carried out. Studies were carried out to lighten the fabric weight by changing the chemicals used in the recipe to be applied and the ratios of the chemicals. The chemicals used and their ratios were given in Table 4. A total of 20 different trials were conducted for 2 different recipes, 5 different chemical mixing ratios and 4 different fabric construction fabrics.

2.2.2. Sensor design

In the sensor design, 4 conductive threads with different resistance values and different yarn numbers were used. Yarns have two different properties: stainless steel and silver/nylon coated conductive thread. Yarn properties were shared in Table 5.

Table 1. Experiment plan

Experiment No and Name		Code	Raw Material	Target Value	Number
1. Lightweight Fabric Design	1. Weaving	a	%100 PES yarn	%20 lighten	4x5=20
		b			
		c			
		d			
	2. Coating Work	e	Water-based coating chemicals		
		f			
		g			
		h			
		i			
2. Sensor Design	1. Appropriate raw material and pattern selection	a	Conductive yarn	Statistically significant change in capacitance value when approach distance exceeds 10 cm	4
		b			
		c			
		d			
		e	Brode pattern design		3
		f			
		g			
		h	Pattern		3
		ı			
		j			
3. Alarm Modelling	1. Creation of mathematical modelling and determination of parameters				
4. System Design and Mobile Application	1. Fotovoltaic panel			Selection of the most efficient system design	1
	2. Circular motor and battery				

Table 2. User test experiment plan

Experimental Number	Facade Selection	Floor Numbers
1	East	2
2	West	2
3	North	2
4	South	2
5	South-West	2
6	South-East	2
7	North-West	2
8	North-East	2
9	East	2
10	East	4

Table 3. Developed construction features

SampleNumber	Pattern	Warp yarn count (D)	Warp frequency (tel/cm)	Weft yarn count (D)	Weft density (piece/cm)
1	2/2 weft rib	150/48f	60	a	12
2			60	a	15
3			60	a	18
4			60	b	17

Table 4. Recipe A and B

	A Recipe			B Recipe		
	0	2	3	1a	2a	3a
Binder	325	275	250	250	250	150
Thickener	30	30	30	75	50	25
Fixator	17	17	17	15	15	15
Defoamer	1	1	1	20	20	20
Weight value of reference fabric (g/m^2)	202	190	183	192	190	185

Table 5. Conductive yarn properties

Conductive yarn number	Thread Number (dtex)	Composition
1	2350	%100 Stainless Steel Thread
2	7600	%100 Stainless Steel Thread
3	235/36 dtex 2-ply HC	%100 Polyamide/silver coated yarn
4	235/36 dtex 4-ply	%100 Polyamide/silver coated yarn

2.2.3. Alarm modelling

2.2.3.1. Creation of mathematical modelling and determination of parameters

The main purpose of this study consists of a capacitive sensing-based electronic circuit design that can detect a contact or approach to the curtain surface and remotely control the situation. In particular, the creation of a mathematical model of electronic circuits containing polymeric-based flexible capacitive sensing sensors and the results to be ontained from the application circuit corresponding to this model are important for the analysis and application of basic physical principles for sensors.

2.2.3.2. Pyhsical modeling for the obtained data

In order for an approaching object to be capacitively detected, an electronic circuit capable of sensing the change in capacitance and a conductive electrode must be placed on the surface to be detected to this circuit. The capacitive sensing electrode system, which is formed with conductive yarns on a polyester-based flexible textile curtain, is symbolically given in Figure 1 [9-10].

After the approaching object enters the sensitive area of the detection capacity, the electronic circuit components that perform the detection of the object are given in Figure 2 in the form of a block diagram.

2.2.4. System Design and Mobile Application

The equipment used in the system design and mobile application was shared in Table 6.

3. RESULTS AND DISCUSSION

Using the 4 different constructions developed, the woven fabric was produced on the air jet weaving machine. Developed fabric construction images were shared in Figure 3.

