Pandemic Stabilizer using Smartwatch

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***Abstract*— An outburst of Covid-19, a new disease by coronavirus has been noted by December 2019 in China and subsequently this Covid-19 spread throughout the world. The serious effect of this disease causes death due to the failure of respiratory system of human. Nowadays the spreading of the coronavirus is uncontrollable especially in crowded places as well as due to avoiding the protocols given by world health organization (WHO) to reduce the spread of Covid -19. Many researchers have involved in identifying vaccine for giving proper treatment to the affected people and to avoid further spreading. In addition, with this some other researchers have also involved in using modern technologies to prevent the spreading of Covid-19 as well as to identify the disease in very earlier stage and to reduce the rate of death. One of the modern systems recommended by the researchers is that smartwatch. By using smartwatches, the user's body temperature, heart rate and blood pressure can be measured, and the smartwatch can be automatically charged by body heat. This kind of smartwatches can be controlled by chatbot Google Assistant. This paper discusses the design, principle of operation and features of different smartwatches and their usage. Based on the analysis, it is identified that the availability of recent cost-effective developments of smartwatches are available on reducing spread of Covid-19.**

Keywords— Covid-19, Mobile Crowd Sensing Device (MCD), Motion capture sensors.

I. INTRODUCTION

The worldwide pandemic of Covid-19 is rapidly increased in very crowded areas easily [1]. Around the world over 1,436,000 persons are affected as on 9th April 2020 [2]. So, at present, the spreading of the coronavirus is increasing rapidly. However, more than 450 thousand people have completely recovered with proper care given by physician and medical assistants. The possibility of recovery from coronavirus is more when it is identified at an initial stage [3]. To reduce the spreading of Covi-19, many growing countries involve in designing information and communication technology-based systems [4]. For instance, recently BOSCH developed a test kit for Covid-19 and many other engineers and researchers have been involved in the design of new personal protective equipment (PPE) [5].

Several sensor-based devices are equipped to evaluate collect and evaluate Covid-19 data to reduce the infection. One of the sensor-based device called mobile crowdsensing device (MCD) which is used to gather data from people through their smart devices and share with social network to maintain social distancing and to reduce the spreading of Covid-19 [6]. Smartwatch is also a wireless sensor-based device which is used to collect the details of users through body sensors and to transmit the information through wireless technologies like WiFi and cellular networks [7].

The modern smartwatch technology is utilized to identify the effect of Covid-19 by measuring the body temperature at any moment in time [8] and anyplace [9] without using additional conventional thermometers [10]. So, the invention in smartwatch is very much useful in detection and prevention of Covid-19. There are many different types of Smart watches which measure the body temperature like Ticwris GTS [11]. Though they offer many advanced features like heart rate sensor, call and message notification, Android, and iOS support, and much more along with a thermometer. But they cannot be charged by human body temperature. Along with all other features, the proposed smartwatch system can be used to measure the body temperature and it is also charging automatically. This smart watch can also be connect with the Aarogya setu app (a mobile application also a tracking app which uses a smart phone's GPS and Bluetooth to have the track of corona virus infection) to know all details related to the disease. This system can provide voice interaction by connecting with Google Assistant.

This article briefs the various features of smartwatch application in section II. Section III gives the overall architecture and operation of smartwatch and section IV provides conclusion.

II. PRINCIPLE OF SMART WATCH

The smartwatch system consists of accelerometer, magnetometer and gyroscope and a touch screen. The touch screen is very much useful to display the status of the user as well as easy interaction with the user moments. It also helps to trace the user's accurate location. Smartwatches are utilized to solve general health issues by using body sensors (BSs) like electrocardiogram (ECG) sensor, pressure sensor, thermometer, and pedometer [12]. It is also used for sleep tracking, reply to the text by voice, weather, and traffic, interacting with non-smart phone devices, controlling music, on-board GPS, etc. The principle of design and the usage of smartwatch is quite simple as compared with other conventional medical equipment. For example, the body temperature of the user can be displayed in watch screen by using inbuilt sensor automatically. The smartwatch system makes exactly accurate measurements if senses more than 60

