Harnessing Power of IoT for Healthcare

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Abstract

An increase in world population along with a significant aging portion is forcing rapid rises in healthcare costs. The healthcare system is going through a transformation in which continuous monitoring of inhabitants is possible even without hospitalization. The advancement of smart sensing, embedded systems, wireless communication technologies, nanomaterials, and miniaturization makes it possible to develop intelligent medical systems to monitor activities of human beings continuously. Internet of Things (IoT) enabled wearable and non-wearable sensors monitor physiological parameters and activities continuously along with detect other symptoms such as any abnormal and/or unforeseen situations which need immediate attention. Therefore, necessary help can be provided in times of dire need. The paper will review the latest reported systems, the trends on wearable cum medical devices and smart sensing to monitor activities of humans and issues to be addressed to tackle the challenges. IoT enabled smart devices can collect, analyze and send data across the web using this technology. It can connect both, digital such as heart monitor and non-digital devices like patient beds to the internet. Harnessing the power of IoT will transform the future of the healthcare industry by providing the world with smart digital solutions at the ease of comfort of the consumers. It's a very big market that was reported to had a worth of 22.5 billion USD in 2016 and it's expected to become USD 332.7 billion by 2027.

Introduction

Advancement of high performance materials, smart sensors cum sensing technology, high speed computing, next generation internet connectivity and of course the efforts of mankind to get connected with each other has made a tremendous success on the technological revolution of Internet of Things or IoT. A wide spread of IoT enabled devices and systems have penetrated in our day-to-day life. It is quite confusing and very easy to mix up with web-based information and information from IoT enabled system. IoT enabled system provides us real-time information of any "thing" which is connected to sensor for sensing its parameters of interest to greater community. The IoT market is keep on increasing as is seen in Figure 1 (https://www.statista.com) and this number will only grow as internet connectivity begins to become a standard feature for a great number of electronics devices. Many more devices will be connected to internet in future with proliferation of next generation internets such as 5G and 6G in the rural areas making it at par with urban internet connectivity. Figure 2 shows a few medical devices which are used to keep humans safe and healthy. Many of these devices are not connected to internet yet still the global market for IoT in healthcare sector is expected to reach US$332.7 billion in 2027, growing at a rate of 13.2% from 2020 (https://www.alliedmarketresearch.com). It is important to look into different aspects of IoT in healthcare sector, many issues it faced, challenges, advantages it provides. This paper will discuss on harnessing power of IoT in healthcare sector to make a connected healthcare system for community.

Significant amount of research activities on connected healthcare is currently undergoing and a lot of technical developments has been reported in public domain in the last two decades. A remote 2-D localization (range and angular information) and vital signs, breathing rate and heart rates monitoring of multiple subjects using a single-input and single-output (SISO) frequency modulated continuous wave (FMCW) radar architecture has been demonstrated (Marco et al., 2021).

An IoT-based non-invasive automated patient's discomfort monitoring/detection system has been presented and implemented, using a deep-learning-based algorithm (Imran et al., 2021). The system is based on an IoT enabled camera device; the body movement and posture of the patient are detected without using any wearable sensors. An IoT enabled wrist-worn prototype for ambient monitoring has been reported which measures toxic/hazardous gases, noise, UV, air temperature, humidity, and pressure (Mostafa et al., 2021). In the reported platform, bidirectional communication between the end user and medics has been established in real time via IoT gateway as an intermediate hub between the wearables and the IoT server. In Charn et al. (2020), a capacitive electromyography (CEMG) monitoring system has been reported for remote healthcare applications. A wireless sensing system to monitor and analyze cardiac condition has been designed and developed (Haoran et al., 2018; Elisa et al., 2016) which sends the information to the caregiver as well as a medical practitioner with an application of the IoT. The reported cardiac auscultation monitoring system provides a way of self-managing of heart disease. Accidental falls are a major concern for the elder people; being the main cause for hospitalization and the second leading cause of unintended injury-related demises among the elder people in the world. A patient-specific fall prediction and detection prototype system utilizing a single tri-axial accelerometer attached to the patient's thigh to distinguish between activities of daily living (ADL) and fall events has been reported (Wala et al., 2019). Fall incidence will trigger an alarming notice to the concern healthcare providers via the Internet. Monitoring activities of human with wearable sensors has been in existence for a long time and is still undergoing. Using one accelerometer, it is possible to recognize daily life activities with higher accuracy based on global and local features and their integrated feature set for classifying countable and uncountable activities (Jianchao et al., 2020). Monitoring physical activities of human as well as early-stage diagnosis of a disease is important for better revival. Kidney function can be qualitatively as well as quantitatively checked by monitoring levels of creatinine in urine or serum samples. A low power IoT enabled microcontroller-associated diagnostic device has been designed and developed for the quantitative measuring of creatinine levels from serum (Sumedha et al., 2019, 2020, 2021; S. Prabhu et al., 2021).

