Süleyman Demirel Üniversitesi
YEKARUM e-DERGİ
(Journal of YEKARUM)
Cilt 9 , Sayı 1 , 1-19 , 2024
E - ISNN:1309-9388

Wearable Technologies: Wearable Sensor and Detectıon of Motion Sensor Data Using Fuzzy Logic

Murat Kodaloğlu[1*], Feyza Akarslan Kodaloğlu[2]

[1*]Occupational Health and Safety Program, Vocational School of Technical Sciences, Isparta University of Applied Sciences, Isparta, Türkiye, (ORCID: 0000-0001-6644-8068), muratkodaloglul@isparta.edu.tr
[2]Textile Enginering Department, Faculty of Engineering and Natural Sciences, Suleyman Demirel University, Isparta, Türkiye (ORCID: 0000-0002-7855-8616), feyzaakarslan@sdu.edu.tr

(İlk Geliş Tarihi 18/03/2024 ve Kabul Tarihi 28/05/2024)

ABSTRACT :

With the developing technology in recent years, innovative products find use in many areas of life. Wearable technologies have a wide range of impact, from healthcare to education, from tourism to applications for the disabled. While these technologies make it easier to monitor people's health, they can enrich the learning experience in education and offer important opportunities in many areas. From a health perspective, while it has advantages such as management of chronic diseases, personalized health monitoring and rapid health access, disadvantages such as privacy concerns, technological problems and cost should not be ignored.

In the future, wearable technologies may have major impacts in areas such as the ability to send signals in health emergencies, virtual reality experiences in the entertainment industry, augmented reality applications in tourism and guidance for the disabled. It is envisaged that these technologies, combined with fashion and functionality, will bring new markets and areas of use. In the future, a great change and progress is expected in the field of wearable technologies in a wide range of application areas. In this study, sensor data obtained while users interacted was used. Fuzzy logic method was used to determine the activity and acceleration of motion sensors within a certain time period from raw sensor data.

Keywords: *Wearable Technologies, Motion sensor, Fuzzy logic, Wearable sensor*

Giyilebilir Teknolojiler: Giyilebilir Sensör ve Hareket Sensör Verilerinin Bulanık Mantık ile Tespiti

ÖZET

Son yıllarda gelişen teknoloji ile birlikte yenilikçi ürünler hayatın pek çok alanında kullanım alanı bulmaktadır. Giyilebilir teknolojiler, sağlık hizmetlerinden eğitime, turizmden engellilere yönelik uygulamalara kadar geniş bir etki alanına sahiptir. Bu teknolojiler, insanların sağlık takibini kolaylaştırırken, eğitimde öğrenme deneyimini zenginleştirebilir ve birçok alanda önemli fırsatlar sunabilir. Sağlık açısından bakıldığında, kronik hastalıkların

* Sorumlu yazar E-mail:

yönetimi, kişiye özgü sağlık takibi ve hızlı sağlık erişimi gibi avantajları bulunurken, gizlilik endişeleri, teknolojik sorunlar ve maliyet gibi dezavantajlar da göz ardı edilmemelidir.

Gelecekte, giyilebilir teknolojilerin sağlıkta acil durumlarda sinyal gönderme yeteneği, eğlence sektöründe sanal gerçeklik deneyimleri, turizmde artırılmış gerçeklik uygulamaları ve engellilere yönelik rehberlik gibi alanlarda büyük etkileri olabilir. Bu teknolojilerin moda ve işlevsellikle birleşerek yeni pazarları ve kullanım alanlarını da beraberinde getireceği öngörülmektedir. Gelecekte giyilebilir teknolojiler alanında, çok çeşitli uygulama alanlarında büyük bir değişim ve ilerleme beklenmektedir. Bu çalışmada, kullanıcılar etkileşim halindeyken elde edilen sensör verileri kullanılmıştır. Ham sensör verilerinden hareket sensörlerinin belirli bir zaman dönemi içinde aktivitesini belirlemek ve ivmelenmesini tespit etmede Bulanık mantık yöntemi kullanılmıştır.

Anahtar Kelimeler: *Giyilebilir teknoloji, Hareket sensörü, Bulanık mantık, Giyilebilir sensör.*

1. INTRODUCTION

The concept of wearability is particularly important in areas such as healthcare, wellness, and fitness/sports tracking. Wearable technology is portable devices that allow users to retrieve information and facilitate user interaction. Wearable technology products are designed as special electronic tracking devices that are synchronized to a computer or smartphone to provide long-term data tracking, in many cases wirelessly. Rings, smart glasses, smart watches, bracelets, etc. They are state-of-the-art wearable computers that can be integrated into various parts of used objects in different ways, such as [1]. Technological advances, miniaturized electronic devices, data storage improvements provide greater energy efficiency [2]. Wearable technologies offer innovative solutions to monitor its user's biometric data (psychophysiological measurements [3, 4], daily activity and behavior patterns [5] throughout the day in both formal and informal settings [6, 7].

It can be said that the most interesting among wearable technology products are smart implants. Implants are products that will always be with the person no matter where they go or what they do. It can be used by surgically implanting it into the body for health reasons such as insulin problems, birth control, and blood pressure problems [8, 9]. Current devices generally fall into two main categories: head-mounted displays and body sensors. These are portable devices designed to detect or record physiological functions of the human body and visual devices mounted on the user's head. However, there are deficiencies regarding the impact of this technology on patients' health [10]. In another study, De Rossi et.al developed a garment called upper limb kinesthetic garment (ULKG) to detect the posture and movement of the arm, especially after stroke. ULKG can act as a virtual trainer to treat patients who need to continue exercises that are vital to regain control of the paralyzed limb and therefore quality of life. It allows medical staff to monitor multiple patients in real time and communicate with each individually [11].

Wearable technology is a type of technology found within electronic devices that is worn on the body as an accessory or as part of materials used in clothing. One of the most important features of wearable technology is the ability to connect to the Internet [12]. In a patient monitoring system architecture using wearable sensors, body-worn sensors communicate wirelessly with fixed (wireless local area network) or wearable (mobile phone) gateway devices to transmit sensor data to remote locations. Measurements can be stored locally in a wearable monitoring device for later transmission or transmitted directly to a medical center (e.g. over the public telephone network) where the patient's data can be accessed online using the internet, regardless of the patient's location. Different approaches are used to detect chest wall movement associated with breathing. (Figure 1). One approach is to measure linear displacements along the anteroposterior axis of the chest.

