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IoT-Enabled Smart Wearable Devices: A Short Review

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Abstract: Smart wearables are changing the way we monitor human activities and behaviour as they provide hands- free access to technology. They are undoubtedly making our life easier by providing wide array of applications in daily lives. These devices are an indispensable part of the Internet of things (IoT). This paper discusses the latest trends and innovations of IoT-enabled smart wearable devices. It also addresses user requirements of wearable technology. The basic components of smart wearables consist of sensors, microcontrollers, cloud platforms, User Interface (UI), connectivity and gateway. In the literature study section, we have given a summary of the innovative papers that are divided into three major domains of wearable technology i.e. i) safety and tracking, ii) medical, and iii) sports and fitness. Further various limitations and challenges of wearable sensor devices are also discussed. This paper is useful to get an in-depth explanation about smart wearables and to know hardware and software components required to design wearable devices that are listed in the final summary table.
Keywords: cloud platforms, hands-free access, medical, IoT, safety, smart wearable safety and tracking, sports and fitness, User Interface (UI), wearable technology

I. INTRODUCTION

In this era of smart growing technology, many new innovations and ideas are emerging which are mainly focused on the betterment of humans. The main aim of technology is to efficiently become part of daily lives of humans and wearable technology has succeeded in doing so. In around 2010, as the prices of sensors dropped, wearables became popular which led to a surge in multitude of areas like health and medicine, sports, safety and tracking and localization. Now wearables have become an integral part of our life. They have provided hands-free access to technology which is required for physically demanding activities. More and more technologies are providing an optimal solution in various domains and soon these devices will be able to self-adjust according to variations in environment. Hence in the course of time, world will experience exponential growth of wearable technology.

Smart wearables are electronic devices that can be worn as watches, wrist bands, eye wear, headsets, body straps, jewellery, belts, and many other external accessories [Fig. 1]. Wearable devices are an indispensable part of Internet of things (IoT). IoT can be described as a network of interrelated computing devices, mechanical and digital machines with unique identifiers (UIDs) and the ability to transmit data over a network without the need for human-to - human or human-to - computer interaction [1].

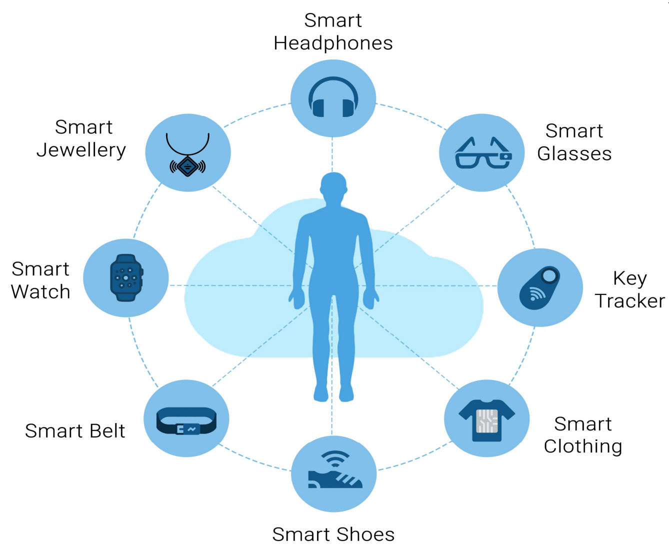

Fig. 1. Wearable devices on a human body

Such devices are non-invasive in operations but on the other hand there are various invasive wearable devices for health-related operations that can be implanted in the body such as pacemakers or Infusion and Insulin Pumps etc.

Sensors gather information about different physical and environmental parameters. These sensors are embedded in the smart wearable device which are in proximity of the user. The devices are able to connect to the Internet in order to collect, send data and receive the information that can be used for smart decision making [2]. In between the device and the cloud platform, gateway acts as a bridge for transmission of data through various data transfer technologies like, Wi-Fi, Thread, ZigBee, Bluetooth etc. and Internet protocols like MQTT, HTTP, COAP etc. [Fig. 2].

In this paper, basic user requirements of smart wearables are discussed in section II. A detailed understanding of components of IoT systems is explained in section III. Section IV comprises of literature study of various innovations and projects developed by researchers in recent years on smart wearable IoT devices. Limitations and challenges of wearables are discussed in Section V and the conclusion is presented in section VI.

II. USER REQUIREMENTS

Smart wearables can be efficiently used only when some basic requirements are met. User requirements can be divided into three categories i.e. physical, cognitive, and emotional [3].

A. *Physical*

As these wearables are worn on human body, they should be non-invasive and have light weight and small size so that they are flexible and can be easily worn. Power consumption of these devices should be low to support longer work of the system Many other factors like comfort, size, adaptability etc. should be included in the physical requirements of wearables. Many devices like smart t-shirts must not affect respiration of user. After long usage, these devices should not harm any parts of body. For example, when a user has worn smart shoes, it should feel like normal shoes. There should not be any discomfort. The user should not go through muscle fatigue. Accuracy and efficiency are also prime factors. Designers must consider all these factors while designing wearables.

B. *Cognitive*

Wearables are used in day to day life and the major reason for the enormous attention they are gaining is that, they provide user-friendliness and ease of use. Designers need to focus on how these devices can best interact with user and make human-device interaction as intuitive as possible. When implementing modern technology, it is important to consider how people view it and how it applies to the technologies. A reality check is often needed to recognize how people would use wearable technology, despite how they are “supposed to” (or expected to) use it [3]. Hence contextual awareness is very important. The devices which are especially used for healthcare should respond quickly according to the user’s actions and health status. Delay in giving alerts and notifications to concerned person may lead to critical situations.

C. *Emotional*

The device should look aesthetic but not too obtrusive. The device should not be too noticeable leading to discomfort of user. While designing, one should focus on aesthetics, simplicity, and fashion trends as much as possible. The data that is collected in real time from sensors must be protected by encryption and controlled access. As these devices are connected to the internet, they may be vulnerable, if there is no security. Users do not want to make their personal data public as sometimes it can be used against them. Hence the data should always stay confidential. User trust in technology is very important.