Figure 1: The forecasted market of IoT (https://www.statista.com)

IoT in healthcare—Current situation

In our life whether at home or at hospitals/clinics, we use different types of medical devices, starting from thermometer, blood pressure monitoring devices, diabetic testing kits to surgical instruments, artificial joints, MRI scanners and many more. The medical technology (medtech) industry designs and manufactures a wide range of products to keep us safe and healthy. Technology is allowing these medical devices to generate, collect, analyze and transmit data. With all data collected and appropriately used it is possible to have a connected infrastructure of healthcare systems and services. The IoT and its relationship to medtech is instrumental in helping healthcare organizations to achieve better patient outcomes, lower climbing

Figure 2: Medical devices keeping us safe and healthy

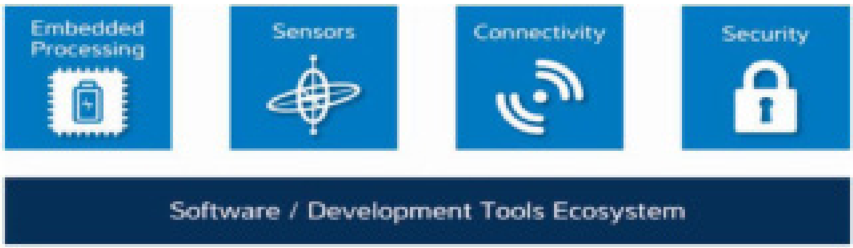

Figure 3: Basic building blocks of IoT enabled system

Figure 4: Wearable watch GARMIN FENIX 6X for monitoring health parameters

healthcare costs, improve efficiency and activate new ways of engaging and empowering patients (https://www.alliedmarketresearch.com). The Figure 3 shows the basic building blocks of any IoT enabled system which can be very well applicable for connected healthcare system. For healthcare applications, the sensors will be medical devices which measure physiological parameters as well point-of-care (POC) devices. Currently internet connectivity is usually not available with many medical devices but with time, the feature of data sharing among different devices as well as data upload in cloud for future use will be slowly included. Security will play a significant role for that to happen. Data need to be securely transmitted without any kind of breach and foul play.

Different products are now available in the market and they come in different forms of ornaments. The most common one is wearable wrist watch, one of them is shown in Figure 4. The product is GARMIN FENIX 6X problack, with current price is AUD1249.00 with a warranty period of 1 year. There are different other models available from many manufacturers. The watch provides heart rate and blood oxygen. It has both Bluetooth and WiFi connectivity. The battery life as specified is 15 to 60 hours. The electronic products consume a significant amount of power if it transmits data wirelessly very frequently. This means the watch needs to be charged almost every day depending on the rate of data transmission. The frequent charging is a major issue as people may forget as well as wearing it continuously on wrist may not be acceptable or comfortable to many people.

There are many companies involved on design and development of healthcare devices. A few of them are Biotronik, General Electric Company (GE Healthcare), Boston Scientific Corporation, Medtronic, Johnson and Johnson Services, Inc., Cisco Systems, Inc., Welch Allyn, IBM Corporation, Siemens Healthcare GmbH, Koninklijke Philips N.V. and others. Most of the current devices are not having full internet connectivity.