Figure 1. Location of various wearable devices on the body that can estimate ventilation from chest surface movement [8].

Wearable technologies offer new opportunities in healthcare by making patient clinical, behavioral and self-monitoring data more accessible. Wearable technologies developed from a patient-oriented perspective allow patients to manage their own health conditions, protect their freedom and perform self-care. However, the integration of these technologies into healthcare systems and the integration of growing amounts of data into clinical practices also present several challenges. In this context, how to use the data obtained using wearable technology to provide added value to healthcare professionals, healthcare institutions and patients is an important problem [13]. For developers of this technology, it is a great challenge to develop solutions that can be easily integrated and used by healthcare professionals, taking into account existing limitations.

The first examples of wearable technology appeared in China in the 13th century with abacus-like calculators. Later, in the 17th century, portable time tracking became possible with pocket watches. With the advancement of technology, wearable devices such as radio headsets and mobile phones emerged, and in the 21st century, popular wearable technologies such as smart watches and health monitoring devices were developed. These devices helped people monitor their activities, track their health data, and communicate. [14].

1.1.Wearable Technologies in Healthcare

Wearable technologies have found a significant area of development in healthcare. It attracts attention with the benefits it offers especially for the aging population. Malwade et al. The study conducted by [15] discussed in detail the advantages of these technologies for elderly individuals and the difficulties in this field. Wearable devices are widely used for health monitoring and diagnostic purposes due to their comfort and ability to provide daily care. Various hardware such as skin-based devices, bio-fluid-based devices, and other competitive wearable technologies play a major role in monitoring and managing various disease conditions.

Chuah et. get. [16], their study examines the use of smart watches and the effects of perceived usefulness and visibility on usage intention. The findings show that perceived usefulness and visibility determine the attitude towards the use of smartwatches, which in turn translates into usage intention. The research makes a significant contribution to understanding user perception of wearable technologies and developing strategies. The study emphasizes that wearable technologies include both technology and fashion dimensions and discusses different approaches from a managerial perspective. Chuah et al.'s study provides a foundation for understanding the impact of smartwatches, as well as other wearable technologies, on consumers' perceptions and reactions.

One of the topics highlighted in the articles is the relevant techniques used to monitor different biological and chemical parameters. Studies have discussed the effectiveness and applicability of wearable technologies in monitoring basic parameters such as blood pressure, heart rate and sweat rate. Additionally, various applications of wearable devices in monitoring physiological and psychological parameters and their potential future impact in these areas have also been extensively studied. However, the current limitations and future development possibilities of these devices have also been evaluated in detail. This information provides important insight into the potential of wearable technologies for healthcare to improve the quality of life of the aging population.

He notes that continuous and real-time monitoring technologies play a critical role in the management of individuals with chronic diseases. According to the World Health Organization (WHO), chronic diseases account for the vast majority of all deaths worldwide and also cause high economic costs. Therefore, different approaches are needed to monitor and diagnose conditions such as cardiovascular diseases, diabetes and neurological disorders. In this context, HWDs (Wearable Health Devices) stand out as an effective strategy. HWDs help us understand changes in the human body and contribute to the prevention and treatment of diseases. For example, wearable biosensors are used to measure different biopotentials (e.g. ECG, EMG, EEG, EOG) and improve the healthcare system by reducing the burden on hospitals and providing more reliable and timely information. Studies examine in detail skin-based HWDs, textile-based HWDs, tattoo-based HWDs, and wearable devices for drug delivery systems, highlighting the important contributions of these devices in the field of healthcare [16].

Wearable devices include input mechanisms for collecting clinical and environmental data, processing units for real-time processing of this information, and output mechanisms that provide feedback or control functions. Wearable devices have a variety of applications, including assisting doctors with care services, remote monitoring, rehabilitation support, and electronic patient records. They can also be used as health trackers or fitness aids for healthy individuals [17]. Integrating telemetric features into wearable devices is compatible with mainstream healthcare and allows citizens to transmit their health data from anywhere, anytime. There are also advances in more complex multi-signal monitoring and decision support devices developed for astronauts and military personnel (Figure 2).

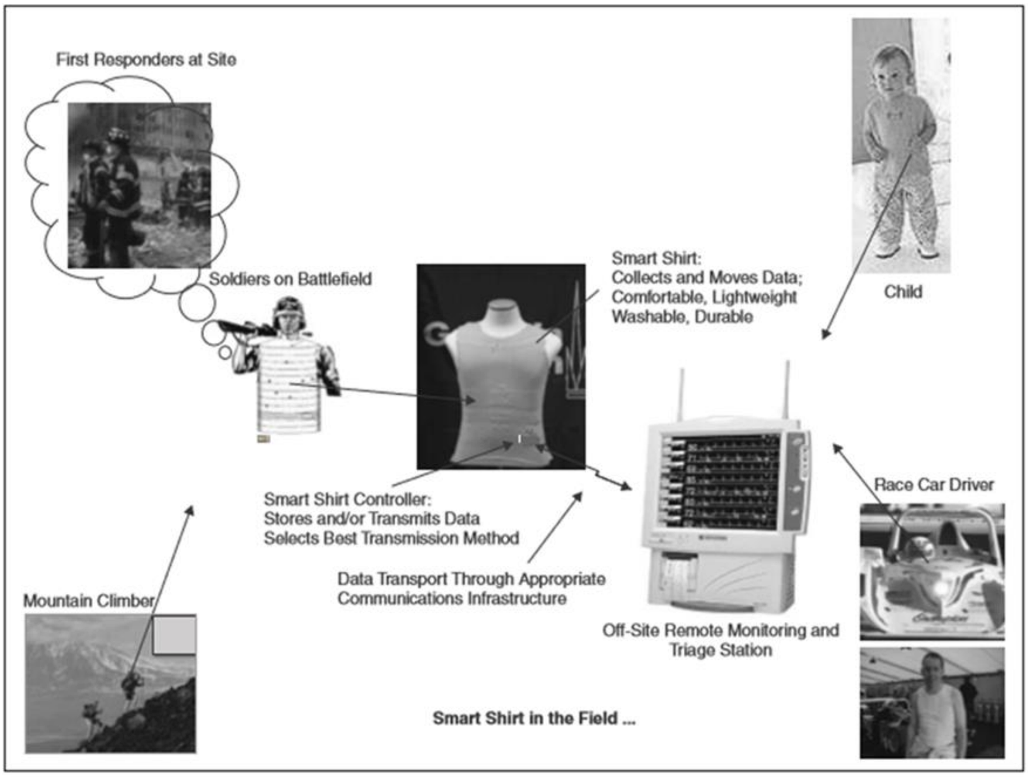

Figure 2. Wearable devices in various fields of application [29]

It is noteworthy that the majority of studies on developed wearable systems are on monitoring heart movements. Heart rhythm and oxygen levels can be monitored with these systems. Original Holter monitors require the patient to carry a relatively large device with several wires leading to electrodes placed on the chest. Newly developed patch-like devices can be worn unnoticed by the patient and benefit from wireless data transfer. Some of these devices also provide more advanced capabilities, such as the ability to measure respiration and skin temperature. Suzuki et.al. In the system developed by [7], ECG, pulse and body temperature information coming from a sensor that can be placed on the chest in the form of a patch can be transferred to a smartphone via Bluetooth connection for 24 hours.

