Çukurova Üniversitesi Mühendislik Fakültesi Dergisi, 38(2), ss. 585-592, Haziran 2023
Cukurova University Journal of the Faculty of Engineering, 38(2), pp. 585-592, June 2023

Body Temperature Related Risk Factor Assessment Using RFID Sensor Tags

Reyat YILMAZ[*1] ORCID *0000-0001-9108-0576*
Özgür TAMER[1] ORCID *0000-0002-5776-6627*
R. Alp KUT[2] ORCID *0000-0002-5781-334X*
Nihal FİDAN[3] ORCID *0009-0008-4905-2967*

[1]Dokuz Eylul University, Electrical and Electronics Engineering Department, İzmir, Turkiye
[2]Dokuz Eylul University, Computer Engineering Department, İzmir, Turkiye
[3]Akar Tekstil A.Ş. 10000 Sokak No:3 İAOSB, 35620 Çiğli/İzmir, Türkiye

Geliş tarihi: 02.02.2023 Kabul tarihi: 23.06.2023

Atıf şekli/ How to cite: YILMAZ, R., TAMER, Ö., KUT, R.A., FİDAN, N., (2023). Body Temperature Related Risk Factor Assessment Using RFID Sensor Tags. Cukurova University, Journal of the Faculty of Engineering, 38(2), 585-592.

Abstract

Detecting and identifying individuals with high body temperature can be critical for preventing the spread of diseases with high body temperature as a symptom like COVID-19. Thermal cameras or manual temperature inspection methods are widely used to identify elevated body temperature. In this work, we propose a novel method to identify and track people with higher disease risk, including the body temperature change of each person in a specified community and other risk factors like family backgrounds, habits, and social life. Results show that each person's body temperature can be tracked and recorded with the user's ID number every time the user passes from specific locations equipped with RFID readers. By using an artificial intelligence-supported risk scoring system, a risk factor is evaluated based on the parameters defined accordingly. If the evaluated risk score of the user is above a specific value, the system generates an alarm to isolate the person with a high-risk score. Therefore, isolating any potentially infected individual helps health professionals reduce the spreading speed of infections through isolated communities.

Keywords: RFID, Sensor tag, Body temperature tracking, Risk assessment, Machine learning

RFID Sensör Etiketleri Kullanarak Vücut Sıcaklığı İle İlgili Risk Faktörü Değerlendirmesi

Öz

Yüksek vücut sıcaklığına sahip kişilerin tespit edilmesi ve tanımlanması, COVID-19 gibi vücut sıcaklığının belirtisi olan hastalıkların yayılmasını önlemede kritik önem taşır. Yükselmiş vücut sıcaklığını tanımlamak için termal kameralar veya manuel sıcaklık kontrol yöntemleri yaygın olarak kullanılır. Bu çalışmada, belirli bir toplulukta her bir kişinin vücut sıcaklığındaki değişimi ve aile geçmişi, alışkanlıklar ve sosyal yaşam gibi diğer risk faktörleri dahil olmak üzere daha yüksek hastalık riski taşıyan insanların

[*]Sorumlu yazar (Corresponding Author): Reyat YILMAZ, *reyat.yilmaz@deu.edu.tr*

tanımlanmasını ve izlenmesini amaçlayan yeni bir yöntem sunuyoruz. Sonuçlar, her bir kullanıcının RFID okuyucularıyla donatılmış belirli yerlerden geçtiği her seferinde kullanıcının kimlik numarasıyla birlikte vücut sıcaklığının izlenebileceği ve kaydedilebileceğini göstermektedir. Yapay zeka destekli risk puanlama sistemi kullanılarak, tanımlanmış parametrelere göre bir risk faktörü değerlendirilir. Kullanıcının değerlendirilen risk puanı belirli bir değerin üstünde ise, sistem yüksek riskli skorlu kişiyi izole etme alarmı üretir. Bu nedenle, potansiyel olarak enfekte olabilecek herhangi bir kişinin izole edilmesi, sağlık profesyonellerinin enfeksiyonların yayılmasını izole topluluklar aracılığıyla azaltmasına yardımcı olur.