III. COMPONENTS OF IOT WEARABLES

Due to advancement of technology, there has been a global trend of improvising a thing as per the user’s need. So, more and more sensors and actuators which are an essential part of today’s IoT devices are getting enhanced. The IoT-enabled devices have various components that help them to gather vital information about the user. These devices can connect to the Internet to collect, send data, and receive the information that can be used for smart decision making [2]. The main components of IoT are sensors, microcontrollers, wireless communication module, data acquisition and processing systems and battery. In Fig. 2, the basic architecture of IoT wearable system is shown. In this section, we will discuss some components of IoT devices which are more focused on smart wearables.

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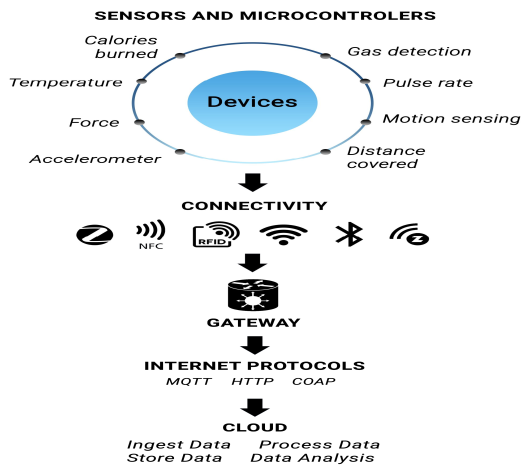

Fig. 2. IoT Architecture of wearable technology

A. IoT Hardware

The IoT hardware majorly consists of sensors and microcontrollers.

1) Sensors: While choosing a sensor for wearables, many factors are taken into consideration. User-sensor interaction must be as low as possible. Various sensors form a device and user always interacts directly with a device. Following are some of the deciding factors while choosing sensor for wearable technology.

a) Accuracy: The more accurate the information captured by the sensor, the better will be the insights gained from data analysis. Accuracy is very critical in healthcare wearables. They should at least have accuracy of +/- 0.2 units.

b) Versatility: Wearable must work accurately in all environmental conditions. During the day there will be variations in surrounding temperature. For example, a device that calculates temperature of the user should not give unsatisfying readings in extreme summer temperatures.

c) Power Consumption: Some of the wearables used for heart rate monitoring, step count etc. need constant monitoring, so power consumption in these cases is high. But for some devices it is possible to have sleep mode and wake up mode which can save power.

Some of the sensors which are frequently used in wearables are mentioned below table [Table 1.] along with their applications.

Sensor	Model name	Application in wearable device
Temperature and Humidity Sensor	DHT11	It is a low-cost digital sensor which has a capacitive humidity sensor and a thermistor to measure the surrounding air.
Pulse Rate sensor	SN-1175	It has two components, a simple optical heart rate sensor and a noise cancellation circuitry which is used to give accurate heart rate readings.
Grove GSR Sensor	N/A	It measures the electrical conductance of the skin. It has two electrodes placed on two fingers that senses strong emotions or anxiety of the user. They are commonly used in projects were sleep monitoring is needed.
The triple axis accelerometer	ADXL335	It is a small sensor that can measure acceleration with a range of ±3 g on all 3 axes.
Hazardous Gas Detecting Sensor	MQ-2	It is used to detect or measure gasses like Alcohol, Hydrogen, Propane, LPG, CO, and methane.
Pressure Sensor	BMP 180	It is a high precision sensor designed to measure Barometric Pressure or Atmospheric pressure.
Ultrasonic sensor	HC-SR04	It is a non-contact measurement sensor, which has a range of 2cm - 400cm and its ranging accuracy can reach to 3mm.
Microphone sensor	KG181	It is a High Sensitivity Sound Detection sensor.
LDR sensor	M-18X50 MM	It is used to detect the presence of light and can measure the intensity of light.
Infra-Red sensor	ZTP-135SR	It can emit or detect infrared radiation and is also capable of measuring the heat that is emitted by an object.
force sensitive resistors sensors (FSRs)	FSR402	It is an ultra-thin pressure sensor. When force is applied resistance changes and pressure is detected.
IMU	EXLs3	It consists of featuring 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer, which is mostly used for motion analysis.

Table 1. Wearable sensors and their applications

2) *Micro-Controllers and Modules:* Many projects that we see in recent years use microcontroller boards that have various features, and which make them an essential component of IoT devices. Using microcontrollers, like Arduino UNO, we can incorporate sensors, light animations, motors, sounds etc. all driven by code [29]. Raspberry Pi 3 (R-pi) provides the more compact and standalone computer systems by involving the Bluetooth, built-in Wi-Fi facility and able to include different programming packages like python, LAMP Stack etc. [2]. The HC-05 module is a Bluetooth SPP (Serial Port Protocol) module intended for the setup of transparent wireless serial connections. The module interacts at 9600 baud speeds with the aid of USART, making it easy to connect with any microcontroller that supports USART. The ESP8266 Wi-Fi module can either host an application or import all Wi-Fi networking features from another device processor [3]. GSM stands for Global System for Mobile Communications and it is based on second-generation (2G) cellular networks used by mobile phones. GSM modules has features of sending messages or the data from the sensor to the mobile where it can be read by the user. GPS receiver modules uses a constellation of satellites and ground stations to calculate accurate location wherever it is located. It provides output serially with default 9600 Baud rate [4].