Pulse and oximetry measurements can also be made with recently developed smart watches. Wang et al. It has been stated that 10% stronger signals can be obtained with the PPG (Photoplethysmogram) system developed by [6], which is attached to the earlobe and uses multiple LED lamps and photodiodes, compared to measurements made from the finger. A new and interesting trend is the use of headphones that combine audio features with pulse oximetry and step counting (Figure 3).

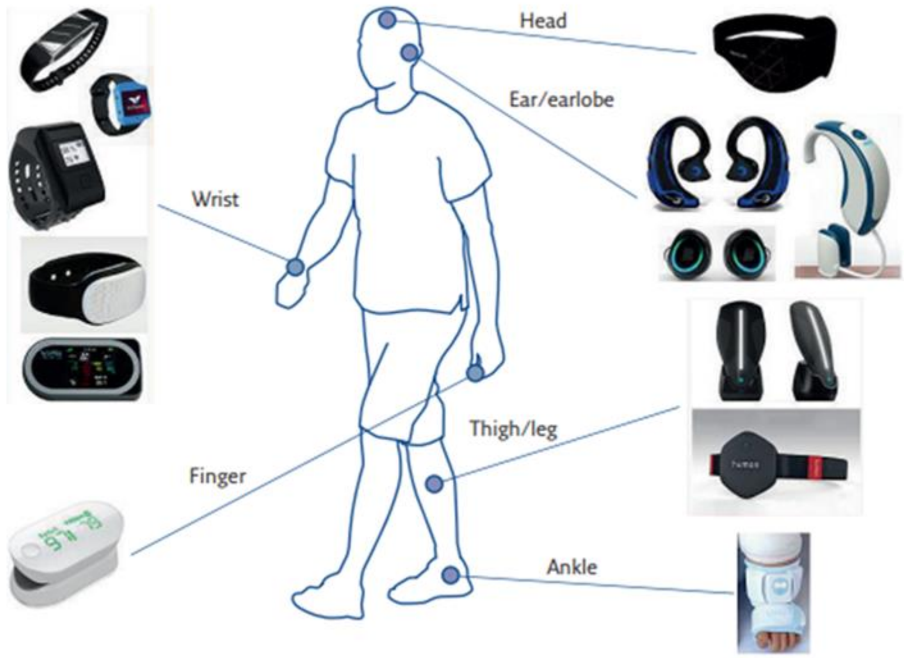

Figure 3. Location on the body of various wearable devices capable of pulse oximetry [8]

1.2.Wearable Technologies in Education

With the development of information and information technologies, communication types and learning-teaching methods also change. The most important impact of technological developments in the field of education is that they provide access to various data sources and content at increasing speeds. Bower and Sturman, 2015 examined the possibilities that wearable technologies can offer in education. This study provides a comprehensive look at how wearable technologies can be evaluated in the field of education, especially what opportunities they offer in terms of pedagogy. The authors investigate how wearable technologies can be integrated into learning processes and how students and teachers can use these technologies effectively. The article reveals the potential that wearable technologies can offer in education through analysis and literature review on a sample of 66 international educators. These potentials include pedagogical uses such as communication, student participation and interaction, recording, simulation, as well as elements that increase learning efficiency and logistical advantages. The article discusses the benefits of wearable technologies in education as well as potential problems. In particular, issues such as distraction, excessive technology addiction, and privacy concerns point to the difficulties that may be encountered in the use of these technologies. This study provides a guide on how wearable technologies can enrich classroom experiences and offers an important perspective on how the role of these technologies in education can be shaped [18].

With the use of wearable technology, children with autistic syndrome can be monitored and alerts can be generated when certain limits are crossed. Thus, the safety of autistic children in the school environment can be increased. In studies conducted in areas where wearable technologies are used, various benefits of these technologies to education are mentioned [19, 20]. Increasing students' interest in the lesson, changing their learning experiences, offering new learning areas, increasing their participation in the lesson, improving their learning, providing feedback during the lesson, and providing faster access to information can be counted among the benefits of wearable technologies. In addition to its benefits, it also has disadvantages such as data security risk, confidentiality of personal information, software development, education quality, cost and technical problems. In the study of Sezgin, 2016, the possible contributions of wearable technologies to the field of education were discussed by classifying them according to the studies in the literature, their theoretical foundations and results. Recommendations are presented for studies on the educational use of these

1.3. Advantages and Disadvantages of Wearable Technologies

• Management of Chronic Diseases: Remote monitoring systems and wearable devices can help individuals with chronic diseases monitor their health status. This may reduce the need for regular doctor visits.

• Personalized Health Tracking: These technologies allow individuals to monitor their own health data more closely. Data such as pulse, sleep patterns, and physical activity can be continuously monitored.

• Fast and Remote Access: Healthcare professionals can access patients' health data quickly and remotely, so they can intervene faster.

However, some disadvantages should not be ignored:

• Privacy and Security Concerns: The collection and transmission of personal health data may raise privacy concerns. The security of this data and the risk of misuse is important.

• Technological Problems and Incorrect Data: If wearable devices have technical malfunctions or provide incorrect data, an accurate health assessment may not be possible.

• Cost: Some wearable technologies can be high-cost, which can limit their accessibility.

It is clear that such technologies have significant potential in the field of healthcare. However, to realize this potential, important issues such as privacy, security and accuracy need to be addressed [22].