Anahtar Kelimeler: RFID, RFID etiket, Vücut ısı takibi, Risk değerlendirme, Makine öğrenmesi

1. INTRODUCTION

Radio Frequency Identification (RFID) is a widely used technology that employs electromagnetic waves to identify an object with a proper tag. It is preferred in several commercial applications, including tracking/locating items to inventory management within a warehouse. Even though commercial uses for it, including electronic toll collection, animal and vehicle tracking, and factory automation, were first presented in the 1970s, it has become more universally accessible in recent years due to the miniaturization and cost reduction of the RFID tags [1]. RFID sensor tags are improved versions of standard RFID tags that can detect several environmental parameters and events and can wirelessly transfer the acquired parameter data to an RFID reader, which can read sensor data [2]. Depending on the application, these tags can sense parameters such as motion, humidity, temperature, pressure, etc. [3].

In recent years, several applications of RFID sensor tags have been proposed. Catarinucci et. al. [4] have proposed a waste management system that employs ultralow power RFID sensor tags [4]. The tags designed specifically for this work are equipped with weight sensors to detect the amount of urban waste produced by the houses, and the weight data are collected via cloud software. The sensor board is equipped with a microcontroller, a weight sensor, and a GPRS module to transfer data. In work presented by Colella and friends Ultra High Frequency (UHF) RFID sensor tags equipped with inertial measurement unit (IMU) sensors are used for biomechanical analysis of human body movements [5]. The tag is equipped with a cell battery to power the sensor and the microcontroller. The authors have shown that the system appropriately reproduces the body's movements. A system for tracking environmental data during logistics operations of perishable products using RFID sensor tags equipped with sensors capable of monitoring temperature, humidity, vibration, etc., as proposed by Mejjaouli et. al. [6]. The proposed approach is not realized by using real sensor tags, but a software model has been implemented. Toda and Shinomiya proposed a fall detection system for older people by employing passive UHF RFID sensor tags equipped with pressure sensors [7]. Sensor tags are placed beneath the footwear and can sense pressure and RSSI to identify the person's fall. The results presented in the paper show that the proposed system is capable of identifying the fall event. In the work presented by Zhongbin et. al., an RFID sensor tag-based temperature monitoring system to be used in measuring the temperature of high voltage equipment in a substation has been proposed [8]. The sensor tags used in the paper are energized from the energy relays that harvest energy from electric fields inside the substation; therefore, the energy source is unlimited, and measurements can be taken long-term. In the work presented by Chen and friends, a temperature measurement is performed using a resistor temperature-dependent value on an off-the-shelf RFID Tag [9]. The authors claim that the temperature measurement range with their approach is 0 C to 85 C with an accuracy of 2.7 C. Catarinucci et. al. [10,11] have proposed a rule-based healthcare monitoring software framework based on a generic RFID sensor tag. The RFID sensors are UHF based, but the acquired parameters are not specified in the proposed work; therefore, the framework seems to provide a flexible and customizable solution for different application scenarios. A textile yarn integration of a temperature sensor RFID tag integrated circuit is presented in work by Benouakta

[12]. The integrated circuit is integrated using the E-Thread assembling technology. Authors claim that the integrated sensor is capable of measuring temperature between 25 C to 70 C with a distance between 4.5 meters to 6.2 meters. Liu and friends propose a system that includes standard and temperature sensor RFID tags to locate the position of the sensor RFID tag relative to the standard tags used as a reference [13]. The received signal strength indicator (RSSI) data of both the reference tags and the sensor tag are acquired and compared for the positioning of the sensor tag. The average error for the location estimate is 0.461 m. for a 12.25 m2 area. Rasheed et al. presented an RFID sensor tag design and textile integration for measuring human body temperature [14]. Measurements from different body regions such as forehead, abdomen, wrist and fabric material and with different antenna polarizations are presented. The antenna polarization seems effective since the antenna feed efficiency depends on the polarization.