In terms of applications of healthcare devices whether IoT enabled or not, hospitals are the largest users of healthcare devices. They are being used for improving healthcare quality while reducing time and cost. Various applications involving healthcare devices in hospitals and clinics involve patient monitoring, X-ray machines, CT scans, and smart apps used to connect patients and doctors. The next large varieties of application of healthcare devices are In-Home Telemedicine, i.e., the devices allowing healthcare services to reach beyond the hospitals and expands their applications. The healthcare devices used On-the-Body will be a significant percentage of the total connected devices now. Smart sensors are now possible to design and build as wearable medical devices which can monitor different health parameters of subject (Muhammad et al., 2021). They can be embedded in apparel, attached to the skin, or can even be implanted under the skin providing full freedom to patients while keeping a watch on their health. The last category of application of healthcare devices are in remote areas. In cases when patients are far away from the physicians, healthcare solutions can be used as a medium to connect them with each other. It not only adds comfort to the healthcare process but also reduces the cost. It will take a significant time to that happen when all medical devices will have internet connectivity and will upload data automatically to cloud. Privacy and security is and will be a strong deterring factor against the high speed proliferation of IoT devices in society in healthcare domain. With time as the society will be more open there will be more complex situations prevail in terms of privacy and security.

IoT enabled sensors for healthcare

Research on healthcare related activities to design and develop different sensing devices for monitoring physiological parameters as well different human activities started more than a decade ago by our group. The first developed prototype system was monitoring elderly people living alone at home, especially to detect fall as shown in Figure 5a (G. Sen Gupta et al., 2007; Mukhopadhyay and Sen Gupta, 2007). The developed wearable system need to be worn 24×7 by the monitored person especially by the elderly for detecting any fall of the subject. In the event of any fall, the system will transmit a massage to the caregiver who can be a very close relatives or company representative. The required help will arrive without any significant delay so the person can be taken to hospital or provided necessary treatment. Though many research papers were reported on monitoring the person by remote system, it is not practical. The system has been extended to monitor physiological parameters such as body temperature, heart rate and body conductance to monitor well-beings as shown in Figure 5b of the person (K. Kaur et al., 2012) and end extensive review was done on wearable sensors (S. C. Mukhopadhyay, 2015; A. Nag et al., 2018). The system has been further extended to determine the Fluid Loss Measurement System using a Smart Non-Invasive way (N. K. Suryadevara et al., 2015). Research on wearable devices or simply wearable is a vibrant area of research and the wearables come in different form and sizes with more complexity.

Our early work on wearable device has been extended to monitoring emotion of a person using physiological parameters. With limited training data it was possible to achieve a success rate of 86% with four simple emotions, Angry, Happy, Sad and Neutral using classification technique as shown in Figure 6 (M. T. Quazi et al., 2012; M. T. Quazi and S. C. Mukhopadhyay, 2011). The system is especially useful for elderly under monitoring as the warning message to the caregiver will be decided by the smart system.

It has been realized that wellness of a person can be understood more deeply if the combination of wearable and non-wearable sensors is used at home to monitor the activities of the person. The system will allow to monitor the subject without using any wearable sensors while the person is staying at home but doing all normal day-to-day activities. The concept of smart homes comes into action. A smart home is sensors and technology assisted home for better living which provides a safe, sound and secured living environment for any person especially any individual lives alone at home as shown in Figure 7a. All sensors are wireless sensor, communicating the measured sensor data using wireless transceivers such as Zigbee (A. Gaddam et al., 2011; N. K. Suryadevara and S. C. Mukhopadhyay, 2012). The system may use either WiFi or LoRa or any other wireless communicating protocols.