B. Cloud Platforms

Number of devices connected to cloud are growing exponentially. The humongous data that is captured by sensors needs to be stored and used for valuable purposes. That is where cloud platforms come into the picture. Cloud platforms are responsible for data visualization, data analysis, monitoring and maintenance of devices. They provide connectivity via which all devices can communicate with each other without human intervention. Cloud platforms are scalable and cost-effective. If the system needs to perform more complex functions, more hardware is added in system. But with cloud platforms, system uses another virtual server and performs the same operations. Main functions carried out by cloud platforms are data ingestion, data processing, data analysis and storing data. After the data is gathered by sensors it is stored in one place by data ingestion. Optimization and management of data is also done in this stage. Data processing includes cleaning data for further processing. In data analysis stage, data is visualized for predictions. This is how valuable data is generated. Some of the frequently used cloud platforms are discussed below.

1) *KAA-IoT:* KAA project is open-source IoT middleware platform, which facilitates the management and maintenance (distribution of firmware updates) of the inventory of devices and near real-time communication between devices [6]. It uses well defined interfaces based on NATS and JSON. It is used in Cars, fitness trackers, telecom transmitters etc. Data processing tools like Hadoop, mongoDB, Oracle etc are inbuilt in KAA. Devices can communicate with each other using MQTT protocol. KAA has automatic application versioning, with updates and current requirements, new features are automatically installed, and old ones retire. Devices can be directly connected or via gateway. With gateway, communication of multiple devices is possible using only one server.
2) *IFTTT:* IFTTT stand for 'If This Then That'. As the name says, certain action is taken if any condition is met. Using IFTTT, chain of conditional statements is created, and execution of these statements is done when an event is triggered. It is used in many IoT projects. It is not a native platform. It is interfaced with many communication mediums like WhatsApp, Gmail, Instagram etc. So, notifications can be directly sent to these apps. Examples of IoT-related recipes are: "delay watering your garden if it's going to rain tomorrow," "receive and make an emergency call if smoke is detected," and others [6].
3) *ThinkSpeak:* ThingSpeak is an IoT platform which can give live updates of data which is detected by sensors. We can get latest updates through graphs, so data visualization is very easy. The data is published by the users. It contains open channels with accessible data from various devices, which are shared by users. This platform enables actuation, namely talking back to the device, which is done over HTTP (Hyper Text Transfer Protocol) [6].
4) *SensorCloud:* SensorCloud is an IoT cloud platform for data collection, visualization, and analysis. Hence various calculations can be done using data and outputs can be represented. Connectivity with LORD Microstain's wireless and wired sensors is possible. One of the key features of sensor cloud is data visualization. It is possible to setup simple alerts, triggered by the data threshold values. Math Engine analysis tools are provided, with a simple interface which facilitates common operations such as FFTs, smoothing, filtering and interpolation [6].
5) *Amazon Web Services:* AWS IoT (Amazon internet of things) is an Amazon Web Services platform that collects and analyses data from internet-connected devices and sensors and connects that data to AWS cloud applications. AWS IoT may obtain information from billions of devices and bind it to endpoints for other AWS software and services, enabling the developer to relate the data to the application [7].

Sr. No	IoT Platform	Protocols	3rd party integration	Supported Hardware Platform	Data analytics
1	KAA IoT	HTTPS, COAP, MQTT	Rest API	Intel Edison, BeagleBone, Raspberry Pi, Econais, LeafLabs, Texas Instruments	NO SQL, more plugins can be added
2	IFTTT	HTTP	Rest API	Amazon's Alexa, Arduino, Raspberry Pi	MATLAB
3	ThingSpeak	MQTT and HTTP	ThingSpeak API, JSON, XML	Arduino, Particle Photon and Core, Raspberry Pi, Electric Imp	MATLAB
4	Sensor cloud	HTTP	Rest API	Arduino, Raspberry Pi	MathEngine, FastGraph, LiveConnect
5	AWS	MQTT, HTTP1.1	Rest API	Broadcom, Intel, Texas Instrument, Marvel	Apache Spark, Spark ML

Table 2. Comparison of Cloud Platforms

These platforms can be compared using various parameters like protocols, integration, hardware used and data analysis tools. IoT connectivity protocols are connectivity modes that secure and maintain optimum protection for data sharing between connected devices [8]. Third party integration is usage of external data from third party. This is done using API's. Data analysis tools are used to process the data and give users fruitful outputs. Comparison of cloud platforms is done in the table [Table 2].

C. Connectivity

There are various options through which IoT devices and its sensors can be connected. Wi-Fi, Thread, ZigBee, Bluetooth, RFID, and NFC, Z-Wave are just some of the possible ways to connect a sensor/device. The table [Table 2] gives the comparison between these communication protocols [6].

D. User Interface

There are various IoT-enabled wearable devices available in the market which can vary from simple ones to complex powerful devices depending upon the users' demand. Some are vital signal detectors, while others may provide an immersive video display. As there is a huge variety of these devices some recently innovated systems such as smart glasses, Virtual Reality (VR) and Augmented Reality (AR) gadgets have more complex functionalities thus requiring more advanced User Interfaces (UI). The wearable form factors, types, use cases, and the intended applications and environment determine the choice of UI. A modern-day UI is a complex piece of software. The basic choice of wearable UI is that it should keep your hands free and will not hinder your daily activities [5].

We see different variety of smart watches having touchscreen UI. But, in future these watches will have more functionality rather than just tracking or measuring heartbeat. Solution for such wearables can be having an UI which does not require much hardware. A new trend which is User of devices connected to cloud are growing exponentially. The humongous Experience (UX) will be required to solve many challenges that are faced. New UX such as voice, eye-tracking, gesture, proximity sensor will play an important role in future wearable devices [5].

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E. Gateway

Gateway is one of the key features of IOT. The IoT devices connect to the IoT Gateway using short-range wireless transmission modes such as Bluetooth LE, Zigbee, Z-wave, or long-range like LTE, LTE-M, Wi-Fi, and then it links them to the Internet (Public Cloud) through Ethernet LAN or Fibre Optics WAN (HDLC/PPP) [9]. Gateway bridges the gap between various devices. Real time control of devices is possible through gateway. Before sending data to the internet for further processing, it cleans and filters the data. It also provides security by translating protocols for communication and encryption.