seconds and the user can consult a doctor when the temperature seems to be abnormal. This pandemic stabilizer smart watch uses a temperature sensor along with a buzzer that vibrates when the temperature is abnormal [13]. This can also relate to an Arogya setu app which is presently used for corona virus tracking by the government of India. This smart watch can even monitor sleeping phase, count calories, and is used to make a record of all the metric like temperatures. Further it is charged by human's body temperature [14]. This smart watch is also connected to google assistant which gives it a look of a smart watch. The smartwatch operation is assisted by an artificial intelligent (AI) - based google assistant methodology [15]. It is a voice interaction tool that is used to make calls, send messages, finding a location, for google searches, and much more. It makes the work easy and make use of it at any place and need not carry other things. This also uses Alexa built-in smart watches; it is also a voice interaction device with many features into it [16] and [17].

III. DESIGN AND OPERATION OF SMARTWATCH

Fig 1. Describes the internal design of a smart watch. Adding features in the smartwatch system is a challengeable task to provide variety of measurements with different sensors and other supporting processors and peripherals. When it comes to design, it contains flash, ROM, SRAM on-chip memories. It also contains an Ultra-low-power processor core like the Cortex-M series, always on sensor-fusion CPU. Regarding all these, sensors play a very vital role in this virtual world

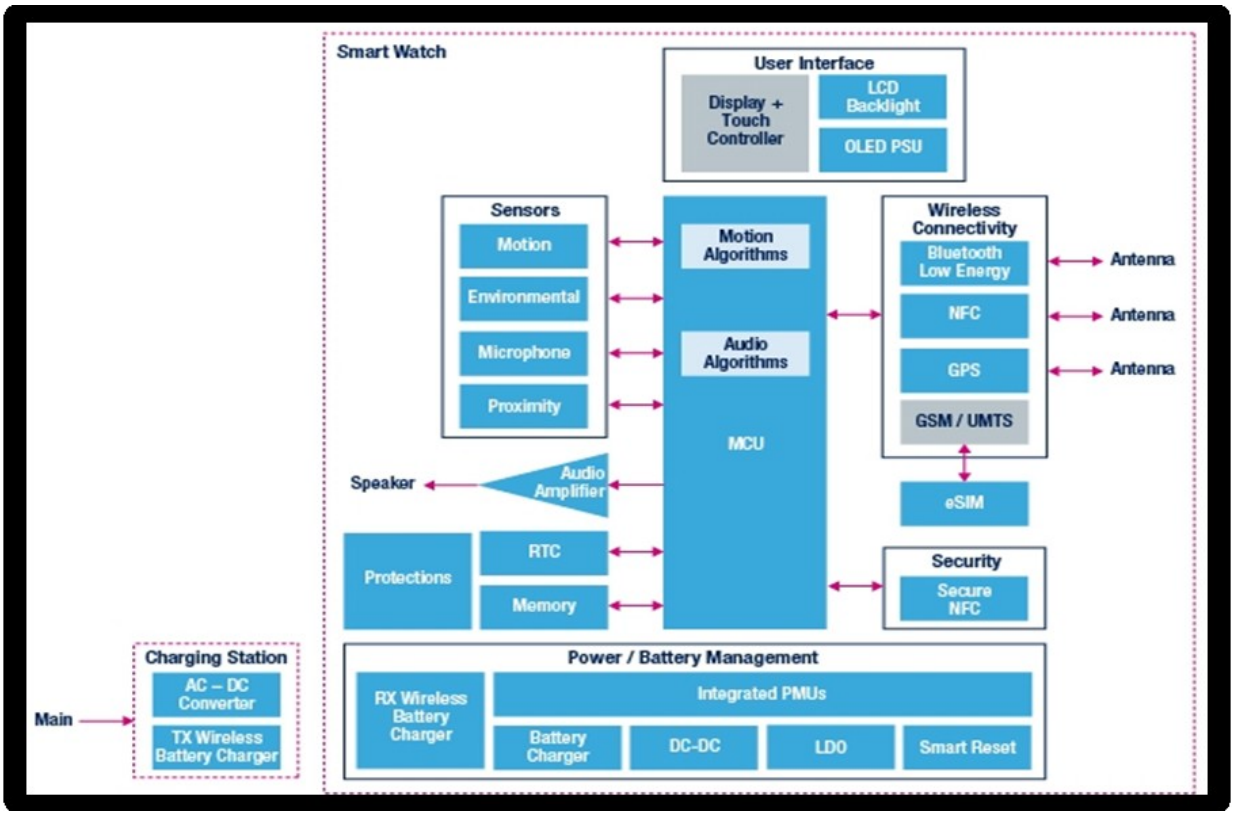

Fig. 1. The internal design of the smartwatch [18]

A. Architecture sensors and communication medium

The new trends in meachine learing (ML), data analisis using big data concept are utilized in proper measurement and analysis of any hidden information. For proper analysing and generaing health details the designers must utilize the sophisticated sensors and algorithms. Further, the users must the extracted information properly. The security of information is more importnant to maintain the privacy and authentification of dealing with medical data. The security of all the information is provided by crptographic technique in association with internet-of-things (IoT) concepts. The IoT plays major roles in the samartwatch system such as extracting the correct information, communicationg the user's data with physician, computing and controlling the overall operations. So, the smartwatch concept is closly related with the IoT technology and wireless body sensor networks (WBSNs) [19]. To communicate the user's data with the doctor, the smartwatch technology utilizes diffferent wirless communication mediums like bluetooth, WiFi and ZigBee. The operations