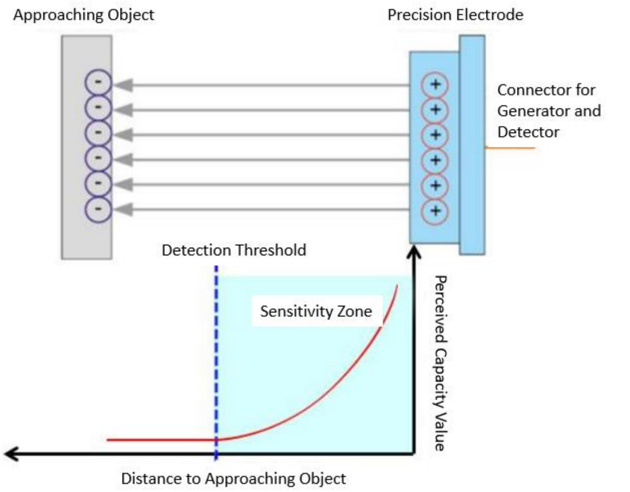

Figure 1. Symbolic representation of capacitive sensing sensor

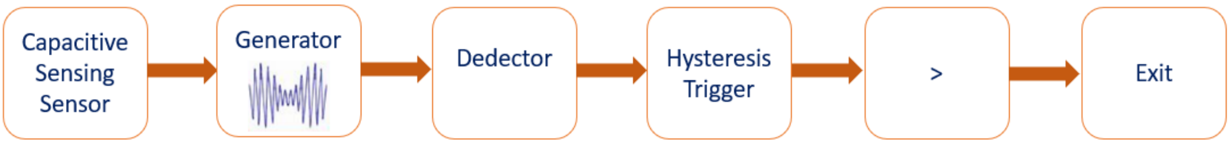

Figure 2. Block diagram of basic components of capacitive sensing circuit

Table 6. System design and mobile application

Equipment	**Property**
Solar Panel	18 V - 0.095A
Engine	7.4 V -900 mA
Mobile Application	Arduino

Figure 3. Developed construction images

In the coating process, coating trials were carried out to reduce the fabric weight. In order to choose the most suitable construction among the constructions developed, quality control was carried out on the samples brought in the form of roller blinds and it was checked whether there was any fluctuation in the fabric. There were cracks on the surface of the fabrics coated with recipe B. For this reason, a selection has been made among fabric constructions coated with recipe A. Before deciding on the fabric construction, the fabrics were brought into the form of blinds and fabric faults were examined. While making the selection, the coated roller blind fabric produced in the standard was taken as a reference. It was expected to have similar properties with the reference roller blind fabric in terms of tough and performance. In this direction, 2. constructions treated with recipe no A were selected.

Pattern studies were carried out using conductive yarns with different properties. While developing the patterns, it was aimed to observe the capacitive changes by creating conductive and insulating areas. Vertical embroidery machine Epoca 7 is used. The sensor structure was observed by changing the parameters of the distance, shape, frequency, and length of the yarns. 28 sensor surfaces were developed with the brode embroidery method using 4 different conductive threads. Pattern studies were shared in Figure 4.

Capacitive change and resistance values were measured by using the developed 28 approach sensor surface Ardunio Circuit. The measurement results obtained was shared in Table 7.

The measurement approach was adjusted so that the length of the sensor surface was 120 cm. In this context, capacitive and resistance values of the approach sensor surface were measured throughout (120 cm pattern length). The resistance values of the developed patterns in different lengths (30 cm, 60, and 90 cm) were also measured, and the proportional change in the resistance values was observed. The measurement of the resistance values was made to create a location map on the curtain.

Figure 5 shows the capacitive changes of 4 different conductive threads depending on 7 different patterns.