1.4. The Future and Impacts of Wearable Technologies

Wearable technologies may have the potential for great impact in the future in areas such as health monitoring, entertainment, tourism and disability assistance. These technologies can monitor health indicators, send automatic signals in case of emergencies, and share users' location with emergency services. For example, it can detect a drop in insulin levels and inject the required amount into the body.

In the entertainment industry, wearable technologies can drastically change the gaming industry. It allows users to experience virtual environments as if they were real. Motion detection devices, on the other hand, can detect real movements without the need for tools such as a keyboard or joystick.

In the field of tourism, augmented reality integrated wearable technologies allow people to virtually tour cities or tourist attractions without visiting them. Tourism agencies can show customers hotels in virtual 3D format, so they can make the right choices.

For people with disabilities, wearable technologies have the potential for great impact. For the visually impaired, smart glasses can provide guidance. For the hearing impaired, smart glasses can detect sound and convert it into text format and display it.

Overall, wearable technologies can have major impacts in many areas such as healthcare, entertainment, tourism and disability assistance. With the spread of these technologies, new opportunities and services may emerge [23].

Wearable technologies represent an extremely exciting market. In every field, from the field of personal hygiene to intensive care hospitals, textile products with specific medical properties and functions are always of vital importance. Unlike functional products such as wound dressings, diapers, and face masks, truly intelligent wearable technologies are products that can combine the functionality of sophisticated medical devices with the comfort and user-friendliness of clothing products. This type of clothing has emerged as a synthesis of recent developments in different fields such as advanced material processing, polymer research, microelectronics, sensor technologies, telecommunications and information technology [24, 25].

The outstanding feature of wearable products is that they not only replace existing heavy or fixed medical devices, but also offer the opportunity to constantly monitor the body functions of individuals at risk or measure the performance of workers, drivers, athletes, emergency personnel or soldiers while doing their job, thus opening up completely new markets. is that it allows. The functions of wearable technologies can range widely, from detection of abnormal conditions to active corrective measures, regardless of whether intervention is made by the user [24]. These new products have the potential to be combined with fashion items and other types of clothing.

Smart shirt can contribute to reducing the cost of healthcare, reducing costs while improving quality of life. For example, a patient undergoing heart surgery at home can wear a Smart Shirt and ECG can be regularly transmitted to the hospital wirelessly (via mobile phone, internet, etc.). This monitoring will help the patient feel more “safer” and can facilitate recovery while also reducing the cost and time associated with recovery. Moreover, in case of an emergency, the doctor can be notified immediately. Using online medical records, the doctor can administer the right treatment, at the right time, at the right cost and save a life. For example, it can be used to monitor mentally ill patients. By treating those suffering from manic depression or even children with suspected ADD (attention deficit disorder) on a regular basis, doctors can better understand the relationship between their vital signs and behavioral patterns so that their treatment can be modified appropriately. Other potential applications include treating anxiety and phobias. Such medical monitoring of individuals is critical to the successful implementation of telemedicine, which has become economically viable in the context of advances in computing and telecommunications, particularly the Internet [26-32] .

2. MATERIAL AND METHOD

The fuzzy logic tables created in this study were described using the MATLAB program and the resulting data were examined. The Mamdani method allows us to define expertise in a more intuitive, more human-like way. Figure 4 shows the fuzzy logic model created with input and output parameters.

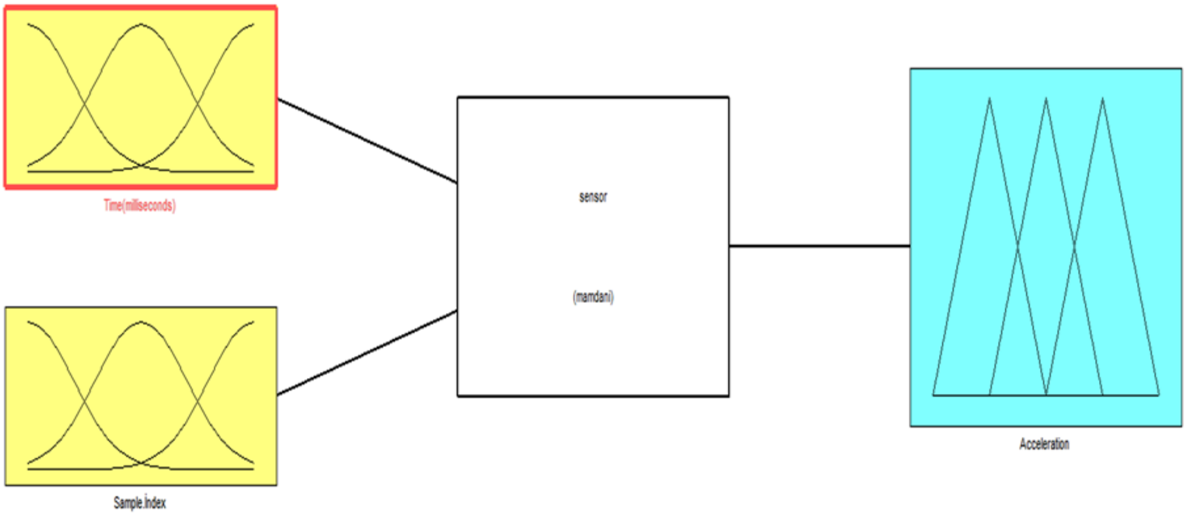

Figure 4. Fuzzy logic method

At the same time, fuzzy logic is rule-based to produce an information output. Figure 5 shows the fuzzy logic rule table. In the study, the type of membership functions used in the input sets is the Generalized Bell Membership Function (GBellMF) method, and the type of membership functions used in the output sets is the Generalized Bell Membership Function (GBellMF) method, thus the trapezoidal shape, which is a geometric shape, is obtained. Our input membership functions, Time (milliseconds), were chosen at three intervals, Sample Index at ten, and our output membership functions, breaking acceleration, at sixteen intervals. It was created with a hundred and thirty rule base in order to understand the effect of the relationship between the determined membership functions on the result.