of sensors and processors in the smartwatch is equipped with propoer operating system (OS) to provide proper functionality. Architecture of smartwatch is almost similar to the architecture of smart phone and tablets. But they are difffer based number and types of operation, speed of operation, size of the device and storage capcity.

Figure 1 illustrates that the structure of smartwatch which includes processors, sensors, interfacing devices, data converters (ADC and DAC), and storage devices. Motion detectors such as gyroscope, magnetometer, and accelerometer are athe important sensors in the smartwatch technology [20]. This accelerometer works on the concept of opertional theory which measures the force of acceleration by using the change of capacitance between two fixed plates in the 2D accelerometer. Figure 2 illustrate that the principle of opertion of accelerometer. The other important sensor in the smartwatch is magnetometer. The magnetmeter sensor works on the principle of change of stengh of magnetic field.

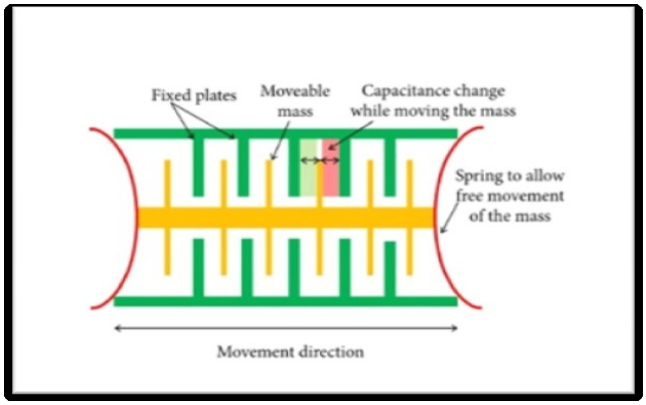

Fig. 2. 2D Structure of the Accelerator [2]

The other sensor used is the gyroscope [22]. A Gyroscope which is used in smartwatch is utilized to obtain the speed of rotation of the unit along with the three axes of operation. The internal architecture of the gyroscope is almost like the accelerometer. In gyroscope, the power of rotation makes changes in mass and the value of the capacitance between two fixed plates. In many smartwatch systems, both accelerometer and gyroscope work together. Figure 3 illustrates that the structure of 2D gyroscope. Smartwatches work even when the user sleep because the tracking capability of smart watches is accurate.

As discussed, the accelerator and gyroscope are used for sensing movement and to measure rotation and orientation. The process that is used to translate movement into a sleep pattern is called actigraphy. It is accurate enough to track sleep patterns and is completely based on movements. When users lie down, smart watches keep a tab on rapid eye movement (REM) sleep. Along with-it heart rate also becomes a basis of tracking sleep. When the user is asleep, there won't be any movement and heart rate changes. Therefore, the smart watch starts measuring time users spend sleeping.