(a) Worn on finger

(b) worn on wrist

Figure 5: Early developed wearable device for physiological monitoring

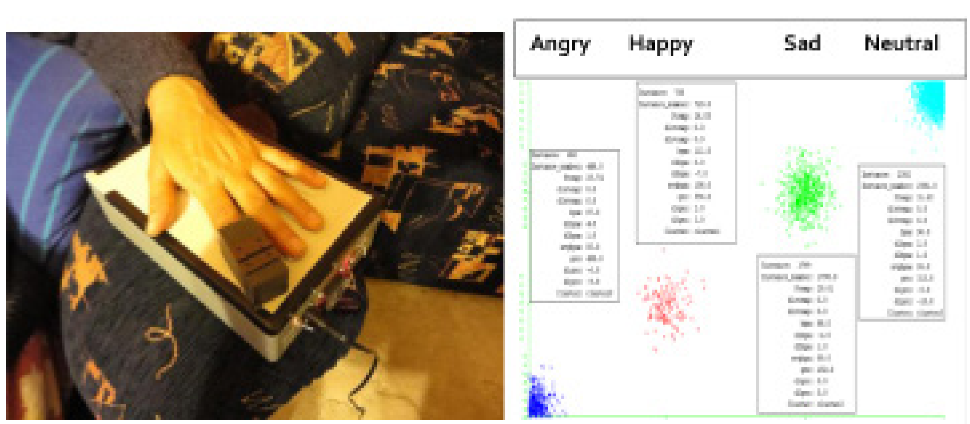

Figure 6: Human emotion recognition system

Using the concept of IoT and WSN based home monitoring system, smart home can be developed which will convert any old home to a smart home. The number of sensors and their types mostly of similar types for all subjects except a few special sensors will depend on individual's habit of lifestyle. Figure 7b shows the placement of sensors for a typical 2-bed room house. The sensors in the house consists electrical sensors for monitoring usage of any electrical appliances, forces sensors for monitoring bed, sofa, chairs, toilet, environmental sensor, contact sensor and Passive Infra-Red sensors (PIR) for monitoring movement as shown in Figure 7c. All sensors are continuously powered ON and are activated when any event takes place and transmit the data to the gateway which has been configured around a laptop (N. K. Suryadevara et al., 2012a, 2012b).

Data processing is extremely important to extract the real meaning from the measured data by the sensors for any system. An integrated intelligent system relies heavily not only on the accuracy of the measured data but also on the adaptive cum intelligent data processing. For smart home applications, different types of intelligent algorithms have been developed as shown in Figure 8. The big picture is to determine the wellness of the subject under monitoring which represent a quantitative method of healthy condition of the monitored person. The raw sensor data provides the status of the sensors which are connected to different appliances. The first task is to collect and store sensors data at near real time and then annotate them. From the active states of the sensor, the activity of the person is determined. This involves some probabilistic approach as well as matching of pattern of sequence of active status of sensors (N. K. Suryadevara et al., 2013; N. K. Suryadevara and S. C. Mukhopadhyay, 2014). Based on the collected data for previous weeks (8 weeks in our project), the future behavior of the monitored person can be forecasted as shown in Figure 9.

We develop sensors both on MEMS (Micro Electro Mechanical Systems) as well as flexible materials-based technology. Interdigital sensors of novel configurations

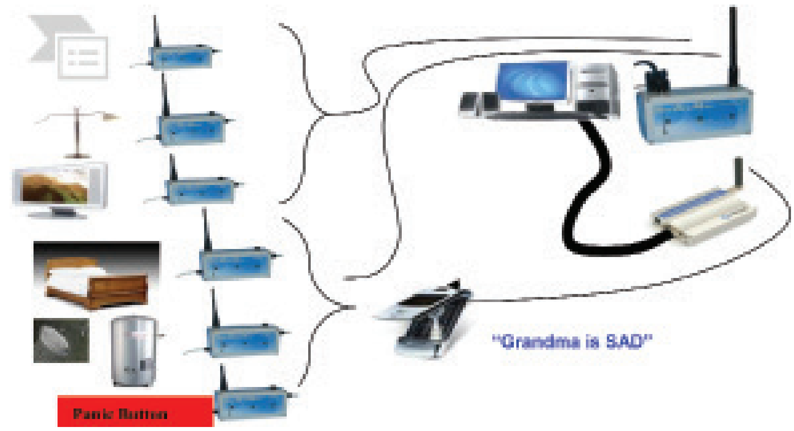

Figure 7a: Concept of smart home: sensors and technology assisted home for better living

Figure 7b: Placement of sensors in an old home to convert it to a technology assisted home