In this paper, we propose a novel method to measure the body temperature of individuals in a population, track data in cloud software, and generate an alert based on the unique ID record of the evaluated risk score for each individual. Off-the-shelf temperature measuring RFID sensor tags are integrated on textiles, while temperature value is acquired from standard RFID readers with appropriate specifications. Each measured temperature data is stored with the tag UID number and transferred to the cloud for long-term body temperature tracking of each individual. The main objective of this work is to alert if any individuals are infected with a feverish disease such as COVID19. The rest of the paper is organized as follows; in section two general methodology of the system is introduced, while in section three, laboratory and field implementation results are presented. In the final section, the results are discussed and concluded.

2. METHODOLOGY

The proposed body temperature measurement and tracking system comprise several hardware and software components. The general scheme introducing the system is presented in Figure 1. Each RFID sensor tag is placed on the inner part of the yoke of the clothing to ensure contact with the skin. The sensor and ID number are acquired using the RFID reader module equipped with a proper antenna. Each acquired data is transferred to the cloud server using the software running on the local PC simultaneously. A web-based application is used to observe the data acquired by the clients.

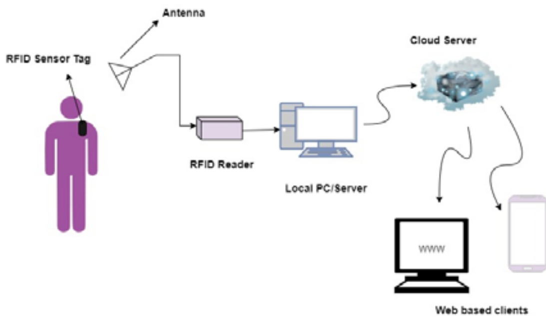


Figure 1. General scheme of the proposed system

2.1. Acquisition of the Temperature

The RFID sensor tags used in this work are off-the-shelf tags equipped with an NMV2D integrated circuit. These integrated circuits are compatible with Electronic Product Code (EPC) Radio-Frequency Identity Protocols Generation-2 UHF RFID Protocol for Communications at 860MHz – 960 MHz [15]. The temperature sensor included in the NMV2D chip operates in the range of -40 °C to +75 °C with a step of 1 °C and ±1°C tolerance.
RF interfacing of these tags to read the identification number stored in the tag is no different from the standard UHF RFID tags. However, to achieve a temperature reading, a two-stage operation is necessary. The temperature-sensing operation is activated by a Gen2 standard Read command sent by the RFID Reader with up to 4 ms. delay time to stabilize the measurement. The temperature measurement can be accessed in two memory registers. The following Equation 1 is used to assess the temperature in Celsius [16].

$$Temp = -0.0006x^2 + 0.0928x + 71{,}288 \quad (1)$$

Where x is the value read from the corresponding registers of the NMV2D integrated circuit. A calibration value based on reference measurements can also be added to the formula by writing this calibration value to the TEMP_TRIM region of the register.

To enable the temperature sensor, an RFID Reader or the I²C Master device must read the RESERVED memory bank, using the WordPtr parameter equal to 7h, through the Gen2 Read command; 11000010_2. If the temperature sensor is being accessed through an RFID Reader, the Read command must be executed in a loop, without turning off the RF signal until a value other than 0000_h is read as a result of the READ command.
The most critical operation in reading the temperature acquired by a tag is to keep the RF signal on until a proper temperature value is read. Most RF readers are equipped with a command to keep the RF signal on; CW (Continuous Wave) command. Under normal conditions, the RF signal of the reader is enabled only during the read operation and then automatically closed; however, to achieve temperature measurements correctly, the CW command is used to keep the signal open until a temperature value is acquired. The temperature value read from the tag is transferred to the local server, along with the tag's ID.

Since each RFID sensor tag is placed on the inner part of the yoke of an individual, the body temperature of the individual is measured and stored in a database with their corresponding ID numbers.

2.2. Cloud Software

A private cloud structure that will work within the relevant organization is built on the software side of the study. With the help of this structure, it is possible to collect data from antennas located anywhere in the organization. During data collection, it is possible to read more than one time for the same data value due to the nature of RFID antennas. With the filter services we have developed in the cloud system, the repetitive data that coincide is eliminated.