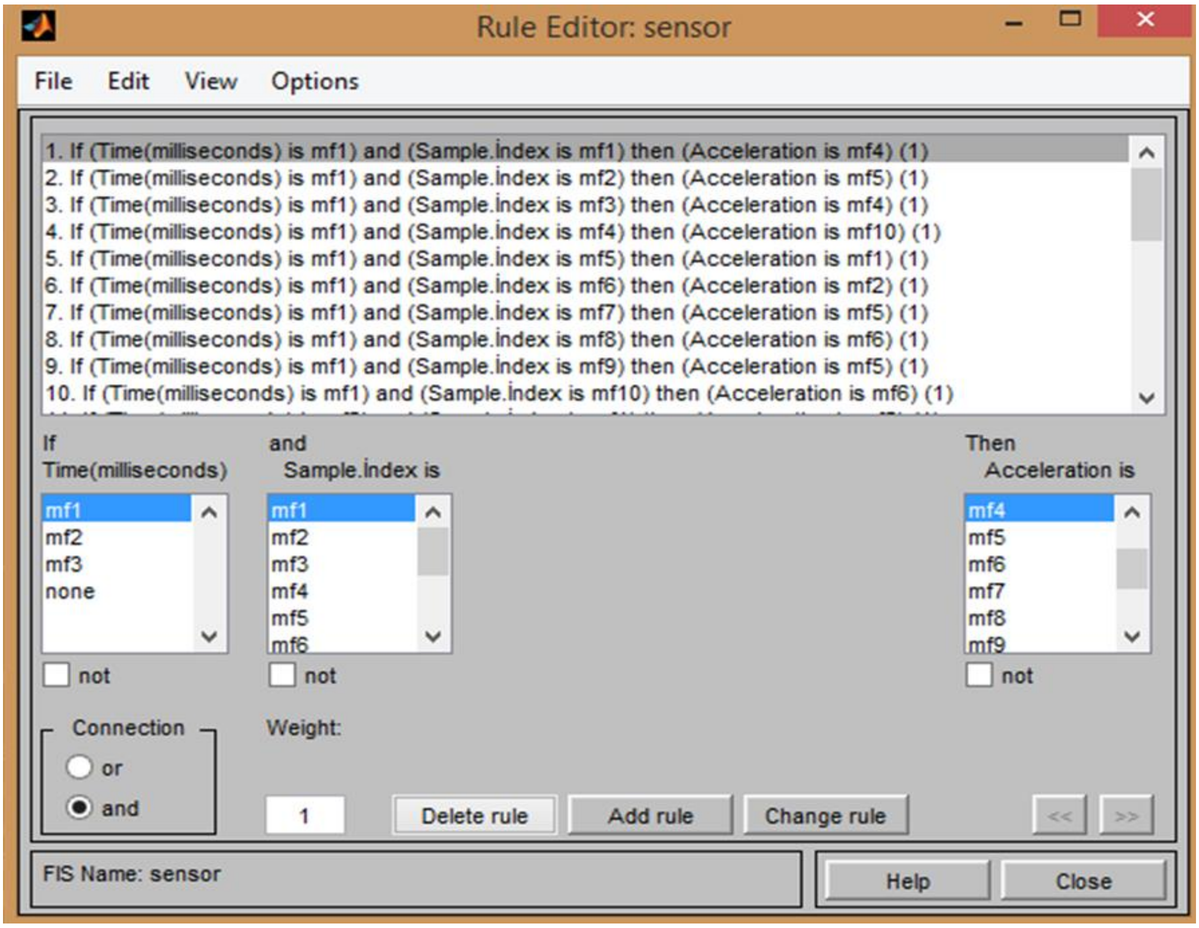

Figure 5. The fuzzy logic rule

3. RESULT AND DISCUSSION

In motion sensors, acceleration and deceleration create a minimum and a maximum in the acceleration curve. The graphs below show movements on the X and Y axis and up-down acceleration patterns. Figure 6 shows the acceleration graph for X-axis.

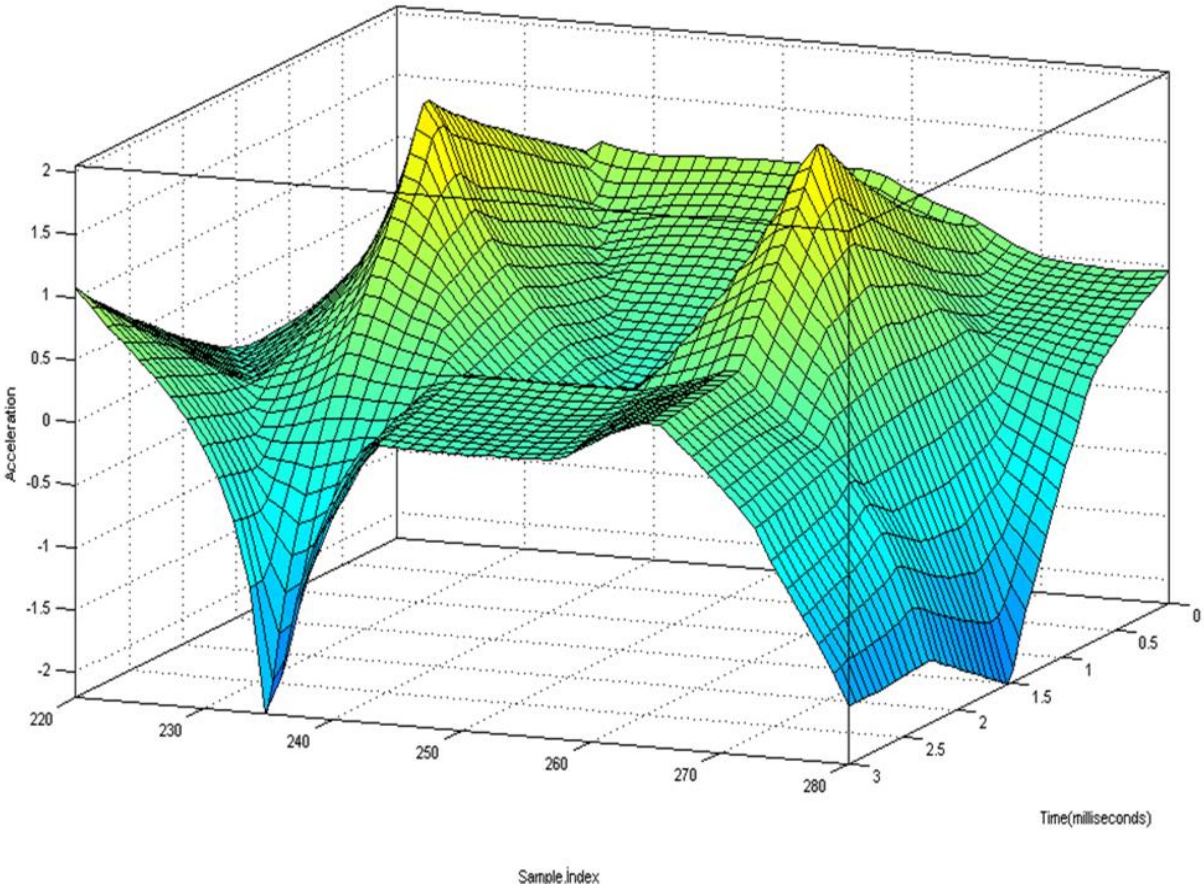

Figure 6. Acceleration graph for X-axis

Figure 6 helps to find out what is happening with the motion sensor. In the X-axis, a deceleration with a value of -2.2 is defined, followed by an acceleration with a value of 1.4.