Parameter	NFC	RFID	Wi-Fi	BLE 5.0	ZigBee	Z-Wave	Thread
IEEE Spec	ISO 13157 etc	802.15	802.1 1a/b/g	802.15.1	802.15.4	ITU-T	802.15. 4-2006
Feasible Distance	4 centimetres	600 meters	50 meters	Up to 100 m	100 meters	100 meters	100 meters
Network Development Models	Point-to-point	Point-to-point	Broadcast, Point-to-point, Mesh	Broadcast, Point-to-point, Mesh	Star, Mesh and Cluster tree topologies	Mesh	Mesh
Data Transfer Rate (Max)	424 kbit/s	640 kbps	1 Mbps to about 500 Mbps	2 Mbps	250 kbit/s	100 kbps	250 kbit/s
Frequency Range	13.56 MHz	LF* is 125-134 kHz, HF** is 13.56 MHz, and UHF*** is 433and 860-960 MHz	2.4 GHz UHF and 5 GHz radio waves	2.4-2.5 GHz	2.4 GHz ISM	800-900 MHz	2.4 GHz ISM

*Low Frequency, **High Frequency, ***Ultra High Frequency.

Table 3. Comparison of wireless data transfer technologies

IV. LITERATURE STUDY

So far, we have discussed the user requirements and various components of IoT-enabled smart wearable devices. In this section we will discuss about the major domains in which wearables are used and recent innovations in these domains. The three major domains are i) safety and tracking, ii) medical, iii) sports and fitness [Fig. 3].

Fig. 3. Domains of wearable technology

A. Safety And Tracking

In this domain, we studied various research papers that mainly focus on the safety of the user or to provide a safer environment for the user. Wearable devices are used to collect vital health parameters of coal mine workers and provide that data to the control room. In case of an emergency, this device will also send the miner's location for accurate evacuation [12]. Another example can be the safety of children. The wearable device uses GSM module to send the child's location via SMS text to the parents [13]. Below are some research papers that illustrate use of IoT-enabled wearable devices in safety domain.

Anand Jatti et al. (2016) have developed a novel system for the safety of women and girls. The device analyses the physiological signals that are generated in stress condition through temperature and galvanic skin resistance sensors. Body position is calculated by collecting data from a triple axis accelerometer. All these data are processed through various Machine-Learning algorithms and then monitored in real-time on MATLAB. In emergency, the data is sent wirelessly to the cloud platform and notifications/signals are generated [14].

Bauyrzhan Krykpayev et al. (2016) have created an unobtrusive and flexible integration of tracking device with clothes. Circuit is printed on the textile using conductive ink instead of having a bulky PCB circuit. It has Wi-Fi module, microcontroller, integrated antenna, a localization device, and server. Localization device scans Wi-Fi access points near it and sends data to it, which sends it to microcontroller which processes data and sends to Google API to receive location coordinates. These coordinates are used to plot the location on map which can be accessed from any smart device. Integration of circuit with textile/cloth can be referred as E-textile. The complete aim of this paper is to keep the circuit and its component as small and compact as possible [18].

Kushal S. Patel et al. (2016) have provided a mechanism and apparatus to protect a person falling from bike or an old person falling using inflating bags attached to smart clothes. System has sensors (accelerometer and gyro sensors) and control unit (microcontroller) which will detect the fall depending on angle/impact. Depending upon calculations, control unit will activate the initiators and decide which part of cloth to be inflated to minimize the impact. All data during the fall as well as before the fall is stored in paired device like smartphone or smart watch which can be further used to assess cause of fall, speed of vehicle, etc [15].

Payal Kalra et al. (2017) have designed an autonomous smart cap for achieving safety among the pedestrian using their smartphones. Whenever the person is facing down the accelerometer signals microcontroller which activates the ultrasonic sensors. The system uses ultrasonic sensors to detect the obstacle and the distance is send to the microcontroller which in turn sends signal to a vibration motor according to the algorithm. Vibrations created by motor increases with the decrease in the distance between pedestrian and obstacle. Smart cap is powered by two sources one is solar panel (when in presence of sunlight) and alternative source is a dc battery [16].

Fan Wu et al. (2018) have presented a wearable IoT sensor node for safety application called WE-Safe incorporating LoRa based gateway with low power components and management techniques. Putting the primary focus on providing early warnings to people, working in extreme and harsh environment, by detecting the level of air pollutants like CO2, carbon monoxide (CO) using sensor nodes. These sensors, including temperature sensors, CO2, and CO sensor, send signals to microcontroller which uses LoRa network to send data to cloud server. System is programmed to wake up the sensor nodes every 1 minute hence saving power and having data send periodically [17].

Ghulam E Mustafa Abro et al. (2018) have designed a prototype that helps in securing the life of coal miners that work in extreme conditions. It suggests a wearable smart jacket that senses various health related parameters i.e. the presence of dangerous gas, pulse rate of miner, revised temperature / humidity, precise location of depth and global positioning of the miner. These parameters are then transmitted through a Wi-Fi shield to a dynamic internet protocol (IP). The jacket sends the last GPS location to the control room and in case of disaster, miners can be easily evacuated [12].

A. R. Abdullah et al. have presented a smart localization and detection system for school children to overcome the issues of missing children. The system is applied to track and alert the location of children using the SIM908 Global Positioning System (GPS) Module with Global Network for Mobile Communication (GSM) technology and the Arduino Super 2560 microcontroller unit. The system kit is mounted inside the children's school bag when they're going to school. The children positioning information is sent through GSM to the parent's smartphone via Short Message service (SMS) that is linked to Google Map [23].