In addition, with antenna placements and related software modules designed in schools or businesses, information about people entering or leaving a place (A Student Classroom, Meeting Room, Dining Hall) is obtained and passed through that area. The collected data are virtual ID numbers representing students or employees, as well as information on the person's body temperature at that moment. After each movement, a timestamp, virtual identity and body temperature information are recorded in our cloud system.

To protect the personal data of the individuals, virtual identity numbers instead of real identity information are preferred for tracking the data of the individuals. However, suppose a detection is made in the system as a suspect with a high-risk score. In that case, the personnel supervisor will be able to reach the person's real identity and ensure that he or she is isolated and undergoes a health check. Suppose there is a positive case after the control. In that case, it is ensured that the person is diagnosed as a patient, and the people who contacted the patient for a certain time in the same environment until one week ago will be contacted and informed about the health risk they are facing. In this way, it will be possible to accurately identify the people who have contacted the patient.

The PostGre SQL Database system and Microsoft.Net Core MVC software technology are used in the Cloud Architecture so that the application can run on any platform without additional licensing fees. In addition, Android and IOS Native Mobile applications have been developed to access the cloud system via the local intranet or remotely using a VPN connection via mobile devices. These applications have features that will enable easy monitoring of the data.

Another feature of our study is analyzing the collected data and discovering hidden connections by employing machine learning algorithms. As an important field of computer science, machine learning helps computer software predict previous information [17]. Its learning process is categorized into four various types, namely supervised learning, by labelled training data for the related algorithms, unsupervised learning, which utilizes an unlabeled training dataset, reinforcement learning, which predicts through observing the environment, doing a suitable action, the semi-supervised learning, whose dataset consists of both unlabeled and labelled cases [18]. We can point to Support Vector Machines, k-Nearest Neighbors, Artificial Neural Networks, Random Forest, Decision Trees, and Linear Regression as the most important algorithms to select for solving supervised learning problems [19].

In addition, machine learning consists of two main processes, scoring and clustering. With the scoring process performed in the first stage, a SCORE parameter is obtained regarding how prone people are to the disease. Clustering estimates the risk of disease for the people detected in the system. The study is performed by combining the SCORE values obtained and the location and temperature values measured by the system. More detailed information on the steps taken is presented in the following sections.

2.3. Stage Scoring

Since fever is not the only risk factor, a risk score is assigned to users using cardholder health, family and physical information. Gender and disease information is used for physical characteristics. They are scored according to their distribution and risk ratio, as presented in Figure 2.

PHYSICAL													
Gender		is_diabetes		is_obesity		is_cardiovascular		is_asthma		is_kidney_failure		is_liver	
VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
Female	0	0 (YOK)	0	0 (YOK)	0	0 (YOK)	0	0 (YOK)	0	0 (YOK)	0	0 (YOK)	0
Male	1	1 (VAR)	1	1 (VAR)	1	1 (VAR)	1	1 (VAR)	1	1 (VAR)	1	1 (VAR)	1

Figure 2. Parameters used to evaluate the physical risk factor

The information is used for family characteristics, information about how many people there are in the family, how many people work and whether there is a smoker. They are scored according to their distribution and risk ratio, as presented in Figure 3.

FAMILY					
CountOfFamilyMembers		number_working_family		is_smoke_someone	
VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
2	1	1	2	0	0
3	2	2	2	1	1
4	2	3	3		
5	3	4	3		
6	3				

Figure 3. Parameters used to evaluate the family risk factor

Information about how he came to school/office is used for his external features. As presented in Figure 4, they are scored according to their distribution and risk ratio.

