

BLUETOOTH-BASED AUTOMATED PATIENT MONITORING DEVICE

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ABSTRACT

Illness, characterized as a disease or a state of sickness impacting both body and mind, often manifests as general body weakness or localized pain. Despite the availability of technical and therapeutic innovations aimed at enhancing human health and life quality, the continuous monitoring of patients by healthcare professionals for 24 hours daily is impractical. To systematically address this challenge, this study sought to create an automated patient healthcare device. Utilizing sensor technology, an AT-Mega microcontroller, and a Bluetooth module, the device facilitates independent health monitoring or monitoring by a caregiver. The system is designed to effectively handle situations where no immediate caregiver is available to attend to the patient's needs. This is achieved by enabling the patient to send a help message to the caregiver through a simple hand motion. Positioned on the patient's hand, the device allows tilting at specific angles to convey programmed help messages, each direction indicating a distinct message. Through sensitivity analysis during device testing, which gauged the device's success in recognizing hand movements for seeking assistance, the average sensitivity was determined to be 76.6%. These results signify promising outcomes, encouraging further exploration in clinical settings. Beyond accommodating seamless use by neurologically intact patients, the device proves beneficial for individuals with hemiparalysis, conditions hindering effective communication, and any circumstance necessitating the presence of a caregiver.

Keywords: Patient monitoring; Sensor technology; Microcontroller; Bluetooth; Healthcare

1 INTRODUCTION

A significant amount of the world population (> 95%) is unwell with different types of illnesses [1]. Ill health may include clinical situations that reduce the person's ability to live a normal and functional life [2]. The field of healthcare has witnessed significant advancement in recent years, driven by the integration of automation and advanced technologies. One of the prominent applications of automation in healthcare is the development of a monitoring device [3, 4]. These devices leverage wireless communication technology to enable seamless health monitoring and improve the overall patient experience [5, 6]. Wireless connectivity technologies including Bluetooth or Wi-Fi are majorly required for communication [5, 7]. However, Bluetooth device can uniquely use Adaptive Frequency Hopping (AFH) to identify which channels are in use and avoid those channels in the hop sequence [8]. This lowers radio impedance and allows Bluetooth packets to get through even the most difficult interference, making it a great addition to any wireless network [8, 9]. In addition to the highlighted advantages, Bluetooth has proven to offer a simple and user-friendly pairing process [10]. Through the use of Bluetooth, patients can

seamlessly connect their wearable monitoring devices to the monitoring system without complex network configurations or manual input of network credentials. This seamless pairing process enhances the user experience and reduces the potential for errors or connectivity issues [11]. There are several evidence of applications of Bluetooth technology in patient monitoring. For example, Barnes and Warren [8] created a personal portable monitoring system that measures a person’s cardiac vector with all the components connected wirelessly through Bluetooth technology [8]. A wireless monitoring system based on a portable ambulatory ECG device and smartphones was also developed by Wu, et al. [12] using Bluetooth module for connectivity [12]. Additionally, nowadays, wireless communication has been implemented in many wearable devices in healthcare to convey data to a host system or another device for diagnosis or disease monitoring purposes. Patients and healthcare workers primarily benefit from this mode of technology since it eliminates the need for loose cables and high infrastructure expenditures [10]. Bluetooth technology is suitable for home environment as it also promotes automation [13]. Typically, automation relieves humans from dangerous, repetitive, and unpleasant engagements [13, 14]. Automation technologies promote a growing social and economic environment in which humans can enjoy a better way of life and a higher standard of living [15]. Based on this background, in the present study, we designed and implemented a Bluetooth-based automated patient healthcare monitor through an alert mechanism. The device enables persons with ill health to be able to send a help message to their health caregiver by a simple hand motion once they are in need of attention or care. Specifically, whenever the patient gives a simple hand movement from the transmitting device hung around their wrist, a signal will be sent to the receiving device which will display a message through the LCD to the caregiver. The device also incorporates a sound indicator in the receiving end of the device/monitor to alert the receiver as soon as a signal is received or detected. This way, the designed system will be able to perform the intended objectives of automated patient health monitoring.

2 MATERIALS AND METHODS

2.1 Materials

Material selection is crucial as it facilitates the choice of appropriate materials for the design implemented in this study. This was carried out to ensure that the materials used were appropriate and inexpensive for the target population. Table 1 displays the types of materials used and the rationale for their selection. Table 2 shows the cost of the materials.