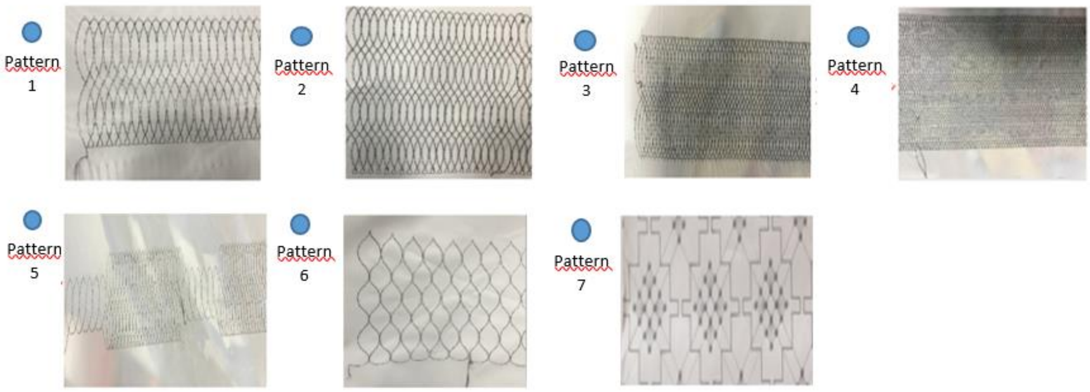

Figure 4. 7 different pattern work

Table 7. Test results of the developed alarm sensor designs

Pattern Number	Conductor Yarn Count Used	Sensing Distance (cm)	Pattern Number	Conductor Yarn Count Used	Sensing Distance (cm)
1	1	14	**5**	1	14
	2	20		2	13
	3	10		3	2
	4	10		4	13
2	1	5	**6**	1	14
	2	15		2	13
	3	10		3	16
	4	15		4	15
3	1	13	**7**	1	15
	2	15		2	15
	3	15		3	12
	4	12		4	15
4	1	10			
	2	12			
	3	15			
	4	15			

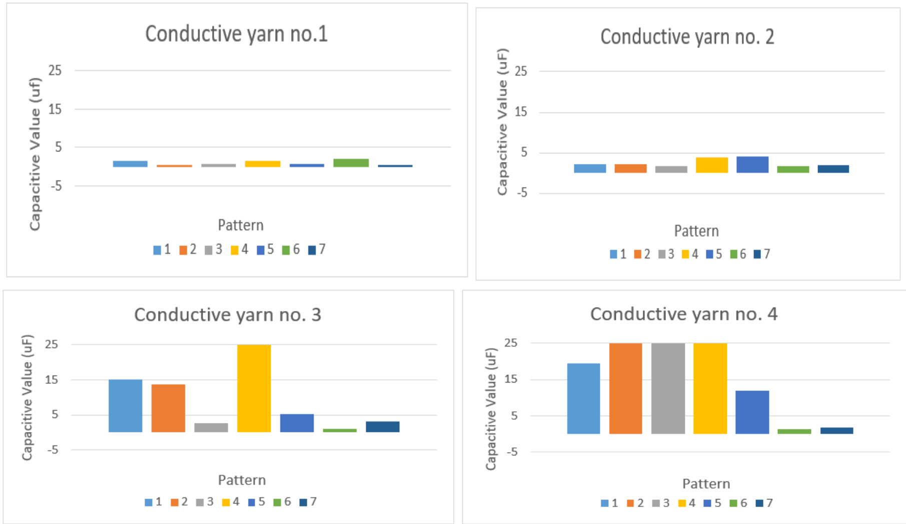

Figure 5. Capacitive change analysis of textile-based sensor

As a result of the measurements, the capacitive values of the 1 and 2 conductive threads for 7 different patterns were shown below 4 microfarads (µF). It has been observed that the lowe index of these values, the better the detection of the capacitive proximity sensor. In addition, values of capacitive changes were expected to be below 20 microfarads (µF). In this context, the conductive threads no. 3 and 4 had values above 20 microfarads (µF) in different patterns. It is expected that this conductive property will vary with the production conditions and conductor values of the yarns. In this direction, the yarn no. 1 and 2 are steel, and the yarn no. 3 and 4 are obtained by metallizing silver. It was seen that the conductive yarn values provided in the metallization process are less than the steel yarn production. The main reason for this is that there is a conductivity difference between the self-conducting yarn and the yarn obtained by the coating process. In an evaluation on the basis of patterns, it was observed that the capacitive values were better in more frequent and dense patterns. As a well, it has been observed that the capacitive values are better regardless of the conductivity values of the yarn in patterns 6 and 7. As a capacitive perception, it was decided to use pattern number 7, which is the most efficient and most appealing to the eye.