EXTERNAL			
TransportationType		is_going_course	
VALUE	SCORE	VALUE	SCORE
walking	1	0 FALSE	0
private car	1	1 TRUE	1
public transportation	3		
service	3		

Figure 4. Parameters used to evaluate the external risk factor

As a result, three different scores are calculated for each user, and a 3-digit risk score is evaluated according to Equation 2.

$$SCORE = PHYSICAL * 100 + FAMILY * 10 + EXTERNAL * 1 \quad (2)$$

2.4. Testbed

A testbed has been built to test the performance of the proposed system. Two antennas are connected to a four-port RFID reader to read the temperature value on one side of a gate. In contrast, the other side of the gate is equipped with a conventional RFID reader and a single antenna to identify the direction of the individual, as presented in Figure 5. The reason to put two RFID sensor tags on the yoke of the clothing is to guarantee the temperature reading for both directions of the user since the head of the individual can block the radio frequency illumination over the tag. As mentioned previously, the sensor IC over the tag cannot get enough energy during the reading operation, which is critical.

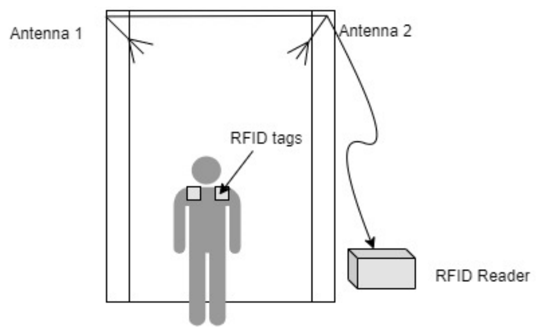


Figure 5. Placement of RFID tags and antennas at the testbed gate.

The other side of the gate is not presented in the figure, but it is equipped with a conventional RFID reader without any capability of reading temperature values. Its only purpose is to estimate the direction of the individual, whether entering or exiting the room. If the temperature measuring side reads the tag first, this means that the person with the RFID sensor tag is moving from the temperature sensing part to the not sensing part of the gate. If the non-sensing part reads first, the opposite direction is valid. Therefore, with the help of a conventional low-cost reader, both the person's direction and body temperature are identified. Photographs of the testbed are presented in Figure 6, while the placement of the tags inside the clothing yoke is presented in Figure 7.

Figure 6. Testbed photographs from both sides of the gates

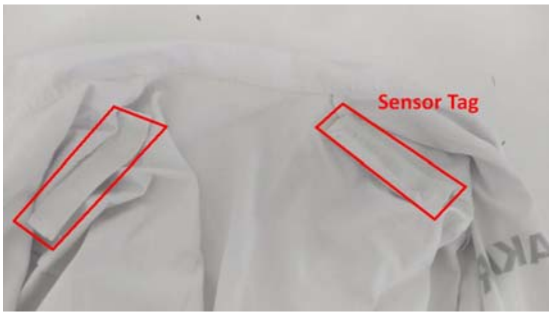


Figure 7. Placement of RFID sensor tags inside the clothing of the yoke

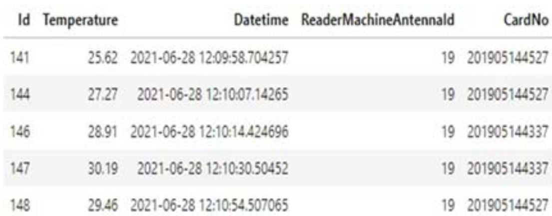
2.5. Results

As introduced in Section 2, the temperature formula for a sensor tag includes an additive calibration value used to correct each measurement. Therefore, as a first step, the testbed is used to evaluate the calibration value for the sensor tags. A sensor is placed under the reading antennas, and 33 temperature readings are recorded. The temperature is measured with a calibrated temperature sensor of 25 ºC. The average measurement in this setup is 21.9 ºC with a 0.153 variance value, and the difference between the real temperature value is 3.1 ºC. Since this value will be used for other sensor tags, it is rounded to 3 ºC and stored as the software's calibration factor. To test the validity of this value, three other sensor tags are used under the same test setup but with different temperatures. As presented in Table 1, the 3 ºC calibration value seems adequate for temperature measurement using these sensor tags.

Table 1. Results of the calibration value test

	Real temperature ºC	Measured temperature ºC	Difference ºC
Tag 1	33.5	31.56	3.06
Tag 2	33.5	31.25	2.75
Tag 3	25	21.89	3.11

The calibration data are used to acquire the correct body temperatures of individuals equipped with RFID tags in their clothing yokes. Each pass from the gate with a dedicated tag to a user is recorded in the database as presented in Figure 8. After the acquisition of the temperature data of the individuals, the Isolation Forrest algorithm is employed to detect anomalies to identify the change in temperature changes that could project to potential risk.