Figure 7c: Sensors used for monitoring different appliances in a smart home

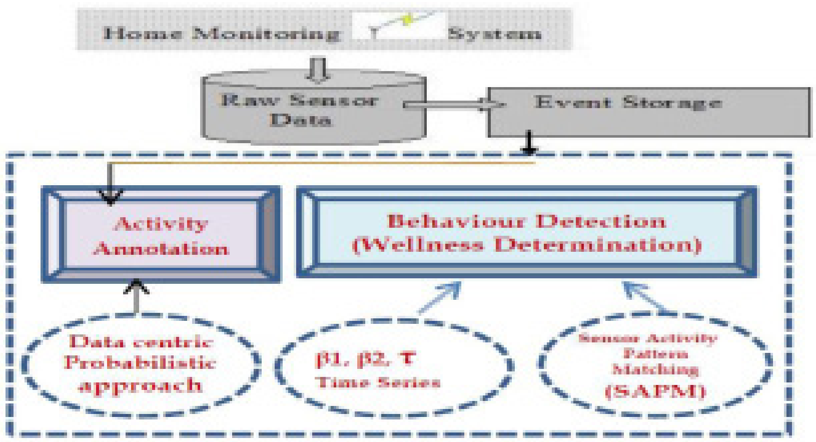

Figure 8: Intelligent data processing for smart home system

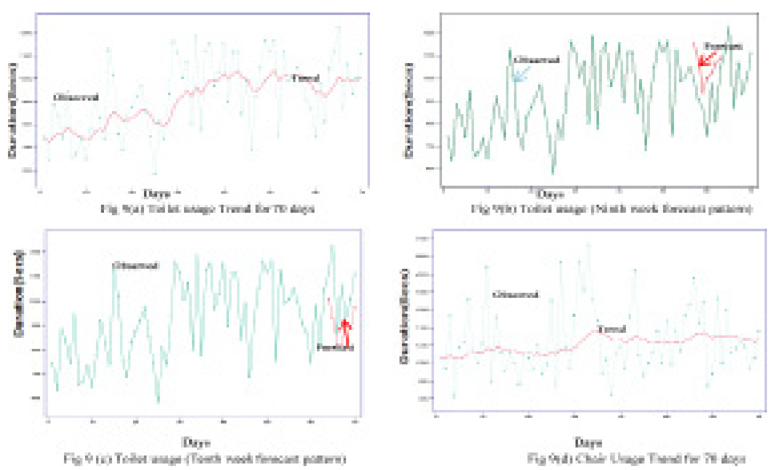

Figure 9: Data analysis and forecasting of results

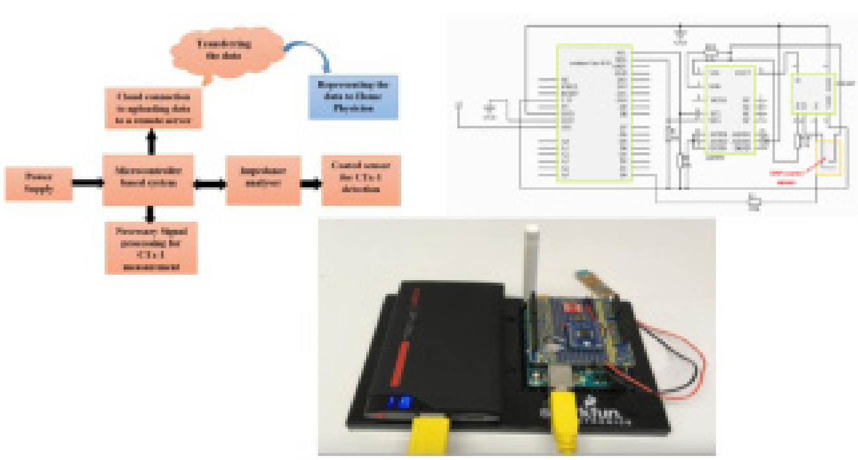

Figure 10: IoT enabled point of care device for early detection of osteoporosis

has been designed and fabricated for higher sensitivity. Molecular imprinted techniques based coating materials have been developed to introduce selectivity.

IoT enabled point of care devices have been developed for early detection of osteoporosis as shown in Figure 10 (Nasrin et al., 2018a, 2018b). The current system is based on blood sample with the C-terminal telo-peptide type I collagen (CTX-I). Research is currently undergoing to develop robust sensor which can detect CTX-I from urine and the sensor can be installed at the toilet to covert the toilet to a smart toilet as shown in Figure 11 (Nasrin et al., 2018c, 2018d).