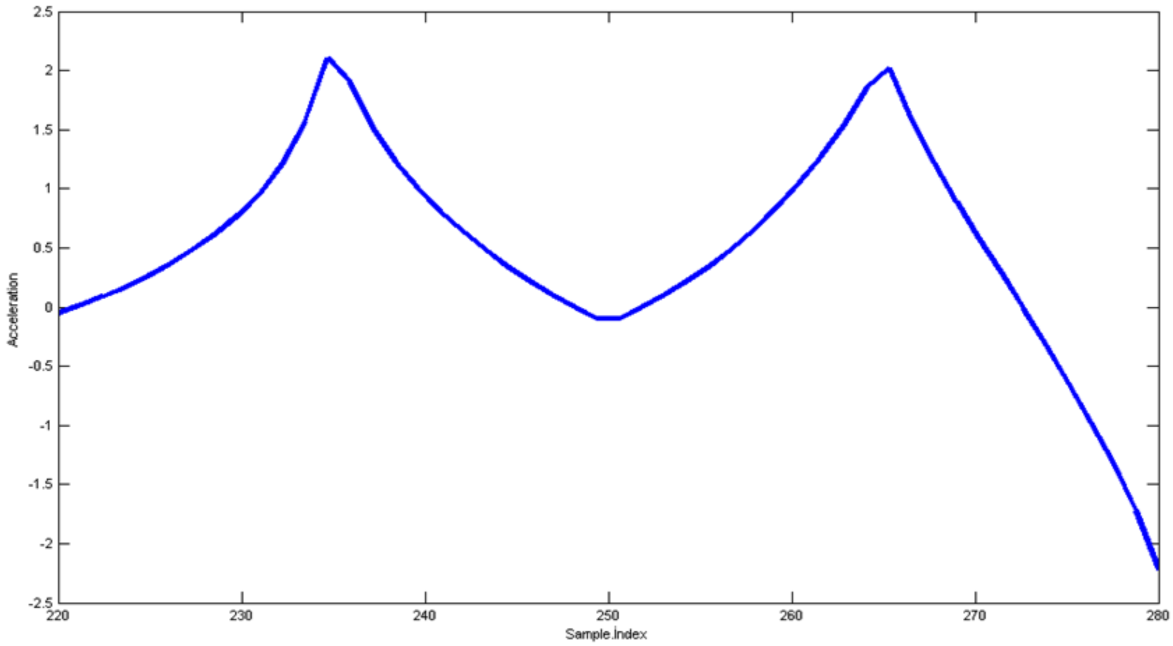

Figure 7. Relationship between sample index and acceleration for X-axis

In the acceleration graph on the X-axis, acceleration becomes 2.2 at a sample index value of 235, acceleration becomes -0.1 at a sample index value of 250, acceleration becomes 2.1 at a sample index value of 265, acceleration reaches a value of -2.4 at a sample index value of 280. These data are interpreted to coordinate the distances of movements using the graphs above. Figure 8 shows the acceleration graph for Y-axis.

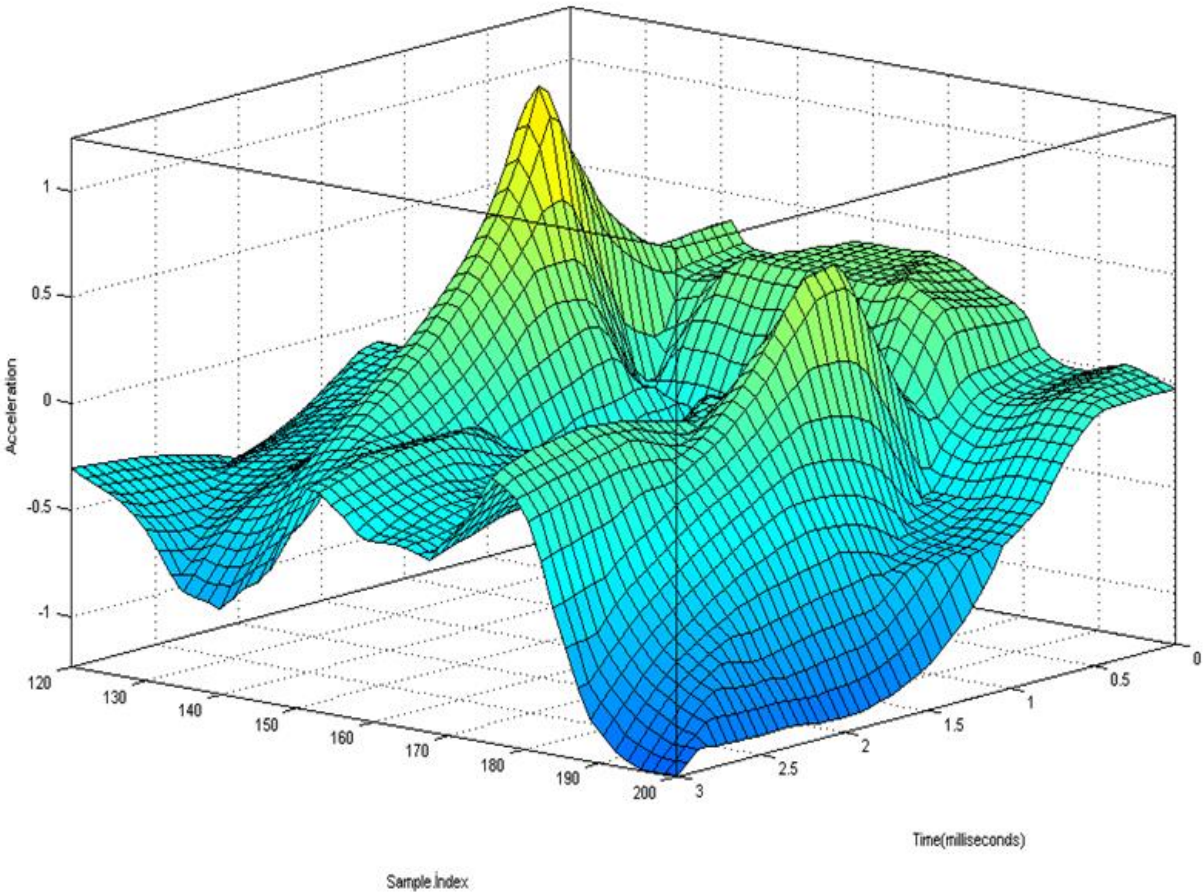

Figure 8. Acceleration graph for Y-axis

Given the y-axis, we can make inferences between the distances and directions of their movements. In the Y axis, a deceleration with a value of -1.2 is defined, followed by an acceleration with a value of 0.9.