Paolo Bellitti et al. (2019) have presented a study that uses modular wearable system for tracking the fingers of the workers to obtain its precision movement in industrial environment. The results show the system capability in discriminating between different ways of handling a tool, such as a precision screwdriver. The system has a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axismagnetometer that sends the data to the external device through microcontroller and Bluetooth module. The collected data helped to enhance the human-robot-interaction by identifying different hand gestures [22].

Ushashi Chowdhury et al. (2019) have discussed about a smart wearable device like a wristband which tracks the child from time to time to ensure their safety. It has the SMS text enabled communication. Parents can send SMS with some keywords and the device replies. The system is capable of detecting the child's approximate location, identify the body and the surrounding temperature, humidity and heartbeat of the child. In case of an emergency, the device has alarm buzzer and SOS light that alerts the by-standers about the situation and to help the child [13].

B. Medical

In healthcare domain, the basic requirement of the user is having a track of the vital information of the body parameters. For such reason he/she can use IoT-enabled wearable device that can show body temperature, pulse rate, anxiety, ECG-variations, and many other parameters. Below are some of the recent innovations that are focused on smart health wearables which are helpful for both the humans as well as animals

Chaitali Kulkarni et al. (2016) have introduced health companion system which can monitor health regularly. The wearable device consists of temperature and pulse rate sensor to keep a regular track of health variations. The system also keeps track of the user's location as well as the date and time. GPS service is used to track location and GSM for sending message to user. When the user's temperature or heart rate reaches the stated threshold, the app may alert the user of the location to the nearest hospitals. Free cloud service called data Sparkfun which is provided by an open cloud server called Phant is used. Phant is a Node.js application. The system also includes daily and monthly report generation for the user and doctor, respectively [24].

Niket Patil et al. (2017) have presented a system which can monitor the health and track the location of soldiers wirelessly. The device can be placed on the back of soldiers that has several sensors such as temperature sensor, pulse rate sensor, oxygen level detector, GPS receivers, etc. All the data from the sensor is transmitted to the cloud by Wi-Fi module. The person in the control room thus can access this information and in emergency, the soldiers can be protected quickly [19].

Joohee Kim et al. (2017) have demonstrated a wearable smart contact lens with highly transparent and stretchable sensors that continuously and wirelessly monitors glucose and intraocular pressure from tear fluid, which are the risk factors associated with diabetes and glaucoma, respectively. The main components used in the sensors are graphene and its metal nanowire combination, which offers transparency greater than 91% and stretchability equalivalent to 25% to ensure reliability, comfort and unobstructed vision. This contact lens sensor shows a big potential for next-generation ocular diagnostics, which not only tracks disease-related biomarkers, but also measures the overall health and ocular conditions of our body.[25]

Mr. V Gokul et al. (2017) have introduced an application of IoT wearables for monitoring cattle health. It implements a non-invasive wearable device to track the health of the cattle and to not allow the spread of diseases in the herd. The wearable tool is designed for early disease detection, irregularities identification, emergency management, location tracking, calving time intimation and disease detection before visual signs. The sensors used are LDR, Infra-red sensor, LM35, humidity sensor and smoke sensor. To allow remote access, all sensor readings will be forwarded to ThingSpeak cloud. The data is analysed and an inspection on health and milk production of the cattle is carried out [26].

Rashi Kansara et al. (2018) have proposed a device which can monitor various health parameters like body temperature, step count, heart rate and sugar level. For software module, the collected data from sensors is displayed on smart phone application. All the sensors are connected to microcontroller Arduino. Main components of the smart fabric are sensors, microcontroller, wireless communication module, battery, end-device, and user. The device needs to be then connected to the smart phone using wireless communication Wi-Fi [27].

Md Shaad Mahmud et al. (2018) have presented a novel, compact and low-cost wearable ring sensor (SensoRing) for the continuous measurement Electrodermal activity (EDA), heart rate, skin temperature and locomotion, which gives the ability to measure one's emotional state using wearable biosensors. The SensoRing consists of three major components: 1) Hardware design, where the sensors collected the physiological data; 2)Wireless network protocol for communication between hardware and software; and 3) Computer architecture that involves a processing unit for the extraction and analysis of data at a reasonable level.Utilizing finger as a tracking site for several biosignals, at the same time miniaturization of the complete system, as well as the architecture of the proposed system that allows for a discreet evaluation of physiological biomarkers, makes it a good candidate for remote health monitoring[28].

Quang Huy Nguyen et al. (2019) have proposed an architecture for real-time tracking of patients and hospital staff. The system uses Bluetooth Low Power (BLE) and iBeacons for real-time tracking of patients. It has four frameworks i.e. server communication, user interaction, cross-platform communication, and indoor localization. The data is analysed by Least Square Estimation approach which gives the accurate location of the patients inside the hospital. The system has a resolution of 12cms [21].

Lan Luo et al. (2020) have introduced a non-invasive fertility tracking system, along with an accurate and scalable statistical learning algorithm to detect and predict ovulation. The device consists of an earpiece that monitors the temperature of the ear canal every 5 minutes during night sleep hours and a base station that transmits data to a smartphone analysis program. A data-cleaning protocol is used for pre-processing data and then model is trained with the Hidden Markov Model (HMM) with two hidden states of high and low temperature. Further, a post-processing technique is created to add details on biorhythm to create a biphasic profile for each subject. The wearable device and learning algorithm described in this paper offers a user-friendly and accurate interface for monitoring ovulation that may have a significant effect on both fertility research and real-world family planning [29].

C. Sports and Fitness

A user always aims for better performance in sports every time he/she does training. So, to help them smart wearables play an important role. It tracks the user data like the distance they ran, the number of steps taken, calories burnt etc. it can also help in improvement in walking style like the paper [30] suggests.

