

A Survey on Affordable Internet of Things (IoT) Enabled Healthcare Systems

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Abstract—Internet of Things (IoT) started as a concept to connect simple devices which would enable them to communicate with each other without any human intervention. IoT has become ubiquitous in various technologies and networking ecosystems which has evolved. With the advent of IoT, these systems have been elevated into “Smart Systems”. The healthcare sector is ever-evolving that is making the dream of curing incurable diseases a reality, due to these advancements there is an adverse effect on the cost and accessibility of the services. With the integration of IoT in this field, the concept of the Internet of Medical Things (IoMT) has come into existence. IoMT creates a network of smart healthcare devices that can provide cost-effective services along with the transmission of the medical data, making the prospect of remote monitoring a reality and improving the quality of life. The survey provides an insight into some inexpensive IoMT devices that utilize simple system architectures and networking models. This paper discusses the prospect of using microcontrollers interfaced with various sensors that record and transmit the data through the aggregator using networking protocols that can help in creating cost-effective and efficient healthcare devices.

Index Terms— Internet of Things, Smart Systems, Healthcare, Internet of Medical Things, Networking, Microcontroller, Cost-Effective and Efficient.

I. INTRODUCTION

Healthcare devices have become an indispensable factor in the health sector around the world. This has been especially true for the ever-changing socio-demographic and epidemiological world that we live in. The requirement for stable healthcare monitoring has led to major advancements in the healthcare sector in recent times. People are leaning more towards technology and healthcare devices in this day and age. This is because these devices can help in the detection and treatment of ailments that were once thought to be incurable. Proper healthcare monitoring can also lead to a decreased rate of mortality as it can help in addressing a problem before the patient's condition deteriorates. Health care in recent times is extensively contingent on technology [1]. With the introduction of development boards such as Raspberry Pi, NodeMCU, ARM-based microcontrollers, Arduino etc, there has been a surge in the field of low-cost medical devices which are widely accessible and help in the early detection of a patient's condition before needing critical care. A range of uncomplicated and cost-effective quality measures that have the potential to improve the outcome considerably without the necessity for expensive equipment have led to the extensive use of these devices in healthcare sectors around the world. The progression of the internet has helped in the instantaneous transfer and receiving of data with global coverage. This has led to the rise in the popularity of devices that can interface with the internet which has resulted in the

inception of the Internet of things as a field of technology that has gained massive popularity due to its ability to operate the data remotely which can, in turn, allow the user to control it over the internet or automate it.

Internet of things is the field wherein devices all over are interfaced with the internet. This interaction helps in the propagation of information gathered by devices to a target system over the Internet. Internet of Medical Things (IoMT) is a classification of IoT wherein medical devices are connected to the central healthcare database over the air using the internet. IoMT can help in the rework of current medical monitoring systems used across the world. By utilizing IoMT devices' the healthcare professional can keep a track of the patient's health condition in real-time in person or remotely which will greatly mitigate the risk of encountering severe health conditions in future. This record of the patient's condition can be by the professional to better diagnose future health conditions or use this record as a resource to help treat other patients with similar health conditions.

Internet of Medical Things (IoMT) is shaping up the healthcare industry by increasing the accuracy, reliability, efficiency of healthcare devices. A formidable challenge in the health care sector is to find the ideal balance between low- cost systems and the needs of growing populations with the evolving disease burden while also providing a sustainable service. In the Internet of Medical Things(IoMT), these devices provide a cost-effective and accessible alternative to conventional healthcare systems.

II. SYSTEM ARCHITECTURE

A. MicroController Unit

The microcontrollers have radically improved the technology-driven revolution that has reformed the current generation. Microcontrollers are economical, compact and versatile devices which can be implemented and programmed by professionals as well as non-specialists. It controls the flow of information depending on the instructions given by the user to the microcontroller unit through a programming language. Microcontrollers comprise the Central Processing Unit (CPU), Flash Memory (ROM), Input/output(I/O) Ports, Universal Asynchronous Transmitter and Receiver (UART), Serial Bus Interface and Random-Access Memory (RAM).

Arduino Arduino is a platform widely used for creating low-cost systems that are purpose-built adhering to use case scenarios. Among the Arduino family, the most commonly used development board is the Arduino UNO which uses the ATmega328P as its microprocessor along with 32KB of FLASH memory, 2KB of static RAM and 1KB of Electrically Erasable Programmable ROM (EEPROM).