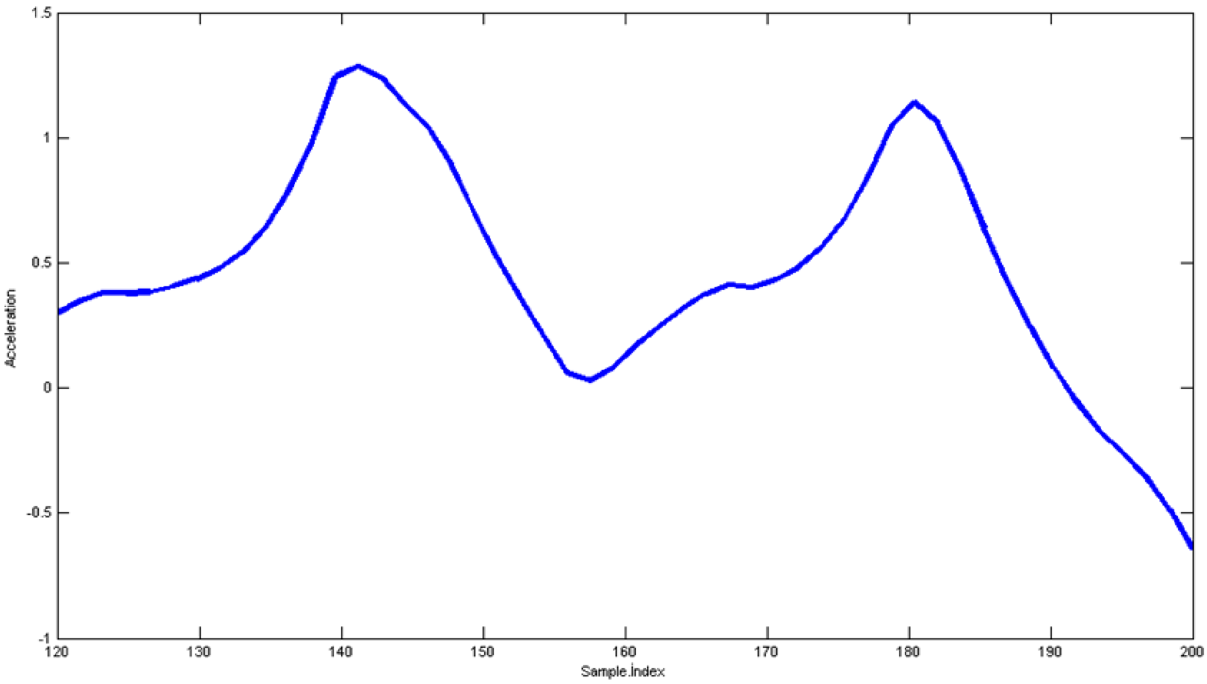

Figure 9. Relationship between sample index and acceleration for Y-axis

In the acceleration graph on the Y axis, the acceleration is 1.3 at 140 sample index value, 0.1 at 155 sample index value, 1.2 at 180 sample index value, and -0.6 at 200 sample index value. One after another, the sensors show unique acceleration and deceleration movements.

4. CONCLUSION AND RECOMMENDATIONS

The broad advantages offered by wearable technologies in the healthcare sector and education are clearly visible. In the field of healthcare, wearable technologies provide a significant increase in patient monitoring, management of chronic diseases and functionality of healthcare professionals. These technologies have found various applications that allow individuals to track their own health data and gain easier access to healthcare. On the other hand, it is observed that wearable technologies in education have a significant potential such as student interaction, efficiency and integration into learning processes.

The evolution of wearable technologies in the field of healthcare is bringing a radical change in modern healthcare. Wearable technologies, which are clinically useful technologies in patient diagnosis, treatment and care, stand out thanks to their low cost and ability to collect data for a long time in any environment. Cloud integration facilitates access to big data, allowing machine learning algorithms to be applied for new results. However, the lack of strict data management and appropriate verification standards in this area remains a significant problem, even though the technology is still maturing. Nevertheless, appropriate data regulations, widespread verification processes and integration into global networks stand out as important steps for wearable technologies to realize their potential. On the other hand, some difficulties that may be encountered in the use of these technologies have also been noted [27-28]. In particular, issues such as privacy concerns, technical malfunctions and cost are important points to consider.

Fuzzy logic method was used to determine the activity and acceleration of motion sensors within a certain period of time. With the fuzzy logic method designed to detect movement in the X and Y axes, it determined a deceleration with a value of -2.2 in the In this way, it is possible to make objective evaluation from fuzzy concepts.

Çıkar Çatışması Beyanı

Yazarlar arasında çıkar çatışması yoktur.

Araştırma ve Yayın Etiği Beyanı

Çalışma, araştırma ve yayın etiğine uygundur.

REFERENCES

[1] K. Kaewkannate and S. Kim, “A comparison of wearable fitness devices,” *BMC public health*, 16, 1-16, (2016).

[2] V. G. Motti, “Wearable technologies in education: A design space,” in Learning and Collaboration Technologies (Lecture Notes in Computer Science 11591), P. Zaphiris and A. Ioannou, Eds. Cham, Switzerland: Springer, pp. 55–67, 2019.

[3] M. Bauer, C. Brauer, J. Schuldt, M. Niemann, and H. Kromker, “Application of wearable technology for the acquisition of learning motivation in an adaptive e-learning platform,” *in Advances in Human Factors in Wearable Technology Design*, T. Ahram, Ed. Cham, Switzerland: Springer, pp. 29–40, 2019.