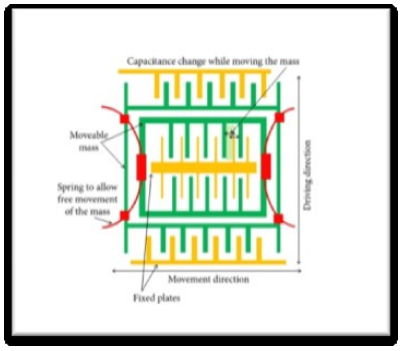

Fig.3. 2D structure of gyroscope

Motion sensors are analog sensors. Varied level of voltage will be the output for these sensors. To get converted into a digital number from voltage variation ADC is used. By this technique, the digital number can not only be read but can also be displayed to the digital field of environment. Motion sensors work with different operating frequency to

obtain different set of new measurements based on movement of the user. It also gives the count of measurements in every single second of time. A standard set of frequency is utilized to abstract the correct features. A window of multithreading is formed with the readings between 10 and 20. By using this window the variety of features like wavelet, frequency and time are measured. In addition, with the accelerometer, gyroscope and magnetometer, some other sensors are also utilized in the smartwatch system. The additional sensors embedded in the smartwatch are battery heat sensor and proximity. The output of battery heat sensor is utilized to identify the general heal condition of the user. That is, it is useful in managing the situation of death of the user while the body heat drops quickly.

Further, the other sensor present in the smart watch is optical heart rate [23], in this; the light from the sensor penetrates the skin to estimate heart rate. This is helpful to measure the heart rate throughout the day and calculates various metrics of the user. It is also helpful for measuring the average heart rate while the user walking, user's heart rate variability (HRV) and heart rate during a workout and breathing sessions.

Next is one of the important sensors called temperature sensors [24]. The digital output sensor generally has a temperature sensor, an analog-to-digital converter (ADC). For managing the IC's operation ADC is used. Temperature can be read at any time and is constantly measured. If the temperature outreaches a programmed limit, the user can command the sensor to monitor temperature and take a pin to high or low depending on the change. When the temperature falls below the lower threshold temperature, the user can be notified if a lower threshold temperature is programmed. Therefore, a digital output sensor can be utilized in micro-based systems for monitoring reliable temperature.

Another is the pedometer sensor. Pedometer sensors are used for a step counter [25]. It can calculate average speed, caloric expenditure distance, and total exercise time, etc. The difference between the ancillary moments and actual steps can be known by the PD 102. PD 102 has a delayed step counter which helps for the differentiation. This feature come up with the most precise results to users by delaying calculation and eliminating overly sensitive step counting until it has step 10 steps in a row.

B. Keystroke (KS) Authentication

Keystroke (KS) authentication (KSA) utilizes a group of techniques and tools. KSA is useful in maintaining the authentication of smartwatch-based user information [26]. Touching pattern is one of the methods of authentication recommended recently by different researchers and it is used to identify the correct user. Along with time-domain feature the sensor that is utilized here is motion sensor of smartwatch. The authentication algorithm based on KS gives more accuracy. Nowadays real-time authentication systems are developed with the smartwatch by using the concept of neural networks. To use this keystroke authentication (KSA), a system has been proposed which is based on the hand waving patterns of a user. For device-to-device authentication, another accelerometer has been conducted when connecting headsets and smart watch to smart phones.

C. Security and threat scenarios

Even though some smart and modern technologies used in the smartwatch systems, several information attackers always try to get the secret information and try to disturb the privacy of the user. By classifying properly by using optimized classifiers, these kinds of attacks can be identified easily, and the secured system can be constructed to prevent the attacks. One of the classification algorithms illustrates the commonly found attacks in the real-time smartwatch is that sub-channel attackers. In smartwatch systems, different health-bands may be manipulated by using this real-time attacker. So, the smartwatch system must be equipped with standard security algorithms. By properly protecting the sensors in the smartwatch systems, the privacy of information can be maintained. Some of the body sensors which are used for analysing the movement of the users are generally attacked and the attack can be avoided by proper security code. A mechanical combination lock and unlock in the motion sensor of smartwatch can be detected by using gyroscope and accelerometer sensors. While using safe-open concept in the smartwatch in any application then it will be used to detect the data by unauthorized users easily. So it is suggested to lock-combination-based systems to be constructed to maintain the security and to avoid unauthorized data access [27].