Significant researches have been conducted which indirectly help to keep our health safe and sound. The sensor for evaluation of amount of fat content in meat has been reported (S. C. Mukhopadhyay and C. P. Gooneratne, 2007). The effect of biotoxin in seafood can be dangerous for human health and a sensing system has been designed and developed (A. R. Mohd Syaifudin et al., 2009; Mohd Syaifudin Abdul Rahman et al., 2011), detection of phthalate from plastic bottles (Asif et al., 2013, 2015) and detection of LPG gas to avoid explosion in kitchen (Nag et al., 2016a, 2016b) and detection of nitrate in contaminated water (Md. Eshrat et al., 2017, 2018a, 2018b).

Opportunities and challenges of IoT for healthcare

The IoT enabled healthcare systems provide an enormous opportunity to individual, family and society. It is not only able to monitor the current health condition or future heath situation but also the technology can be used for many other situations. The whole world is now at the hands of coronavirus pandemic (COVID-19) and we are extremely fortunate that the developed vaccine is effective against the COVID-19 virus. Significant researches have been taken place to develop different wearable system to address the challenges posed by COVID-19. An autonomous hand hygiene tracking combining different IoT technologies, which can be applied in healthcare environments to monitor hand hygiene activities and better prevent hospital associated infection has been designed and developed (Fan et al., 2021). The system can record hand-washing activities and provide prompt feedback if the hand-washing is not performed as required using wearable devices and smart dispensers. A smartphone based app has been

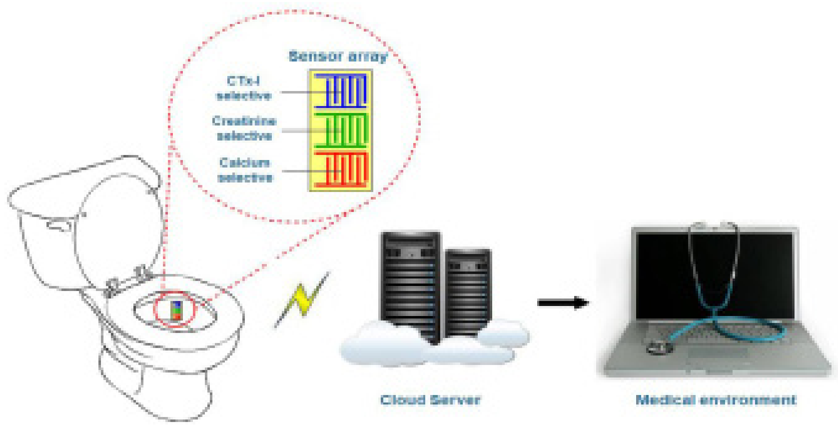

Figure 11: Smart toilet for future

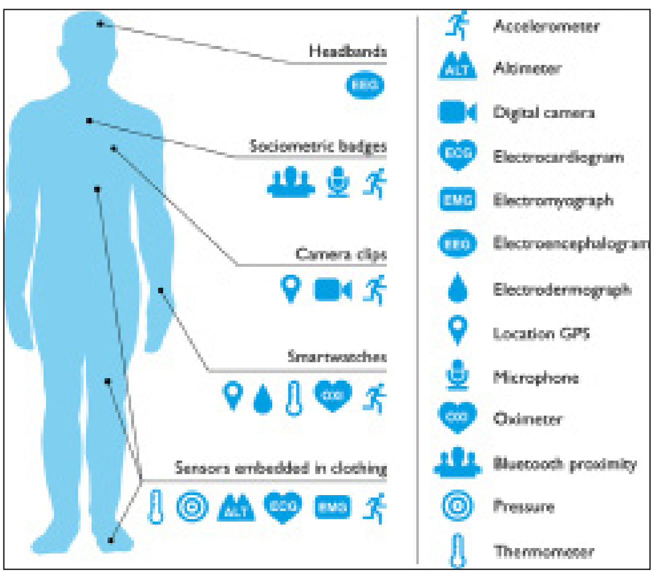

Figure 12: Different wearables on human body

developed which collects smartwatch data and activity tracker data along with self-reported symptoms and diagnostic testing results. Analyzing the personal data collected over time it is possible to identify subtle changes indicating an infection, such as patients with COVID-19 (G. Quer et al., 2020). The paper (Itamir et al., 2021) aims to extend the platform by integrating wearable and unobtrusive sensors to monitor patients with coronavirus disease. Furthermore, the researcher has reported a real deployment in an intensive care unit for COVID-19 patients in Brazil. When a huge amount of data is involved, machine learning will play an important role to analyze the healthcare data as well for prediction any future possibility (Hemantha et al., 2021). In future there will be varieties of wearable used for monitoring human activities as shown in Figure 12 which will provide a great deal of opportunities (Jeong-Hyeon Bae and Hyun-Kyung Lee, 2018).