[4] A. A. Vartak, C. M. Fidopiastis, D. M. Nicholson, W. B. Mikhael, and D. D. Schmorrow, “Cognitive state estimation for adaptive learning systems using wearable

physiological sensors,” *in Proc. 1st Int. Conf. Bio-Inspired Syst*. Signal Process, no. 2, pp. 147–152, 2008.

[5] H. A. Frank, K. Jacobs, and H. McLoone, “The effect of a wearable device prompting high school students aged 17–18 years to break up periods of prolonged sitting in class,” *Work*, vol. 56, no. 3, pp. 475– 482, 2017.

[6] L. Wang, B. Lo, and G.-Z. Yang, “Multichannel reflective ppg earpiece sensor with passive motion cancellation,” *Biomedical Circuits and Systems*, IEEE Transactions on, vol. 1, no. 4, pp. 235–241, 2007.

[7] T. Suzuki, H. Tanaka, S. Minami, H. Yamada, and T. Miyata, “Wearable wireless vital monitoring technology for smart health care,” *Medical Information and Communication Technology (ISMICT)*, 7th International Symposium, pp. 1–4, 2013.

[8] A. Aliverti, “Wearable technology: role in respiratory health and disease,” *Breathe* 2017; 13: e27–e36.

[9] F. S. Çakır, A. Aytekin, and F. Tüminçin, “Nesnelerin interneti ve giyilebilir teknolojiler,” *Sosyal Araştırmalar ve Davranış Bilimleri Dergisi*, 4(5), 84-95, (2018).

[10] M. H. Iqbal, A. Aydin, O. Brunckhorst, P. Dasgupta, and K. Ahmed, “A review of wearable technology in medicine,” *Journal of the Royal Society of Medicine*, 109(10), 372–380, 2016.

[11] R. Paradiso, and D. De Rossi, “Advances in textile technologies for unobtrusive monitoring of vital parameters and movements,” *In 2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 392-395, (2006).

[12] H. Ö. Kılıç, “Giyilebilir teknoloji ürünleri pazarı ve kullanım alanları,” *Aksaray Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi,* 9(4), 99-112, (2017).

[13] H. Lewy, “Wearable technologies – future challenges for implementation in healthcare services,” *Healthcare Technology Letters*, 2(1), 2–5, 2015.

[14] A. Ometov, V. Shubina, and L. Klus, “A Survey on Wearable Technology: History, State-of-the-Art and Current Challenges,” *Computer Networks*, 108074. https://doi.org/10.1016/j.comnet.2021.108074, 2021.

[15] S. Malwade, and L. Cilliers, “Mobile and Wearable Technologies in Healthcare for the Ageing Population,” *Computer Methods and Programs in Biomedicine*, doi: 10.1016/j.cmpb.2018.04.026,(2018).

[16] S. H. Chuah, and Lade, S. "Wearable technologies: The role of usefulness and visibility in smartwatch adoption," *Computers in Human Behavior*, 65, 276–284. https://doi.org/10.1016/j.chb.2016.07.047, 2016.

[17] S. M. A. Iqbal, and W. Asghar, "Advances in healthcare wearable devices," *npj Flexible Electronics,* 5(1), 9. https://doi.org/10.1038/s41528-021-00107-x, 2021.

[18] C. Glaros, and D. I Fotiadis, "Wearable Devices in Healthcare," *In StudFuzz* 184 , pp. 237–264, Springer-Verlag Berlin Heidelberg. (2005).

[19] M., Bower, and D. Sturman, "What are the educational affordances of wearable technologies," *Computers and Education*. http://dx.doi.org/10.1016/j.compedu.2015.07.013, 2015.

[20] H. A. Almusawi, C. M. Durugbo, and A. M. Bugawa, "Wearable technology in education: A systematic review," *IEEE Transactions on Learning Technologies,* 14(4), 540-554, (2021).

[21] B. Attallah, and Z. Ilagure, "Wearable technology: Facilitating or complexing education," *International Journal of Information and Education Technology,* 8(6), 433-436, 2018.

[22] S. Sezgin, "Eğitimde giyilebilir teknolojiler: firsatlar ve eğilimler," *Mehmet Akif Ersoy Üniversitesi Eğitim Fakültesi Dergisi,* 1(40), 2019.

[23] R. Collier, and A. B. Randolph, "Wearable Technologies for Healthcare Innovation," *In SAIS 2015 Proceedings* (pp. 18). Southern Association for Information Systems. Retrieved from http://aisel.aisnet.org/sais2015/18, 2015.

[24] M. Çiçek, "Wearable Technologies And Its Future Applications," *International Journal of Electrical, Electronics and Data Communication,* 3(4), 45-50, (2015).

[25] L. Walter, "Research in Intelligent Biomedical Clothing vs. Realities in the European Textile Business," *In A. Lymberis & D. de Rossi (Eds.), Wearable eHealth Systems for Personalised Health Management,* pp. 75-80, IOS Press, 2004.

[26] C. E. Erkılıç, and A. Yalçın, "Evaluation of the wearable technology market within the scope of digital health technologies," *Gazi Journal of Economics and Business*, 6(3), 310-323. doi: https://doi.org/10.30855/gjeb.2020.6.3.006, 2020.

[27] M. M. M. Nawawi, K. A. Sidek, and A. W. Azman, "ECG in Real World Scenario: Time Variability in Biometric Using Wearable Smart Textile Shirts," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 40(2), 36-49, 2024.

[28] A. Godfrey, V. Hetherington, H. Shum, P. Bonato, N. H. Lovell, and S. Stuart, “From A to Z: Wearable technology explained,” *Maturitas*, 113, 40–47. DOI: 2018.

[29] S. Park and S. Jayaraman, “Enhancing the quality of life through wearable technology” *IEEE Engineering in medicine and biology magazine*, 22(3), 41-48 2003.

[30] N. Morresi, V. Cipollone, S. Casaccia, G. M. Revel, “Measuring thermal comfort using wearable technology in transient conditions during office activities,” Measurement, 224, 2024.

[31] M. Jafarzadeh Esfahani, N. Sikder, “Citizen neuroscience: wearable technology and open software to study the human brain in its natural habitat,” European Journal of Neuroscience, 59(5), 948-965, 2024.

[32] M. Tanaka, S. Ishii, A. Matsuoka, “Perspectives of Japanese elders and their healthcare providers on use of wearable technology to monitor their health at home: A qualitative exploration,” International Journal of Nursing Studies, 152, 2024.