D. Charging through body temperature

Generator technology: When it comes to battery life and charging, this Smartwatch can be charged by using our body temperature. Smart watch work on a phenomenon on the conversion of heat to electricity. It converts our body temperature heat into electricity [28]. It works on a concept called generator technology. A thermoelectric system consists of a cooler in one side and a heater in another side to work properly. The idea behind this construction of the thermoelectric is the difference between the temperature on two sides is very much useful for proper functioning in a smartwatch system. The human body maintains the temperature about 98.6^{o} F in normal temperature environment as well as normal body temperature. Due the change of heat in the environment as well as due to the body temperature variations this normal human body temperature is varied. To maintain the charge in the battery of the smartwatch, the human body temperature ids used. By using the thermoelectric circuit, the required heat to maintain the battery charge is generated through the user's skin and the other sensors and supporting peripherals get the required power from the battery. However, if the watch is not used by the user then the battery goes to the sleep mode

maintains the correct real time data of time and date until the user gets back the watch.

E. Connection with Google Assistant

Nowadays, Google's assistant [15] is an in-built feature in almost all android smart phones. Google assistant (GA) is one of the artificial intelligent (AI) – based networks bundled by ML algorithms used for voice-recognition and image-recognition purposes. By using the GA, the user can build a personal network for sharing information through smartwatch. WaveNet is one the modern technologies which is used to share information throughout the world in the form of audio by using AI. Google's assistant is not limited to 'OK Google', it is also efficient of holding a two-way conversation. This assistant has a chatbot connected to various devices like TVs, speakers, smart watches, etc. To connect a smart watch with smart phones, the user needs to add a device and there the setup will be ready for interaction. Users can also ask about body temperature along with all other features like calories burnt, steps walked, to send messages, heart rate, etc. We can say smart watches are also hand-free google. Fig.4 illustrates the overall features of smartwatch as discussed in the article.

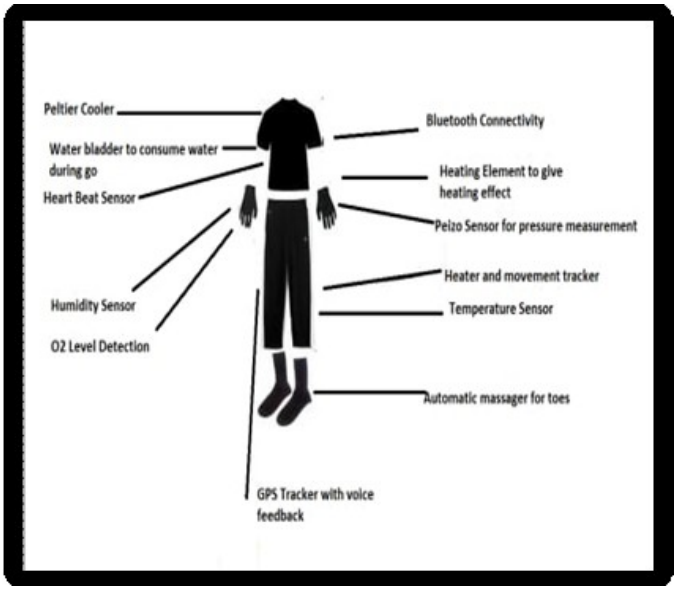

Fig. 4. Features of Smart Watch

IV. DIFFERENT TYPES OF SMARTWATCH

This section briefs the different recent development on smartwatches by different researchers such as LG Urbane2 [29] suggested by Aurizio et al. 2020, Wrist accelerometer (WA) - based [30] presented by Soltani et al. 20, Wrist Ballistocardiogram (WBCG) [31] proposed by yousefian et al. 2020, HAWAD [32] by Mondol and Stankovic (2020), Apple watch [33] tested by Seshadri et al 2020 by measuring heart rate, Polymer Mxene composite nono-fiber mat (PMCN) - based smartwatch [34] proposed by Sharma et al. 2020, Sesimo watch [35] implemented by Ganti et al. 2020. Table I illustrates the principle of operation used, sensors/peripherals used to design, application and characteristics of such smartwatches.