3.1. Alarm modelling

The simple electronic circuit of the security systems containing the designed capacitive detection sensors is given in Figure 6.

One of the plates of the C1 capacitor, which is given as the detection sensor in the circuit, is connected to the output of the microcontroller (MD), which is configured to give a square wave output with a frequency of 120-180 kHz, and the other plate is connected to ground. In the electronic circuit diagram we designed for capacitive sensing, this microcontroller is symbolically shown in the form of V2 voltage source.

The representation of this electronic circuit representing the detection sensor in the LTSPICE simulation environment is given in Figure 7. Here, the capacitance values obtained depending on the capacitance value of the ''curtain- approaching object'' system formed with conductive threads on the roller blind surface are converted to voltage and read over an R6=36 kOhm resistor. As seen in Figure 8, Figure 9, and Figure 10 depending on the capacitance value of the ''curtain- approaching object'' system, the type of object approaching the curtain can be determined depending on the voltage change rate on the R6 resistor.

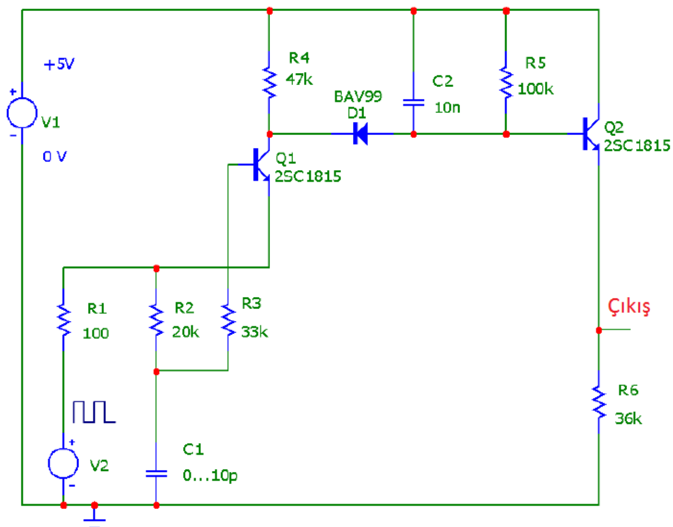

Figure 6. Simple circuit view of security system with C1 capacitive sensing sensor

In the graphs seen in Figure 8, Figure 9, and Figure 10 above, the variation of the voltage on the R6 resistor with time is seen when the C1 capacitance is 0.1 pF, 4 pF and 10 pF according to the object model approaching the curtain.

Based on this modelling result, it has been seen that the type of object approaching the curtain can be predicted according to the information obtained from the capacitive sensing sensor formed with conductive threads on a polymeric-based curtain.

3.2. System design and mobile application

It is designed to the microcontroller circuit in order to interpret the information coming from the capacitive sensor and to manage the system. The circuit diagram of the designed card is shown in Figure 11.

3.3. Users test results

Usage tests will be carried out for 1 month to analyze the user experiences of 10 prototype solar curtains with the same features, dimensions, and weights. Usage test parameters: The number of up and down movements of the curtain in a day, the battery charging time of the photovoltaic panels, the operability of the alarm system in line with the movements determined as a result of the modelling.

In the Figure 12, it seen that the curtain in the south-facing position gives the best results and that the motor battery can withstand 10 repetitions downward and 10 repetitions upward movements for 30 days. It was observed that the engine battery of the curtain on the north façade was the least durable. The results based on 10 repetitions and 10 repetitions for 14 days are shared in Table 3.