Ahmed et al. (2015) have introduced mobile, low power and low-cost wearable for real-time recording and visualization of bowling action in cricket. Using the flex sensor as an activating component, the system conducts continuous arm angle measurements with one-degree precision. It also uses a force sensor to measure the instant moment at which the ball is released. The wearable device connects wirelessly to a smart phone using BLE 4.0, where a complete visual and graphical evaluation of the data collected is conducted, and a judgment on the validity of the action is taken. The power consumption of the wearable is only 5.45 mW, allowing up to 82 hours of working and a low production cost of just $50 [31].

Lars Büthe et al. (2016) have designed a wearable sensor system consisting of three inertial measurement units (IMUs) that allow to capture the racket and foot movement of a tennis player. Recorded data can be used to independently classify both the type of shot and the type of step of the player. They have also built a process to identify and recognize leg and arm actions and introduce a gesture identification for the shooting arm based on the LCSS (longest common subsequence) algorithm. The program identifies the forehand and the backhand as well as the smash actions. Footwork is first segmented into potential steps and then classified by a support vector machine between shot and side steps [32].

Raffaele Iervolino et al. (2017) have proposed a prototype for the motion study of an athlete during a race. The system is based on a STMicroelectronics with storage capability via an SD card. The portable instrument consists of a 32-bit low power MCU, a tri-axis accelerometer, a tri-axis gyroscope, and a Bluetooth wireless transmission module, integrated with tri-axis magnetometer, barometric pressure, and humidity sensors. Preliminary data is obtained from the available sensors in the SD-card at a predefined sampling rate. They are then transferred to a PC, where more complex and sophisticated analysis is performed offline in the MATLAB environment, in order to identify the system characteristics and derive synthetic indicators of the athlete's motion features. An ANN has been trained in order to discriminate among some possible activities and the acquired acceleration data can be segmented into instances, each one related to a particular classified activity. The main Gait parameters, associated to the detected activity, can now be determined from the accelerations frame data and numerical procedures can be designed for their computation [33].

Satetha Siyang et al. (2018) have developed a smart shoe data that are used for the human gait monitoring. The shoes have 5 FSR (force sensitive resistors sensors) placed on various locations of the feet. Whenever the user walks these force sensors send the data wirelessly using Wi-Fi module to the cloud. It uses an android or iOS application called Blynk to show the results of the gait analysis. User can improve their walking by analyzing various graphs and table which are provided in this application [30].

Yufan Wang et al. (2018) have proposed an IoT framework for next-generation racket sports training. It uses a smart Badminton Action Recognition Platform composed of Bluetooth Low Energy Technology, MEMS Inertial Measurement Module, Cloud Computing, and various machine learning algorithms. The MEMS system comprises of a 3-axis accelerometer and gyroscope. All the readings from the sensor unit is transferred to a mobile phone by BLE and then to cloud and then various machine learning algorithms are applied like SVM, Nearest Neighbours and Naïve Bayes. The results show an accurate classification of the three strokes with 97% accuracy which helps the user to improve their Badminton training [34].

Jose Toledo Monsalve et al. (2019) have proposed a system that can help the user in doing work-out or fitness exercises. This device analyses the real-time multiple sensor data and sends it to the cloud. It uses an accelerometer and an ultrasonic sensor to track the workout sessions and Personal Communication Node (PCN) is used to analyse the data from it. They have provided an application where the user can keep a track of his/her workout. This project can be further used for keeping the activity track of patients with disabilities or workers working in hazardous environmental conditions [20].

Zhelong Wang et al. (2019) have presented a wearable sensors-based swimming stroke recognition method. This system contains several sensor nodes, each equips with MEMS sensors, an SD card, a 1200mAh lithium polymer rechargeable battery and a radio frequency module, which collects raw data with respect to four swimming styles. The characteristics of pose and statistical information have been obtained by the data fusion process. Subsequently, HMM has been used for action / stroke recognition [35].

Sensor	Safety and Tracking	Medical	Sport and Fitness
Temperature and Humidity Sensor	✓	✓	
Pulse Rate sensor	✓	✓	
Grove GSR Sensor	✓	✓	
The triple axis accelerometer	✓	✓	✓
Hazardous Gas Detecting Sensor			
BMP 180 Pressure & Depth Sensor	✓		
Ultrasonic sensor	✓		
Microphone sensor		✓	
LDR sensor		✓	
Infra-Red sensor		✓	
Force sensitive resistors sensors (FSRs)			✓
IMU			✓

Table 4. Sensor usage by domains

Microcontrollers and Modules	**Safety and Tracking**	**Medical**	**Sport and Fitness**
Arduino	✓	✓	✓
Raspberry Pi 3 (R-pi)	✓		✓
HC-05 Bluetooth module	✓		✓
ESP8266 Wi-Fi Module	✓	✓	✓
GSM module	✓		
GPS receiver modules		✓	
XBee S2C ZigBee transceiver	✓		
BLE and iBeacon	✓		✓

Table 5. Micro-controller/Module usage by domains

Sr. No.	Name of the paper	Hardware Used	Software Used	Application
		SAFETY AND TRACKING		
1.	Prototyping IOT Based Smart Wearable Jacket Design for Securing the life of Coal Miners (2018) [12]	DHT 11 Temperature and Humidity Sensor, Pulse Sensor, MQ-2 Hazardous Gas Detecting Sensor, BMP 180 Pressure & Depth Sensor, GPS Module & ESP8266 Wi-Fi Shield, Arduino Mega, Toggle Switch.	Router, Dynamic Internet Protocol	It is used for the safety of coal mine workers that are prone to hazardous working conditions.
2.	Multi-sensor Wearable for Child Safety (2019) [13]	Temperature and Humidity Sensor, Heart Rate Pulse Sensor, GPS (Global Positioning System) Module, GSM Module, Alarm Buzzer, SOS Light, Arduino Uno.	Arduino IDE, SMS text, GPS tracking	It is used for ensuring child safety in which the parents can track their wards by SMS texting.
3.	Design and Development of an IOT based wearable device for the Safety and Security of women and girl children (2016) [14]	Temperature, Sensor (LM35), Triple Axis Accelerometer (ADXL335E), Skin Resistance sensor (Copper Strips), ESP8266 Wi-Fi Module, ATMega328P.	ThinkSpeak Cloud Platform, Arduino IDE, MATLAB, Weka toolkit (ML)	It is used for safety of women and girl children by continuously monitoring their physiological signals.