Id	Temperature	Datetime	ReaderMachineAntennaId	CardNo
141	25.62	2021-06-28 12:09:58.704257	19	201905144527
144	27.27	2021-06-28 12:10:07.14265	19	201905144527
146	28.91	2021-06-28 12:10:14.424696	19	201905144337
147	30.19	2021-06-28 12:10:30.50452	19	201905144337
148	29.46	2021-06-28 12:10:54.507065	19	201905144527

Figure 8. Temperature data of the individuals with unique ID numbers

Other factors affecting the potential risk are also included as additional data and used to evaluate the total risk of the individual. These factors include past health records, family and physical information such as sex, age, weight, etc. Using this data; a risk score is evaluated with three factors. The first factor is calculated using gender and past health records, while the second factor is family records, including employed people and smokers in the family, and the last factor is the external effects factor, which includes transportation method and the other possible social environment the individual might contact with other people. The cumulative risk is evaluated by a weighted combination of these three risk factors. The physical factor is the most influential factor among all, with a weight of 100, while the family factor affects the risk evaluation by 10 and external factors weight 1.

Data that are thought to affect an individual's risk status were produced and added to the table. Then, considering the distribution of these characteristics, three scores were calculated. Due to a lack of sufficient data, the database was intervened, and more data was produced. In this direction, an exploratory data analysis was performed, including a detailed statistical and visual analysis of the data, which is presented in Figure 9.

Id	FirstName	LastName	Gender	ParentName	ParentLastName	ParentPhone	CountOfFamilyMemb...	TransportationType
3	Laird	Roome	Female	Faber	Roome	4271666344	6	service
4	Aurora	Burdett	Female	Leslie	Burdett	7186225274	3	service
5	Bunni	Pavlett	Male	Minta	Pavlett	5364986936	3	service
6	Barret	Bullene	Female	Pattin	Bullene	8425021502	2	private car
7	Daphne	Syson	Agender	Rosaline	Syson	3676448480	6	public transportation

ProfilePicture	BodySize	BirthDate	LastTemperature	is_diabetes	is_obesity	is_cardiovascular	is_asthma	is_kidney_failure
boy.jpg	4	2013-06-06 21:41:34	0	0	1	0	0	0
girl.jpg	2	2013-06-05 00:20:24	0	0	1	0	1	1
girl.jpg	2	2012-04-06 00:37:52	0	1	1	1	1	1
boy.jpg	4	2015-07-27 18:37:40	0	1	1	0	1	1
girl.jpg	0	2013-02-17 12:55:40	0	0	0	1	0	1

is_liver	is_going_course	number_working_family	is_smoke_someone
0	1.0	4	0
1	1.0	2	1
1	0.0	2	1
1	1.0	1	0
0	0.0	4	1

Figure 9. Risk factors of the individuals in the database

3. CONCLUSION

This paper presents an RFID sensor tag-based body temperature tracking of the individuals in a population. RFID sensor tag is located on the uniform's yoke, and the person's temperature is measured every time the person passes from specific locations with the developed RFID reader with temperature reading capability. The temperature data is evaluated on cloud software, and changes in the temperature of each individual are tracked. Change in temperature data is used to evaluate the cumulative risk of the user, which also includes other factors like physical, family, and external factors. If the cumulative risk is above a threshold, an alert is generated to the person's isolation and stop the spreading of the disease.
The important contribution of this study is to diagnose possible fever outbreaks at an early stage and to prevent their spread with the help of a low-cost tag and an RFID system. In addition, thanks to the artificial intelligence-supported risk scoring system used in the study, a risk factor is obtained by using demographic characteristics such as age, gender, family characteristics, chronic diseases, as well as the fever of the people. Thus, risky people are provided to go to health inspection even if they have a lower fever value.

4. DECLARATIONS

4.1. Human and Animal Ethics

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards

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