Raspberry Pi Raspberry Pi is a platform based on Advanced RISC Machines (ARM) which is a cost-effective and miniature-sized system. One of the recent boards that are being used commonly is the Raspberry PI 4, it comprises the ARM Cortex-A72 (x64) microprocessor with four cores clocked at 1.5 GHz with an SDRAM size of either 2GB/4GB/8GB based on the system clocked at 3200MHz.

ARM7LPC2129 ARM7LPC2129 is a 32-bit microcontroller from the family of ARM7 microcontrollers. This RISC Microcontroller has support for thumb extensions and comprises 256KB on-chip Flash ROM, CPU that has a frequency of operation of 60 MHz, 16KB of RAM, on-chip PLL and on-chip crystal oscillator. It also comprises a 10-bit ADC for data conversion.

NodeMCU ESP8266 NodeMCU is a platform that is based on the ESP8266 microcontroller which expands the base ESP8266 module's interfacing capabilities to 16 GPIO pins. ESP8266 utilizes the Tensilica Xtensa L106 microprocessor which is a 32-bit RISC CPU (reduced instruction set computer) clocked at a base frequency of 80 MHz with data RAM of 96 KB and boot ROM of 64 KB. Due to the presence of an on-board WiFi (IEEE 802.11 b/g/n) antenna that operates at 2.4 GHz, this microcontroller is commonly used in low powered IoT devices .

ATMEL 89s52 ATMEL 89s52 is an 8-bit microcontroller with 8K bytes of Flash storage and 256 bytes of RAM. It operates in the frequency range of 0 to 33MHz. This is a powerful microcontroller that is also cost-effective. It contains 32 GPIO lines for peripheral interfacing and also contains a total of three 16-bit counters.

B. Sensors

A sensor is a device that utilizes the changes in the surroundings as input to generate a corresponding electrical output. The electrical signals obtained as output are processed through an Analog to Digital Converter (ADC) resulting in the output being in binary which can be further processed by the microprocessor that it is interfaced with. This data is then used by the aggregator in the system and the values received from the healthcare system are transmitted to the destination.

Some of the commonly used sensors are:

Temperature Sensor One of the most common yet most useful sensor when approaching healthcare monitoring systems. Some of the typically used sensors for temperature monitoring are DHT11, DHT22, DS18B20, LM35 etc. The temperature sensors are interfaced with the central aggregator and the data is transmitted to the receiver device through the internet.

Optical Pulse Sensor The heart (or) Pulse rate sensing module is a light-based sensor that works on the law of reflection of light. This sensor detects the pulse rate in the body and relays it to the end receiver with the transmission protocols used by the aggregator. Some of the typically used heart (or) pulse rate sensors are SEN11574 and KG011.

ECG Sensor ECG is an approach to estimate the heart rate using sensors, that are tethered to the body, which send an electrical impulse to track the rhythm of the heart that is recorded in beats per minute. These sensors can be useful to detect some underlying heart conditions. One of the typically used ECG Sensors for low powered devices is the AD8232.

Vibration Sensor A vibration sensor is also known as a piezoelectric sensor that is based on the principle of conversion of mechanical energy to electrical energy, it outputs an electrical pulse when it detects any fluctuations in acceleration or movement.

Humidity Sensor A humidity sensor is a component that estimates the environmental humidity and generates an electrical impulse that is in accordance with the value of the humidity. Relative Humidity is a measure of humidity wherein the temperature plays a key role in the determination of the humidity. The signal obtained is processed further by the ADC and passed onto the microprocessor. Some of the typically used sensors for measuring relative humidity are DHT11 and DHT22.

Blood Pressure Sensor The Blood Pressure sensor employs an Oscillometric algorithm to provide the ratio between the systolic and diastolic pressure. The blood exerts pressure on the veins to help the sensor attain the data. The sensor makes use of an inflatable arm cuff for data acquisition.

C. Wireless Protocols

IoT as a field of technology is thriving due to the advancements in the wireless sector leading to the integration of the internet with many devices that were previously lacking the ability. With the evolution in the field of networking, wireless networking has become the industry standard due to its ability to transmit data between any two points around the globe seamlessly. This has been achieved with the help of inventions in wireless protocols like Wi-Fi (IEEE), z-wave, Zig-Bee, Bluetooth, Bluetooth low energy etc. IoT utilizes the machine to machine (m2m) mode for the transfer of data without requiring any human intervention.