In terms of the architecture of the connected healthcare system, the most important thing after the collection of data is to store them safely. The proposed architecture is shown in Figure 13. Different sensors will measure different parameters indicating status of human condition and will be collected by doctors, nurses, caregivers and other people. The common point of data collection will be the cloud and all devices need to be IoT enabled to make it happen.

Till the time the cloud for connected healthcare data is made possible, it is heartening to note that individual can upload their activities through various Apps. One of such Apps is Health app available in smart phones. The activities such as walking cum running for the month of September for myself is shown in Figure 14. The apps can accept many parameters though some of them are to be entered manually. If all activities of an individual are noted with time of the day as baseline, it will be possible to know wellness of the subject.

There are many challenges impacting widespread usage of IoT in healthcare applications. There is a need of change of funding, business and operating models. Innovation will require different business models, and progress will depend on both the innovators themselves working in new ways to take on risks and rewards. The next issue is the interoperability to work effectively, the direction of development should be towards open platforms, based on open data standards. This will enable researchers, providers and technology vendors to come together to make data more available to each another. The next item is cyber security—the increasing numbers and capability of connected healthcare devices present additional risks for data security. The scale and cost of breaches is often significant and far reaching. Though not a big challenge but the society and government also need to think of digital talent and building digital capability—there is increasing concern among key stakeholders that a growing skills gap will delay the deployment of IoT enabled healthcare solutions and constrain market growth. We also need to think of maintaining trust in a digital age—as medtech companies develop strategies and services based on the generation and transmission of patient data, they need to ensure they demonstrate clearly to patients, the public and healthcare professionals how their data is being used to reduce the risk of undermining the benefits that access to data can bring. The