4.	Method and apparatus for safety using inflated bags through smart sports clothes (2016) [15]	Accelerometer, Gyro sensor, Microcontroller, Inflating bags.	--	It is used as an inflatable bag for avoiding fall damage.
5.	Autonomous Solar Smart Cap (ASSC) for pedestrian safety (2017) [16]	Atmega8, ADXL335 accelerometer, HC-SR04, Flexible solar panel, Vibration motor, SPDT switch.	Arduino IDE.	It is used to safeguard pedestrians using mobiles while walking.
6.	WE-Safe: A Wearable IoT Sensor Node for Safety Applications via LoRa (2018) [17]	ATmega328p, LoRa (RFM95 module), BME280 (Temperature, humidity, and pressure sensor), COZIR CO2 sensor, ULPSM-CO 968-001 (CO sensor), SI1145 (UV sensor), LTC3130-1 (buck-boost converter).	Arduino IDE, RadioHead Packet Radio library, LoRaWAN protocol.	It uses LoRa technology for warning people against harmful gases.
7.	A Wi-Fi Tracking Device Printed Directly on Textile for Wearable Electronics Applications (2016) [18]	Wi-Fi module, Atmega328p microcontroller, modified inverted F-antenna, CM 116-20 UV-curable dielectric ink, silver nanoparticle ink DGP 40LT-15C conductive ink.	Arduino IDE, Google Geolocation Application Program Interface (API).	It is a tracking device on clothes used to plot the location on map which can be accessed from any smart device.
8.	Application of a Modular Wearable System to Track Workers' Fingers Movement in Industrial Environments (2019) [22]	Inertial measurement unit (IMU)., LMS9DS1, produced by STMicroelectronics, and includes a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis Magnetometer. Bluetooth) microcontroller	LabVIEW	It is used to track the fingers of the workers to obtain precision movement in industrial environment and to enhance the human-robot-interaction by identifying different hand gestures.
9.	Smart Localization and Detection System for School Children [23]	Arduino Mega 2560, SIM908 GPS module with GSM and GPS antenna, Start Button, Power Switch	Arduino IDE, SMS text, GPS tracking, Google Maps	It is used for tracking and notifying the location of the children and ultimately to overcome the issues of missing children.
		MEDICAL		
10.	Health Companion Device using IoT and Wearable Computing (2016) [24]	Grove -Temperature and Heart Rate Sensor, GPS module, Wi-Fi module, Arduino	Arduino IDE, sparkfun cloud platform, GUI application.	It is used as a health companion system which can monitor health regularly.
11.	Wearable smart sensor systems integrated on soft contact lenses for wireless ocular diagnostics (2017) [25]	Contact lens Sensor (glucose sensor and intraocular pressure sensor), developed by using graphene/graphene nano-stuructures.	--	It monitors glucose and intraocular pressure from human tear fluid, which used analysis of risk factors associated with diabetes and glaucoma.
12.	Health Monitoring and Tracking System for Soldiers Using Internet of Things (IoT) (2017) [19]	LM35 Temperature Sensor, Pulse rate sensor, Grove - Gas Sensor (O_2), GPS Receiver, Arduino, Panic Button, Buzzer, 16*2 LCD display, Nodemcu ESP8266 Wi-Fi module	ZigBee, Dynamic Internet Protocol, Arduino IDE, GPS, GSM.	It is used for tracking and safety of the soldiers.
13.	Implementation of Smart	LM35 sensor, ADXL335 accelerometer	Arduino IDE,	It is used for tracking the health

	Infrastructure and Non-Invasive Wearable for Real Time Tracking and Early Identification of diseases in Cattle Farming using IoT (2017) [26]	sensors, KG181 Microphone sensor, Arduino Nano, ESP01-8266 Wi-Fi, LDR sensor, Infra-Red sensor, DHT11 Humidity sensor, MQ-02 smoke sensor	thingspeak cloud.	and milk production of the cattle.
14.	Designing Smart Wearable to measure Health Parameters (2018) [27]	Grove GSR (GSR), MLX90614 Temperature Sensor, Wi-Fi, Accelerometer, Battery, Arduino Mega 2560	Database server, Ardunio IDE, smart phone application.	It is used to monitor various health parameters like body temperature, step count, heart rate and sugar level.
15.	SensoRing: An Integrated Wearable System for Continuous Measurement of Physiological Biomarkers (2018) [28]	Heart rate sensor (MAX30105), EDA Sensor (Electrodermal activity), Accelerometer (ADXL335), Bluetooth Low Energy (BLE) mirco-controller chip.	Gazell/GZLL protocol: to connect the wireless microprocessor to a computer. Python notebook: data processing. BITalino [Plux Inc.]: to validate the performance of the system.	It is a compact and low-cost wearable ring sensor (SensoRing) used to measure one's emotional state using biosensors
16.	A novel architecture using iBeacons for localization and tracking of people within healthcare environment (2019) [21]	BLE and iBeacon, gyroscopes, sensitivity sensor, accelerometer, Mobile nodes, and smart bracelet.	RSSI, Least Square Estimation Approach, Server system	It is used for real-time tracking of patients inside the hospital.
17.	Detection and Prediction of Ovulation from Body Temperature Measured by An In-Ear Wearable Thermometer (2020) [29]	Earpiece with temperature sensor to collect temperature data	Hidden Markov Model (HMM): prediction model/algorithm	It is used for fertility monitoring and propose an effective and flexible statistical learning algorithm to detect and predict ovulation.
		SPORTS AND FITNESS		
18.	Development of IoT-Based Data Shoes for Daily Life Step Count (2018) [30]	5 force sensitive resistors sensors (FSRs), ESP8266 Wi-Fi module, Li-Po battery, ADXL345 accelerometer	Wireless communication with iOS and android applications.	It is used for human gait monitoring based on a data shoe system over the internet.
19.	A Wearable Wireless Sensor for Real Time Validation of Bowling Action in Cricket (2015) [31]	Flex sensor by Spectra Symbols, Force sensor from Interlink Electronics, RFD22102 BLE micro-controller chip	--	It is used for real time monitoring and analysis of bowling action in the game of cricket using flex and force sensors.
20.	A Wearable Sensing System for Timing Analysis in Tennis (2016) [32]	EXLs3 IMU modules/sensors (featuring 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer)	Bluetooth: transmit data to data capturing device; LCSS (Longest Common Subsequence) algorithm: for classifying the shot movement; Support Vector Machine (SVM):	It is used to capture the racket and foot movement of a tennis player, thus providing time analysis in tennis.