Wireless LAN (IEEE 802.11) Wireless Local Area Network (WLAN) or Wi-Fi is a communication protocol that is established on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. Wi-Fi has come a long way since the first iteration wherein the data transfer speed was restricted to 1-2 Mbps and the frequency band was 2.4 GHz to the latest version Wi-Fi 6E where the data transfer speed can reach 9608 Mbps and frequency bands can operate at 6 GHz.

Z-Wave (ITU-T G.9959) Z-Wave is a wireless communication protocol that is based on the International Telecommunication Union – Telecommunication (ITU-T) G.9959 standard. Z-Wave protocol utilizes mesh network topology in order to facilitate a two-way medium for communication. It operates in the 865.2 MHz – 926 MHz frequency range and has a data transfer rate of 9.6 kbps, 40 kbps or 100 kbps based on the model of the central chipset. Z-wave can include a total of up to 232 devices in its network.

ZigBee (IEEE 802.15.4) ZigBee is a wireless protocol that operates on the IEEE 802.15.4 standard. It is commonly used for low powered devices requiring a low rate of data transmission. It functions in the 2.4 GHz wireless band and offers a data rate of up to 250 kbps. ZigBee has a field of operation with a radius of 100m without any interference.

Bluetooth (IEEE 802.15) Bluetooth is a wireless standard that is established on the IEEE 802.15 standards. Bluetooth offers transmission of data over short ranges over a frequency band of 2.4 GHz. Since IoT devices inherently require less data throughput and higher power efficiency, Bluetooth low energy (BLE) came into existence using the same IEEE 802.15 standards but adapted for IoT specific applications.

Cellular Network protocols (CDMA/GSM/LTE/VoLTE) Cellular networks help in the transmission of data over very long distances, classifying them as wide area networks (WAN). There have been many versions and advancements in the cellular network field. It has moved a long way since the earlier versions of CDMA that supported 2nd Generation (2G) speeds of about 5 kB/s to the latest iteration 5th Generation (5G) where the speeds can reach up to 1Gbps.

III. NETWORKING MODEL

To get a better understanding of these protocols, networking models were proposed. There are a number of different network models among which there are two widely accepted networking models namely Transmission Control Protocol/ Internet Protocol (TCP/IP) and Open System Interconnection Reference Model (OSI -RM). A networking model is theoretically established as a stack of layers wherein each layer consists of various protocols depending on its respective functions. A network model reflects the implementation of sequential communication bridging two systems. TCP/IP model has been the building block of every connected device due to it being the model that was utilized to develop the internet whereas the OSI model was established to accommodate the different networks that were created after the dawn of the internet helping them overcome the problems of interoperability.

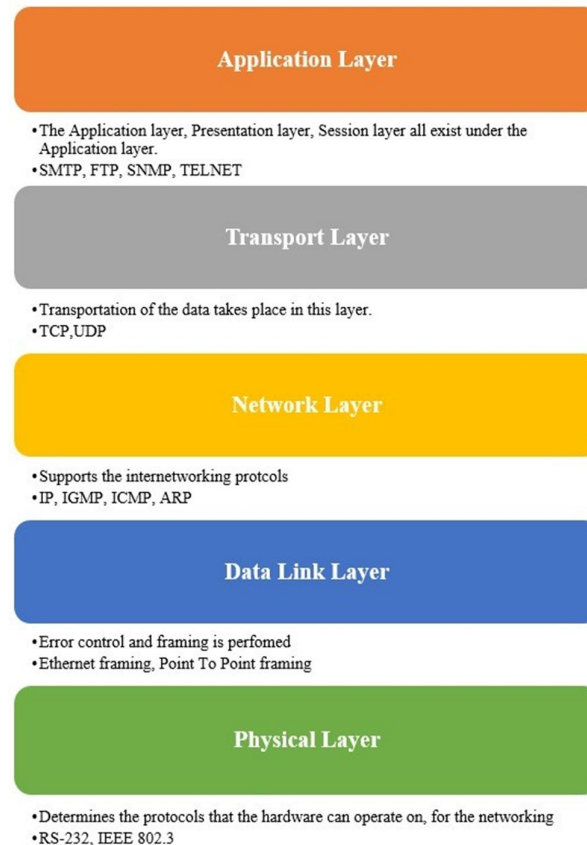


Fig. 1. TCP/IP Networking Model

TCP/IP TCP/IP model was first implemented/established using 4 layers which are Application layer, Transport layer, Internet layer and link layer in a hierarchical order (see Fig. 1). Due to the introduction of new protocols which consisted of both wired and wireless mediums, the link layer was further segregated into the data link layer and physical layer which has become the current standard for the TCP/IP networking model [2].