Based on Table I, it is identified that most of the recent smartwatches can be used to reduce the spreading of Coviod-19 by avoiding touching of face suggested by [31] and measuring blood pressure convinced by [31], [34] and [35] and by regular handwashing encouraged by [32].

V. CONCLUSION

The first step to detect corona virus is thermal scanning. Body temperature is also considered as important and a vital sign thus its measurement is required for any preliminary test before starting any kind of treatment, so, a built-in thermometer plays a very important role and is helpful in the present scenario. As per WHO guidelines, the suspected COVID-19 cases are advised to monitor their body temperature twice a day. Many people face challenges when it comes to charging issues. But this smartwatch enables us to overcome even with the charging problem by using the generator technology. It works as a pandemic stabilizer and a smart device with voice interaction, making calls, sending messages, etc. Smartwatch can be associated with Google assistant to provide information in voice instead of typing the message. Further, based on the analysis of different recent smartwatches developed by wrist sensors, it is identified that most of the smartwatches are available to monitor the general health of human. Among the various smartwatch systems, the ARM processor-based system using Gait bout identifications provides higher accuracy as 96.6 %. However, this Gait bout identification-based

smartwatch consumes more power as compared with Seismo watch. The Seismo watch consumes very less power suggested that for implementing low power pandemic stabilizer, the Seismo watch is mostly suitable and which can also provide better battery life. It is also suggested that the Seismo watch may be optimized to measure different heath parameters. Furthermore, by using properly these systems based the protocol mentioned by WHO in Covid – 19 pandemics, the spreading of virus can be reduced efficiently.

as 19 mA with the principle of pulse transit time. So, it is

Table I: Characteristics and applications of different recent smartwatch systems

Smartwatch system	Principle/ Technology used	Sensors/ Peripherals used	Applications	Parameters measured	Software/ OS used
LG Urbane2 (Aurizio et al. 2020) [29]	Multiplicative extended Kalman filter	Accelerometer, Magnetometer and RGB Camera	To prevent Covid-19 by avoiding face touch	Accuracy = 91.3 %	Wear OS
WA-based (Soltani et al. 2020) [30]	Gait bouts identification, Bayes estimator	Accelerometer and ARM Processor	To identify general health status and physical activities	Accuracy = 96.6 %. Power consumption = 135.5 mAh; Computation time = 6 seconds	MATLAB
WBCG-based (Yousefian et al. 2020) [31]	Analysis of pulse wave	BCG, Photoplethysnogram (PPG) sensors	Blood pressure monitoring	Correlation coefficient = 0.35	NA
HAWAD (Mondol and Stankovic 2020) [32]	Neural network	Inertial sensors	Regular handwash (To reduces the risk of spreading diseases)	FI- score = 30 %	NA
Apple watch (Seshadri et al. 2020) [33]	Atrial fibrillation	ECG sensor	Heart rate monitoring (Fitness tracking)	Correlation coefficient = 0.86	NA
PMCN-based (Sharma et al. 2020) [34]	Field emission scanning electronic microscopic	PMCN	Health diagnosis (pressure sensor)	High sensitivity	NA
Seismo watch (Ganti et al. 2020) [35]	Analysing pulse transit time	ECG, Triaxia Seismo Cardiogram (TSCG) sensors	Blood pressure measurement	Mean standard deviation = 2.72; Power consumption = 19 mA	MATLAB

REFERENCES

[1] A. A. R. Alsaeedy and E. K. P. Chong, "Detecting Regions At Risk for Spreading COVID-19 Using Existing Cellular Wireless Network Functionalities," in *IEEE Open Journal of Engineering in Medicine and Biology*, vol. 1, pp. 187-189, 2020.