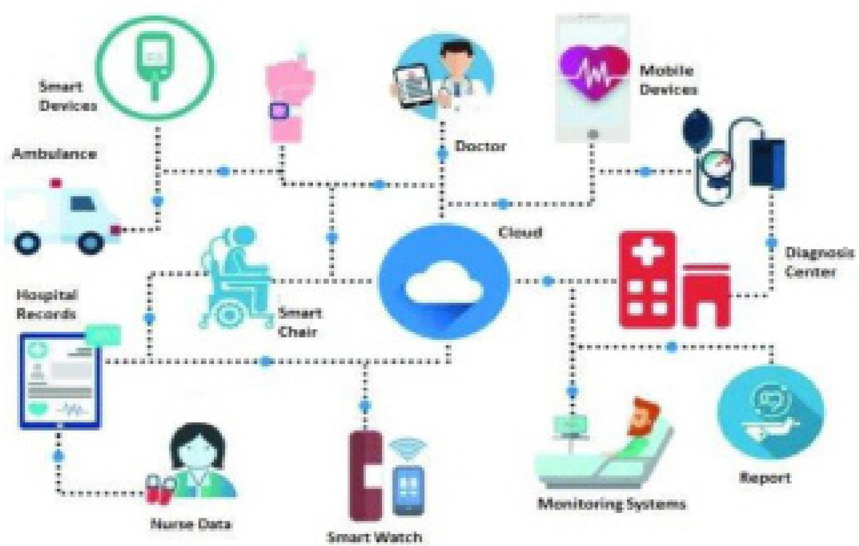

Figure 13: Architecture of connected healthcare system

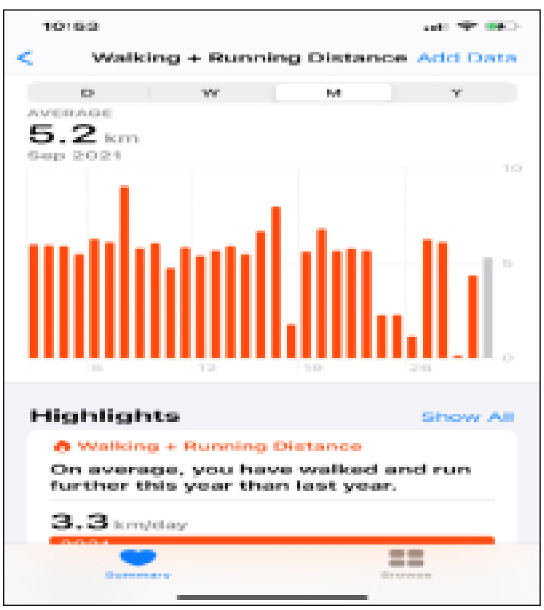

Figure 14: Collection and storage of activity data through health apps

last one is scale—a challenge for medtech companies is to ensure that healthcare organizations, clinicians and patients understand the added-value of connected medical devices and use them at scale to drive better economics and patient outcomes. Affordability of smart phone by everyone may not be financially possible so it will hinder the prospects of using it. The biggest challenge humanity is facing and will continue to face against the harnessing of full power of IoT and its widespread usage in society is the security, trust and privacy issue. Though a significant amount of research activities has taken place and continue to do so to make cyber system, wireless communication fully secured (Guanglou et al., 2018, 2019), there are many incidents happened around us. Many new ways will be developed by dishonest people to cheat common people and the society will pay price for that. The design of security in an IoT system must follow a systematic approach and should be very robust against any intrusion (S. Pal et al., 2020). Along with design and implementation of robust security system, it is more important to make aware of common citizens of the country different ways to the technologies are misused by bad people and consequences it brings. It is extremely important to know for every citizen that private information such as bank account, birth day etc. should not be shared with anyone over phone. If any fake emails or text messages come from someone who is unknown, they must be ignored. Overall, to have the real harness of power of internet connectivity and IoT, there is a need of more community engagement.

Conclusions

A connected healthcare system will offer many advantages for any individual as well as for the whole community and it is only possible to make it happen if the full potential of IoT for health sector is properly harnessed. Researchers throughout the world are developing varieties of medical devices for keeping us safe and healthy but a concerted effort is required to make it happen to extract all advantages and positive power of IoT for the humanity. The effort towards making an open platform for IoT and its availability to everyone will further enhance the pace of development. Though the biggest challenge any individual and society is facing is the issue of privacy and security, there will be some way of avoiding those issues to a certain extent. The on-going research on cyber-security will definitely make the IoT a much stronger and secured for future applications.

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COVID-19 Technology Access Pool

In May 2020, the World Health Organization (WHO) and partners launched the COVID-19 Technology Access Pool (C-TAP) to facilitate timely, equitable and affordable access of COVID-19 health products by boosting their supply. C-TAP was launched in partnership with the Government of Costa Rica, under a global Solidarity Call to Action endorsed by nearly 40 Member States. WHO C-TAP implementing partners include the Medicines Patent Pool, Open COVID Pledge, UN Technology Bank and Unitaid. Developers of COVID-19 health technologies and holders of related knowledge, intellectual property and data are invited to "share their intellectual property, knowledge and data, and join the Solidarity Call to Action."

The C-TAP provides a platform for developers of COVID-19 therapeutics, diagnostics, vaccines and other health products to voluntarily share their intellectual property, knowledge, and data, with multiple quality-assured manufacturers through public health-driven voluntary, non-exclusive and transparent licenses. This enables manufacturers that currently have untapped capacity to produce COVID-19 health products by giving them the legal rights to manufacture and sell the products; the technological know-how required to develop high-quality products effectively and efficiently; and access to clinical data needed to obtain regulatory approval for their products.

By sharing intellectual property and know-how through the pooling and these voluntary agreements, developers of COVID-19 health products can facilitate scale up production through multiple manufacturers that currently have untapped capacity to scale up production.

Developers of COVID-19 health technologies and holders of related knowledge, intellectual property and/or data are invited to voluntarily share with C-TAP by joining the Solidarity Call to Action. C-TAP works through its implementing partners to facilitate timely, equitable and affordable access to COVID-19 health technologies.

For more information, access:

Email: CallToAction@who.int

https://www.who.int/initiatives/covid-19-technology-access-pool