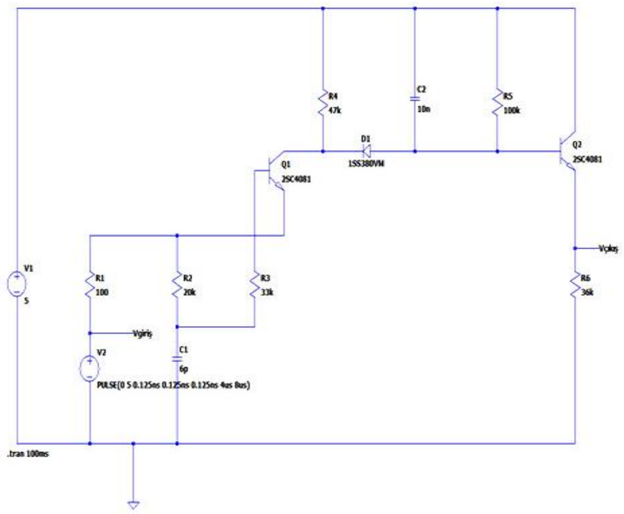

Figure 7. Model of capacitive sensing circuit created with LTSPICE program

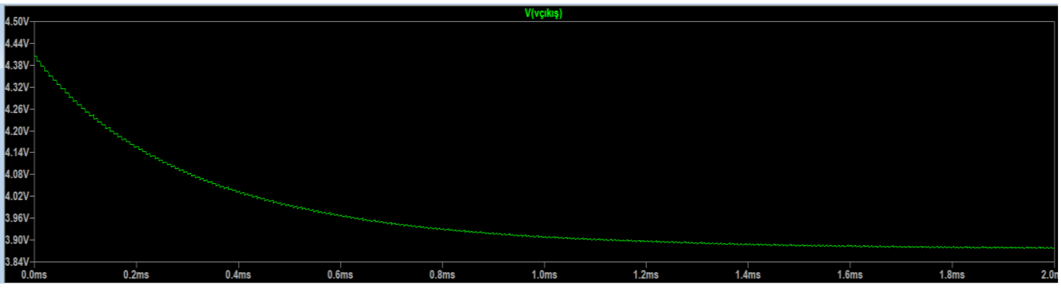

Figure 8. Voltage-time graph on R6 when C1 value is 0.1 pF

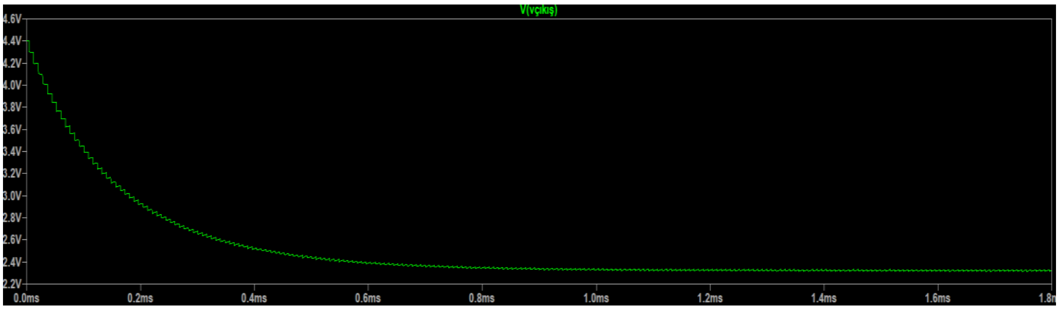

Figure 9. Voltage- time graph on R6 when C1 value is 4 pF

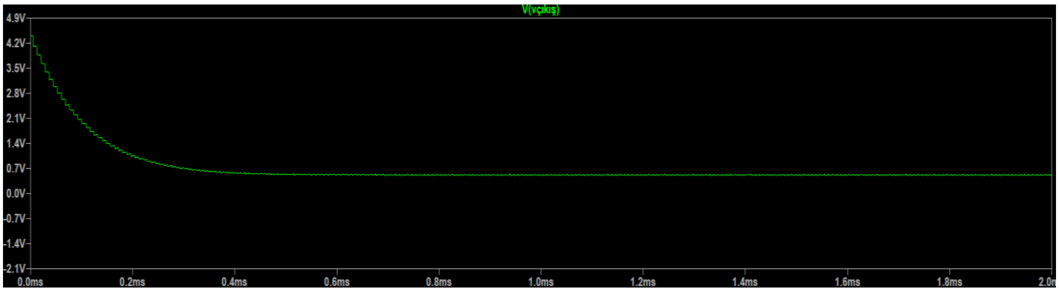

Figure 10. Voltage- time graph on R6 when C1 value is 10 pF

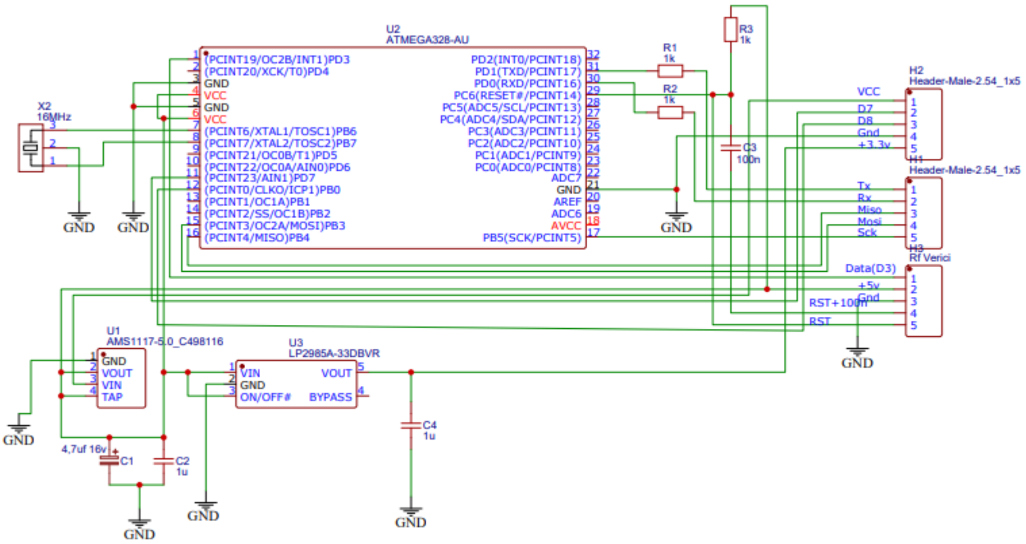

Figure 11. Circuit diagram of the designed microcontroller board

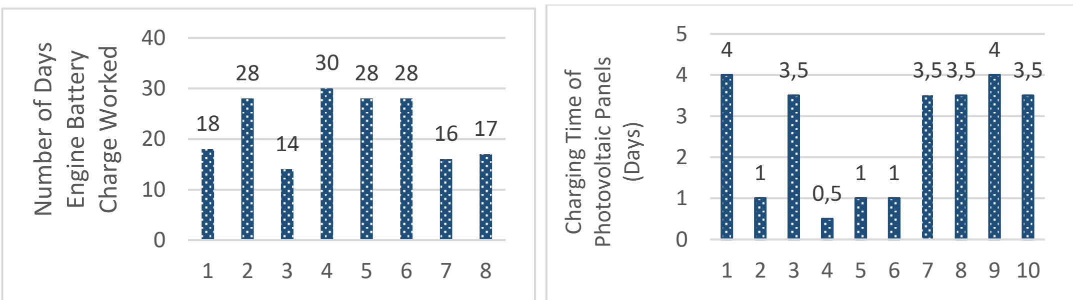

Figure 12. The results of the number of days the motor battery charge works and the charging time of the photovoltaic panels

4. CONCLUSIONS

It has been observed that the number of up/down movements of the developed alarm feature curtain can meet the desired 10 cycle operation. It has been tested that the battery charging time of the photovoltaic panels is tested as about 24. The optimum rate of fabric lightweight achieved 34% success. As a result of the reference values obtained for the alarm modelling, it has been tested that the alarm system is sensitive to the approach distance of 15 cm in cases where the thief tries to enter through the window. It has been seen that the mobile application works as desired.

ACKNOWLEDGEMENT

This study is funded by the Zorluteks Textile Trade and Industry Inc. Scientific Research Project under grant no. TUBITAK TEYDEP 1501. (Project Number: 3181104)

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