Table 1. Type of material and rationale for the material selection

S/N	Material	Device module	Rationale
1.	AT-Mega328P Microcontroller	Hardware module	Code efficient, it allows very fast start-up combined with low power consumption, is easily available in the market and it is cost-efficient.
2.	Bluetooth HC-05	Hardware module	It allows for the construction of a transparent wireless serial connection. This module allows you to switch between master and slave modes, which means you may use it for both receiving and delivering data.
3.	05MPU6050 gyro- accelerometer	Hardware module	It allows measurement on all three axes (x, y, and z), static acceleration owing to gravity as well as motion, shock, or dynamic acceleration due to vibration.
4.	16*2 LCD	Hardware module: user interface	To easily display the message programmed into the transmitting device when movement occurs.
5.	Arduino Uno	Software module	Affordable and not difficult to programme

Table 1. Cost analysis of the device

S/N	Items	Units	Price/Unit (₦)	Total Price/(₦)
1.	PCB	1	5,000	5,000
2.	Arduino Uno	1	7,500	7,500
3.	Atmega 328	2	2,500	5,000
4.	Gloves	1	1,500	1,500
5.	Bluetooth	2	2,500	5,000
6.	Gyro-Accelerometer	1	2,500	2,500
7.	LCD	1	2,000	2,000
8.	Voltage Regulator	2	150	300
9.	Capacitor	8	100	800
10.	IC Socket	2	150	300
11.	Crystal Oscillator	2	250	500
12.	Buzzer	1	400	400
13.	Packaging Box	1	1,000	1,000
14.	Push Button/Switch	2	250	500
15.	RFID	2	1,500	3,000
16.	Crystal Oscillator	1	250	250
17.	Battery	1	400	400
18.	Miscellaneous		1,000	1,000
	Total			₦36,950 Approx. USD 40

2.2 Methods

Figure 1 illustrates the simulation of the circuit diagram using Proteus 8 Professional software (North Yorkshire, BD235AJ England, UK), aiding in assessing the circuit's efficiency. The circuit was then assembled on the breadboard to determine how effective the project would be. After the device worked on the breadboard, the same arrangement was done for the PCB design. The design was printed on the PCB glossy paper which was then placed on the PCB copper clad. Iron was used to transfer the printed part to the copper clad. The iron-on glossy method was used for this design because the method is easy to carry out compared to other methods. This stage was very necessary to recognize faulty components and be able to replace them before the major construction will be carried out.

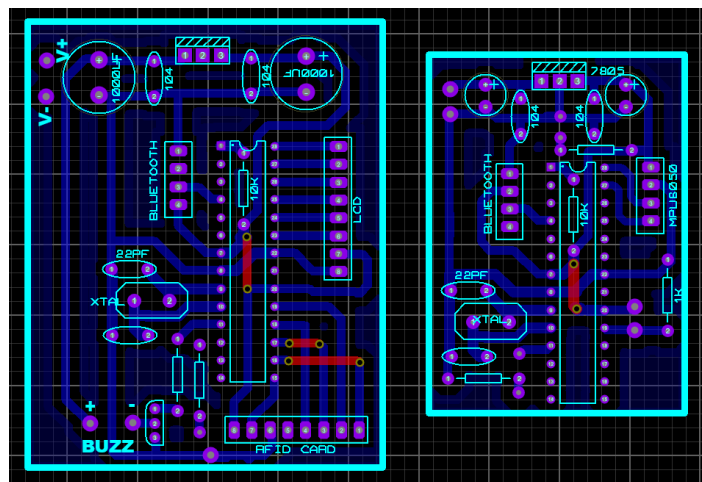


Figure 1. PCB design for the device using Proteus 8

Figure 2 depicts the comprehensive circuit diagram for the entire device' design, created through the utilization of Proteus 8 software. Figure 3 illustrates the flow chart of the receiver and transmitter units of the device.