[2] X. Ouyang *et al*., "Dual-Sampling Attention Network for Diagnosis of COVID-19 From Community Acquired Pneumonia," in *IEEE Transactions on Medical Imaging*, vol. 39, no. 8, pp. 2595-2605, Aug. 2020.

[3] "Coronavirus," *World Health Organization*. [Online]. Available: https://www.who.int/health-topics/coronavirus#tab=tab_1. [Accessed: 10-May-2020].

[4] M. N. Islam and A. K. M. N. Islam, "A Systematic Review of the Digital Interventions for Fighting COVID-19: The Bangladesh Perspective," in *IEEE Access*, vol. 8, pp. 114078-114087, 2020.

[5] F. Tietze, P. Vimalnath, L. Aristodemou and J. Molloy, "Crisis-Critical Intellectual Property: Findings From the COVID-19 Pandemic," in *IEEE Transactions on Engineering Management*, doi: 10.1109/TEM.2020.2996982.

[6] J. M. Cecilia, J. Cano, E. Hernández-Orallo, C. T. Calafate and P. Manzoni, "Mobile crowdsensing approaches to address the COVID-19 pandemic in Spain," in *IET Smart Cities*, vol. 2, no. 2, pp. 58-63, 7 2020.

[7] E. Hernández-Orallo, P. Manzoni, C. T. Calafate and J. Cano, "Evaluating How Smartphone Contact Tracing Technology Can Reduce the Spread of Infectious Diseases: The Case of COVID-19," in *IEEE Access*, vol. 8, pp. 99083-99097, 2020.

[8] “Smartwatch,” Wikipedia, 02-May-2020. [Online]. Available: https://en.m.wikipedia.org/wiki/Smartwatch. [Accessed: 10-May-2020].

[9] A. Liszewski, “This Smartwatch Powered By Your Body Heat Never Needs Charging,” Gizmodo, 15-Nov-2016. [Online]. Available: https://gizmodo.com/this-smartwatch-powered-by-your-body-heat-never-needs-c-1788878862. [Accessed: 10-May-2020].

[10] “Smartwatch,” Wikipedia, 02-May-2020. [Online]. Available: https://en.m.wikipedia.org/wiki/Smartwatch. [Accessed: 10-May-2020].

[11] Simpranchal Singh, “Ticwris GTS smartwatch measures real-time body temperature to prevent the spread of Covid-19,” gizmochino, 17-Apr-2020. [https://www.gizmochina.com/2020/04/17/ticwris-gts-smartwatch-measures-real-time-body-temperature-to-prevent-covid-19/].

[12] “Smartwatch,” Wikipedia, 02-May-2020. [Online]. Available: https://en.m.wikipedia.org/wiki/Smartwatch. [Accessed: 10-May-2020].

[13] "Manage alarms on your Samsung smartwatch," Samsung Electronics America. [Online]. Available: https://www.samsung.com/us/support/answer/ANS00084103/. [Accessed: 10-May-2020].

[14] A. Liszewski, “This Smartwatch Powered By Your Body Heat Never Needs Charging,” Gizmodo, 15-Nov-2016. [Online]. Available: https://gizmodo.com/this-smartwatch-powered-by-your-body-heat-never-needs-c-1788878862. [Accessed: 10-May-2020].

[15] “Google Assistant,”Wikipedia, [Online]. Available:https://en.wikipedia.org/wiki/Google_Assistant

[16] “Amazon Alexa,” Wikipedia, [Online]. Available:https://en.wikipedia.org/wiki/Amazon_Alexa.

[17] “How does Google assistant work as artificial intelligence?” [Online]. Available: https://www.geospatialworld.net/blogs/how-is-google-assistant-using-artificial-intelligence-ai/

[18] http://meseec.ce.rit.edu/551-projects/spring2016/1-2.pdf.