			step detection and classification; MATLAB: data post-processing.	
21.	A Wearable Device for Sport Performance Analysis and Monitoring (2018) [33]	STEVAL-STLCS01V1 by STMicroelectronics, BlueNRG-MS – Bluetooth low energy network processor, MEMS nanopressure sensor: 260-1260 hPa	MATLAB, artificial neural network (ANN) algorithm, BLE	It is used to assess the main Gait parameters during walking or running road-tests of athletes for better performance
22.	IoT f or Next-Generation Racket Sports Training (2018) [34]	IMU consisting of microprocessor, a MEMS motion sensing chip, an on/off switcher, a coin cell battery DA14583 radio transceiver and baseband processor for Bluetooth Low Energy	Cloud technology, and machine learning algorithms like SVM, Nearest Neighbor, Naïve Bayes.	It is used to analyze the training of racket sports of the user.
23.	Swimming Motion Analysis and Posture Recognition Based on Wearable Inertial Sensors (2019) [35]	MEMs Sensors	Hidden Markov Model (HMM): stroke and posture recognition.	It is used for stroke and posture recognition, providing analysis in swimming.
24.	Design Flow of Wearable Internet of Things (IoT) Smart Workout Tracking System (2019) [20]	ADXL345 low-power tri-axial accelerometer, HC-SR04 ultrasonic sensor, Arduino UNO, XBee S2C ZigBee transceiver, R-pi.	Ruby on Rails, Amazon AWS, RESTful API, SQLite database, WebSocket, ActionCable.	It assists the user in doing work-out or fitness exercises properly and it can keep a track on their exercises.

Table 6. Summary of Literature Review Papers

V. LIMITATIONS AND CHALLENGES

A. Power Consumption

When we talk about wearable devices, battery life and power consumption always play an important role. A user is always in need of a smart device that is long-lasting. The devices are generally rechargeable, or battery operated. In a study, it was found that devices working on BLE consume less power (approx. 3% less) than those devices working on Wi-Fi modules due to which Bluetooth communication module is preferred majorly for smart wearable devices [36]. But range of Bluetooth communication module is less which is a huge drawback in many situations. The limitations of solar operated wearables are that, they cannot be recharged if used indoors or in cloudy weather conditions.

B. Wearability and Ergonomics

The wearability and ergonomics of a wearable device are crucial factors for deciding whether to use it or not. As discussed earlier in the Physical section under User Requirements (II), a wearable device should be non-invasive, flexible, light weight and small sized for minimizing the dis-comfortability of the user. None of the function of the wearable should hinder the daily activities of the user. Heating up of the device when operated for a long time can cause irritation to the user [36].

C. Miniaturization and Integration

In the present era, we see many modern functionalities and problem-solving abilities of a wearable device like, mobile communication, music, video, tracking, and many more. All these functions and operations should be readily available in small and compact design which is a challenge to many prototypes using Arduino and other microcontroller boards. Integration of Antennas and various communication modules in the wearable device is also a challenge but there are a lot of devices which have overcome such limitations and are available in the market like Fitbit, Apple smart watches, Samsung gear etc. [36].

D. Accuracy of Sensors

Sensors are initial point in IoT architecture and if the sensor does not respond accurately to the changes in environment or health status of the user, ultimate result is affected which leads to dissatisfaction of user. So, the whole IoT ecosystem relies on data captured by sensors. Precision plays a very important role in IoT. The data gathered by sensors is stored and processed in cloud platforms. So, if the data is legitimate and precise, better results will be yielded.

E. Privacy and Security

Although IoT is changing the human-technology interaction, privacy and safety have always been major concerns in applications of IoT. The devices are becoming smarter and autonomous but are exposed to different security threats as the data resides between these smart devices. Privacy and security need to be developed as the base of IoT applications, with robust validity tests, authentication, code encryption, and all data needs to be encrypted [37]. It is important for users to have surety that their personal data is secure and will not be used against them. User trust in technology should always be first and foremost priority while designing IoT wearables.

VI. CONCLUSION

Wearable Technology is changing the way we live. Assistance of wearables in our lives is growing exponentially. In this paper, we provided a survey on most important domains that are getting influenced by the wearable technology. The reviewed papers were divided into four domains. Information on hardware and software used with applications was provided for all the papers.

The data that we get from the sensors can be made more valuable by combining various finest technologies like IoT, Machine learning and Artificial intelligence. Lifesaving applications of wearable technology in healthcare domain show its true potential. Society issues like women and child safety can be minimized by using wearable technology. New innovations are providing an optimal solution to not only social issues but also fulfilling various personal requirements. It is getting easier for athletes and fitness freaks to track and analyse their performance. Using data insights from cloud they can easily know their weaknesses and overcome them. These abilities of wearables will revolutionize the future.

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