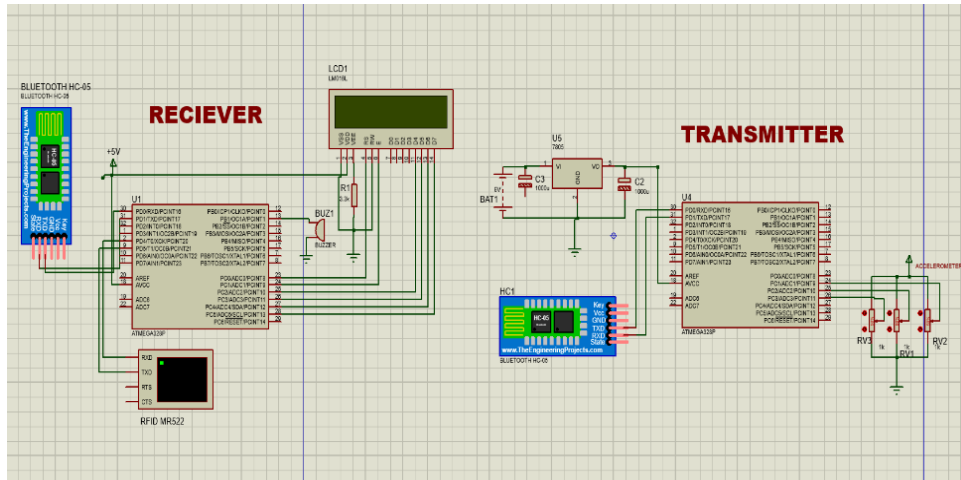


Figure 1. Overall circuit diagram

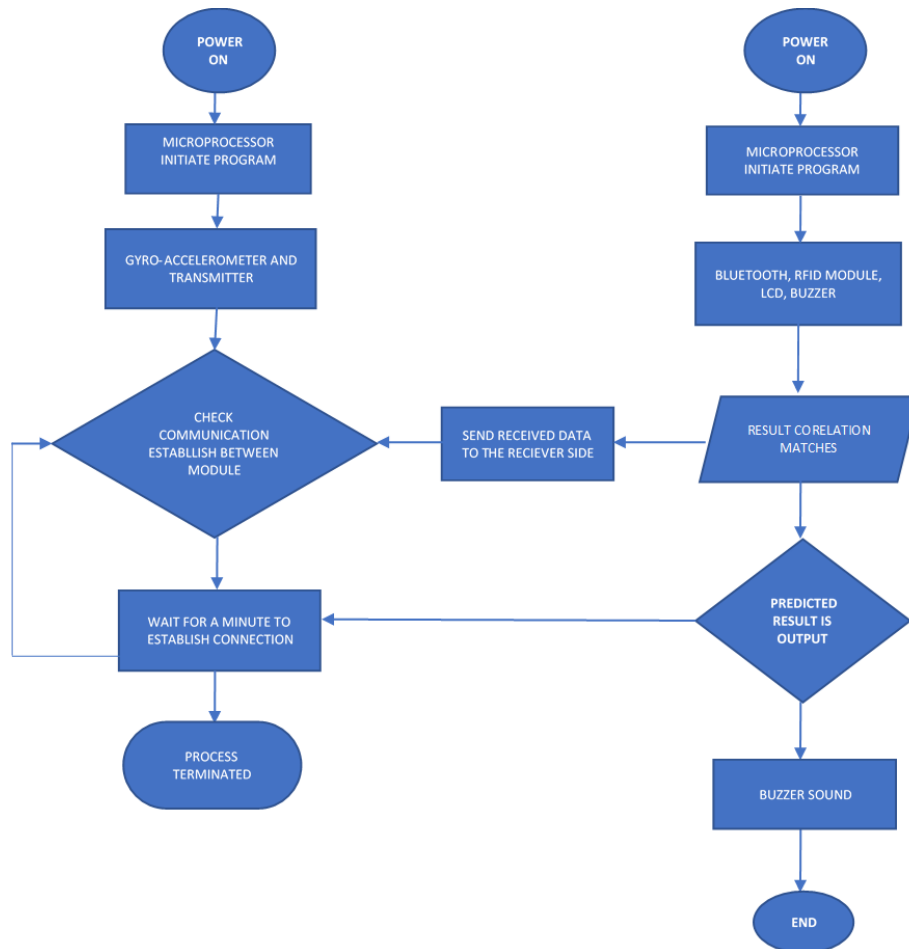


Figure 2. Flow chart of the device



Figure 3. Assembled designed device

Figure 4 illustrates the whole device package. Following assemblage of the device, the receiving unit is enclosed in a packaging box, as presented in Figure 5A. This packaging serves the purpose of safeguarding the device while allowing the visibility of essential components. Also, the transmitting unit (Figure 5B) is equipped with soft, breathable hand gloves to enhance comfort and prevent any potential harm to the patient. Figure 5C presents the Radio Frequency Identification (RFID) tags employed to deactivate the buzzer when necessary.