[19] Yousef Jaradat, Ahmad Manasrah, and Ismael Jannoud, “Sensors of Smart Devices in the Internet of Everything (IoE) Era: Big Opportunities and Massive Doubts”, Journal of Sensors, vol. 2019, pp. 1-26, 2019, https://doi.org/10.1155/2019/6514520.

[20] Serkan Balli , Ensar Arif Sagbas and Musa Peker, “Human activity recognition from smart watch sensor data using a hybrid of principal component analysis and random forest algorithm”, Measurement and Control, vol. 52, pp. 37-45, 2019.

[21] https://www.digikey.com/en/articles/apply-sensor-fusion-to-accelerometers-and-gyroscopes

[22] https://en.wikipedia.org/wiki/Vibrating_structure_gyroscope#MEMS_gyroscopes

[23] "Ways to monitor heart-rate." [Online]. Available: https://www.which.co.uk/news/2020/03/best-ways-to-monitor-your-heart-rate-with-a-smartwatch.

Journal of Sensors / 2019 / Article. [Online]. Available: https://www.hindawi.com/journals/js/2019/6514520/

[24] https://www.maximintegrated.com/en/products/sensors/healthcare-sensor-ics/wearable-temperature-sensor-ics.html#:~:text=Wearable%20temperature%20sensor%20ICs%20are%20digital%20thermometers%20which,as%20wrist%20watches%2C%20medical%20patches%2C%20and%20smart%20clothing.

[25] Tom Mikael Ahola, “Pedometer for Running Activity Using Accelerometer Sensors on the wrist”, Medical Equipment Insights, vol. 3, pp. 1-8, 2010.

[26] Hyungu Lee , Jung Yeon Hwang , Dong In Kim , Shincheol Lee , Sung-Hoon Lee , and Ji Sun Shin, “Understanding Keystroke Dynamics for Smartphone Users Authentication and Keystroke Dynamics on Smartphones Built-In Motion Sensors”, Hindawi, Security and Communication Networks, vol. 2018, pp. 1-10, 2018.

[27] https://www.kaspersky.co.in/resource-center/threats/smartwatch-security-risks.

[28] https://digitmize.com/best-self-charging-smartwatches/.

[29] N. D’Aurizio, T. L. Baldi, G. Paolocci and D. Prattichizzo, "Preventing Undesired Face-Touches With Wearable Devices and Haptic Feedback," in *IEEE Access*, vol. 8, pp. 139033-139043, 2020.

[30] A. Soltani, A. Paraschiv-Ionescu, H. Dejnabadi, P. Marques-Vidal and K. Aminian, "Real-World Gait Bout Detection Using a Wrist Sensor: An Unsupervised Real-Life Validation," in *IEEE Access*, vol. 8, pp. 102883-102896, 2020.

[31] P. Yousefian *et al*., "Pulse Transit Time-Pulse Wave Analysis Fusion Based on Wearable Wrist Ballistocardiogram for Cuff-Less Blood Pressure Trend Tracking," in *IEEE Access*, vol. 8, pp. 138077-138087, 2020.

[32] M. A. Sayeed Mondol and J. A. Stankovic, "HAWAD: Hand Washing Detection using Wrist Wearable Inertial Sensors," *2020 16th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, Marina del Rey, CA, USA, pp. 11-18, 2020.

[33] D. R. Seshadri *et al*., "Accuracy of the Apple Watch 4 to Measure Heart Rate in Patients With Atrial Fibrillation," in *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 8, pp. 1-4, 2020.

[34] S. Sharma, A. Chhetry, S. Ko and J. Y. Park, "Highly Sensitive and Stable Pressure Sensor Based on Polymer-Mxene Composite Nanofiber Mat for Wearable Health Monitoring," 2020 IEEE 33rd International Conference on Micro Electro Mechanical Systems (MEMS), Vancouver, BC, Canada, pp. 810-813, 2020.

[35] V. G. Ganti, A. Carek, B. N. Nevius, J. Heller, M. Etemadi and O. Inan, "Wearable Cuff-less Blood Pressure Estimation at Home via Pulse Transit Time," in *IEEE Journal of Biomedical and Health Informatics*, doi: 10.1109/JBHI.2020.3021532.