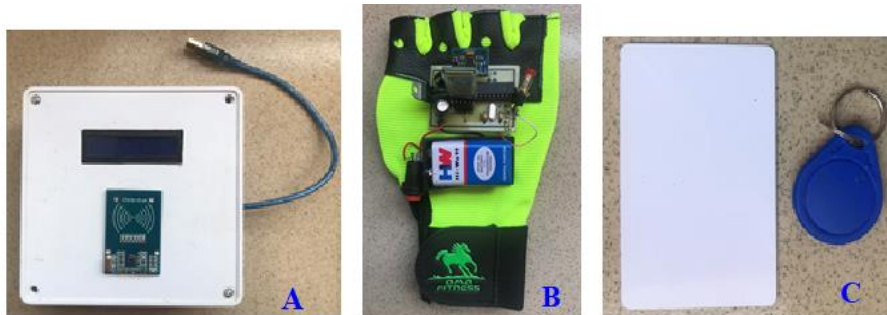


Figure 4. Whole device package. A. Receiving unit, B. Transmitting unit and C. RFID tag

2.2.1 Mode of operation of the device

The operation of the developed device included five major steps as detailed hereunder. Step I: Both units are powered on by toggling the switch on the transmitting unit and connecting the receiving unit to a power outlet using a USB cord. Step II: Establishment of the Bluetooth connection when the red light on the transmitting unit's Bluetooth ceases to blink rapidly, indicating a successful power-up. Step III: Once the Bluetooth connection is established, and if there is movement detected in the x, y, or z plane on the transmitting unit, or if the push button is pressed, a signal is transmitted to the receiving unit. This prompts the display of a “HELP.....” message and activates the buzzer to emit a sound notification. Step IV: The “HELP.....” message remains displayed, and the buzzer continues sounding until the authorized RFID tag is placed on the RFID module. This action stops the buzzer and clears the message. Alternatively, the device can be disconnected to achieve the same result. Step V: The notified caregiver is then expected to promptly attend to the patient's needs. Fundamentally, the device employs a gyro-accelerometer [16] to track a patient's movements in the x, y, and z planes. Additionally, the device integrates an RFID module for security and control purposes (Step IV).

2.2.2 Data collection procedure

Five healthy volunteers consented to serve as experimental participant. Their consents were given after they were informed about the mode of operation of the device, device's applications and its

harmlessness. Their right to discontinue the experiment without notification or reason was also confirmed to them. The demography data of the participant is as presented in Table 3.

Table 2. Participants' demographic data

S/No	Age	Gender	Height/ (M)	Body Weight/ (Kg)
1.	24	F	1.75	65
2.	29	F	1.62	58
3	34	M	1.7	76
4.	30	M	1.81	68
5.	23	F	1.67	71

Specifically, following a comfortable sitting on a chair with arm rests while resting the back on the back rest as deemed convenient by the participants, the transmitting unit of the monitoring device was firmly attached on the back of hand of the participant (Figure 6). Each participant was instructed to ensure the comfortability of the unit before and during the testing of the device. For device testing, participant was clearly instructed to move the hand in various directions about the wrist joint (i.e., abduction, adduction, flexion, extension) as convenient to call for help, and the resulting data generated from the device were documented (Table 4). Twelve (12) trials (i.e., six instances of hand movements and another six instances no hand movements) were administered per participant for ease of performance evaluation of the device. Sensitivity analysis was used to access the performance of the device using equation 1.

$$\text{Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{False Negative (FN)}} \quad (1)$$

Where True Positives (TP) means the outcomes where the device correctly picks the hand movement and False Negatives (FP) means the outcomes did not show that hand movement occurred when it did occur. Figure 6 shows the experimental setup for a representative participant for data collection.



Figure 5. Experimental setup for a representative participant for data collection

3 RESULTS AND DISCUSSION

Sequel to the results collection from the setup in Figure 6 and by applying the equation 1, Table 4 presents the corresponding results obtained.

Table 3. Experimental results for five participants

		Hand Movement	Hand Movement	No Hand Movement	No Hand Movement
	Total Trials	True Positives (TP)	False Negatives (FN)	True Negatives (TN)	False Positives (FP)
P1	12	5	1	5	1
P2	12	4	2	5	1
P3	12	5	1	4	2
P4	12	5	1	6	0
P5	12	4	2	5	1

Abbreviations: True Positives (TP) - instances where the device accurately detected a hand movement; False Negatives (FN) - represents when the device failed to detect a genuine hand movement; True Negatives - denotes instances where the device correctly did not detect any hand movement when there was none; and False Positives indicates instances where the device incorrectly detected a hand movement in the absence of actual movement.

$$\text{For participant 1 (P1), \%Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{Force Negative (FN)}} \times 100$$

$$\% \text{Sensitivity (S1)} = \frac{5}{5+1} \times 100 = 83.3\%$$

$$\text{For participant 2 (P2), \%Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{Force Negative (FN)}} \times 100$$

$$\% \text{Sensitivity (S1)} = \frac{4}{4+2} \times 100 = 66.7\%$$

$$\text{For participant 3 (P3), \%Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{Force Negative (FN)}} \times 100$$

$$\% \text{Sensitivity (S1)} = \frac{5}{5+1} \times 100 = 83.3\%$$

$$\text{For participant 4 (P4), \%Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{Force Negative (FN)}} \times 100$$

$$\% \text{Sensitivity (S1)} = \frac{5}{5+1} \times 100 = 83.3\%$$

$$\text{For participant 5 (P5), \%Sensitivity} = \frac{\text{True Positive (TP)}}{\text{True Positive (TP)} + \text{Force Negative (FN)}} \times 100$$

$$\% \text{Sensitivity (S1)} = \frac{4}{4+2} \times 100 = 66.7\%$$

$$\text{Average Sensitivity (\%)} = \frac{(S1+S2+S3+S4+S5)}{5}$$

$$= \frac{(83.3+66.7+83.3+83.3+66.7)}{5}$$

$$\text{Average Sensitivity (\%)} = 76.7\%$$

Following the calculation of the average sensitivity from the five participants to assess the device's performance in recognizing their hand movements in calling for help, the device demonstrated an average sensitivity value of 76.7%. This results could be adjudged promising and encouraging for application in clinical settings following rigorous reevaluation in larger population of test participants. As presented in this study, the development of a Bluetooth-based automated patient monitoring device plays a crucial role in enhancing the quality of patient's life by providing a seamless means for a patient to seek clinical assistance as and when needed. The preliminary performance evaluation of the monitoring device with an average sensitivity value of 76.6% shows its potential for clinical deployment, independent home use and for

outpatients once the healthcare giver is within the patient vicinity. The outcome from our study is supported by the design proposed by Barnes and Warren [8]. However, unlike Barnes and Warren's study, our study presented the results from five participants and uniquely used gyro-accelerometer and RFID technologies. Also, Barnes and Warren's [8] study, like other similar studies in the literature, was mainly on some physiological parameter monitoring, whereas the device developed in our study provided a sensitive healthcare assistance solution for patient at a remote site. Potential enhancements for this device may include recording of patient data on a digital device that can be transferred to the cloud for further processing as proposed by Yang et al. [17]. However, this additional capability will also come with its cost implication, may make the device bulkier and requires special skills and devices for use. The current device was meant to be cost-effective (\leq USD 40), portable, and user-friendly, making it an attractive option for healthcare solutions in resource-constrained settings, particularly in sub-Saharan Africa countries.

4 CONCLUSIONS

In this study, a patient monitoring system has been developed with an average sensitivity rate of 76.6%. This innovative device utilizes a gyro-accelerometer to track a patient's hand movement and integrates an RFID module to enhance security measures. In the future, Bluetooth wireless connectivity may be replaced by other alternatives with broader or wider communication range such as Wi-Fi for IoT, enabling the implementation of a system that stores and provides access to the names of caretakers by utilizing key tags, and considering the use of biometric fingerprint scanners as an alternative to RFID to mitigate issues that may be related to stolen or misplaced key tags. Despite these proposed potential future improvements, the current device is unique for its affordability, portability, and user-friendliness design compared to the existing alternatives.

REFERENCES

1. Vos, T. (2015). Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*, vol. 386, no. 9995, pp. 743-800. doi: [https://doi.org/10.1016/S0140-6736\(15\)60692-4](https://doi.org/10.1016/S0140-6736(15)60692-4).
2. Anders, W., Staffan, M. and Kristina, A. (2005). Illness, disease, and sickness absence: an empirical test of differences between concepts of ill health. *Journal of Epidemiology and Community Health*, vol. 59, no. 6, pp. 450-454. doi: 10.1136/jech.2004.025346.
3. Baig, M.M. and Gholamhosseini, H. (2013). Smart Health Monitoring Systems: An Overview of Design and Modeling. *Journal of Medical Systems*, vol. 37, no. 2, pp. 1-14. doi: 10.1007/s10916-012-9898-z.
4. Kadhim, K.T., Alsahlany, A.M., Wadi, S.M. and Kadhum, H.T. (2020). An Overview of Patient's Health Status Monitoring System Based on Internet of Things (IoT). *Wireless Personal Communications*, vol. 114, no. 3, pp. 2235-2262. doi: 10.1007/s11277-020-07474-0.
5. More, A.H. and Keeping, S. (2010). Bluetooth Low Energy: Wireless Connectivity for Medical Monitoring. *Journal of Diabetes Science and Technology*, vol. 4, no. 2, pp. 457-463. doi: 10.1177/193229681000400227.
6. Barger, T.S., Brown, D.E. and Alwan, M. (2005). Health-status monitoring through analysis of behavioral patterns. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 35, no. 1, pp. 22-27. doi: 10.1109/TSMCA.2004.838474.
7. Singh, B., Urooj, S., Mishra, S. and Haldar, S. (2019). Blood Pressure Monitoring System using Wireless technologies. *Procedia Computer Science*, vol. 152, pp. 267-273. doi: <https://doi.org/10.1016/j.procs.2019.05.017>.

8. Barnes, G. and Warren, S. (2002). A wearable, Bluetooth-enabled system for home health care, in *Proceedings of the Second Joint 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society Engineering in Medicine and Biology*, 23-26 Oct. 2002, vol. 3: IEEE, pp. 1879-1880. doi: 10.1109/IEMBS.2002.1053073.
9. Haartsen, J.C. and Mattisson, S. (2000). Bluetooth-a new low-power radio interface providing short-range connectivity. *Proceedings of the IEEE*, vol. 88, no. 10, pp. 1651-1661. doi: 10.1109/5.889005.
10. Marcel, J. (2023). 4 Reasons to Use Bluetooth in Your Healthcare Facility. Bluetooth Special Interest Group, Inc. <https://www.bluetooth.com/blog/4-reasons-to-use-bluetooth-in-your-healthcare-facility/> (accessed 11/12/2023, 2023).
11. Putra, G.D., Pratama, A.R., Lazovik, A. and Aiello, M. (2017). Comparison of energy consumption in Wi-Fi and bluetooth communication in a Smart Building, in *2017 IEEE 7th Annual Computing and Communication Workshop and Conference (CCWC)*, 9-11 Jan. 2017 2017, pp. 1-6.
12. Wu, T., Hu, J.d., Gao, C., Zhao, J. and Ye, W. (2010). Wireless monitoring system based on Bluetooth smart phones, in *2010 International Conference on Networking and Digital Society*, vol. 2, pp. 648-651.
13. Sriskanthan, N., Tan, F. and Karande, A. (2002). Bluetooth based home automation system. *Microprocessors and Microsystems*, vol. 26, no. 6, pp. 281-289. doi: [https://doi.org/10.1016/S0141-9331\(02\)00039-X](https://doi.org/10.1016/S0141-9331(02)00039-X).
14. Endsley, M.R. (2017). From Here to Autonomy:Lessons Learned From Human–Automation Research. *Human Factors*, vol. 59, no. 1, pp. 5-27. doi: 10.1177/0018720816681350.
15. Almotiri, S.H., Khan, M.A. and Alghamdi, M.A. (2016). Mobile Health (m-Health) System in the Context of IoT, in *2016 IEEE 4th International Conference on Future Internet of Things and Cloud Workshops (FiCloudW)*, 22-24 Aug. 2016: IEEE, pp. 39-42.
16. Kortier, H.G., Sluiter, V.I., Roetenberg, D. and Veltink, P.H. (2014). Assessment of hand kinematics using inertial and magnetic sensors. *Journal of NeuroEngineering and Rehabilitation*, vol. 11, no. 1, pp. 1-14.
17. Yang, Z., Zhou, Q., Lei, L., Zheng, K. and Xiang, W. (2016). An IoT-cloud Based Wearable ECG Monitoring System for Smart Healthcare. *Journal of Medical Systems*, vol. 40, no. 12, pp. 1-18..