OSI Open system interconnection (or) OSI model was implemented using 7 layers which are Application layer, Presentation layer, Session layer, Transport layer, Network layer, data link layer and physical layer in a hierarchical order (see Fig. 2). It defines the flow of data through various layers in the networking model and helps in the segregation of large data blocks/protocols/hardware through various layers based on the respective functions [2].

IoT MODEL With the development of new protocols in the field of networking in IoT, many industries are leaning heavily on these wireless standards for their ease of access and user experience which has led to the introduction of new networking models that supports these new standards. Among these models, the widely accepted model is the 5-layer model as shown in Fig. 3. The model consists of the Business Layer, Application Layer, Middleware Layer, Network Layer and the Perception Layer [11].

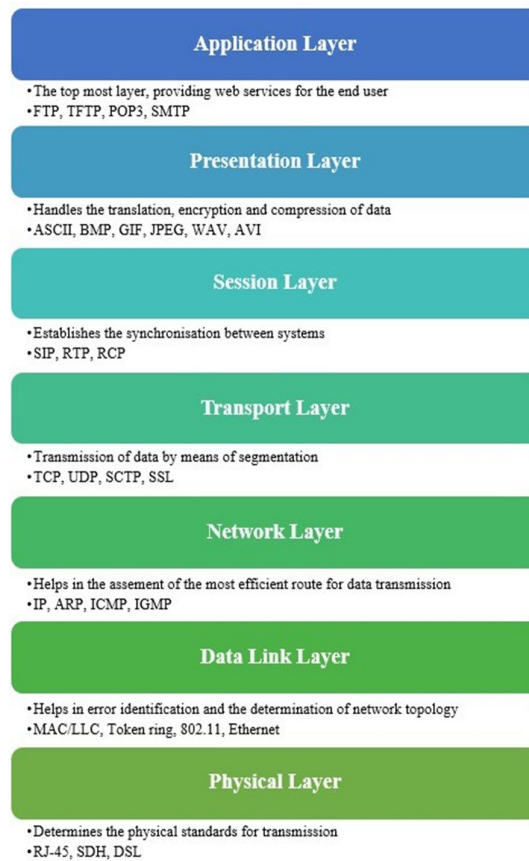


Fig. 2. OSI Networking Model

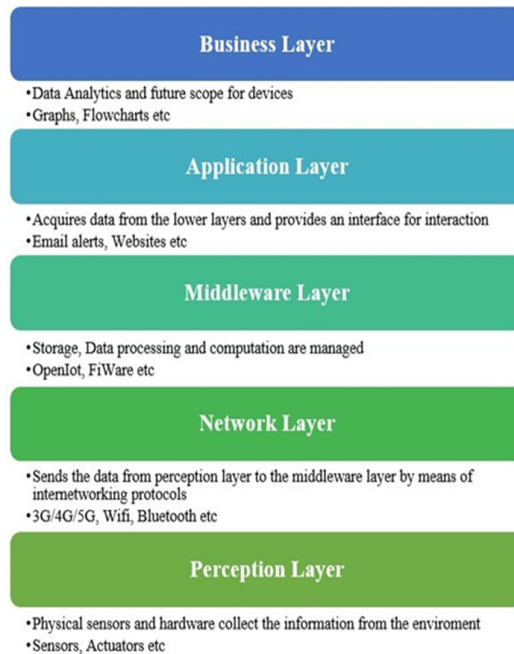


Fig. 3. IoT Networking Model

IV. LITERATURE REVIEW

D. A. M. Budida et al. [3] have proposed a smart IoT healthcare monitoring system that comprises the ATME89s52 microcontroller as an aggregator. This system promises to establish a methodology to monitor health by the means of interfacing pulse and temperature sensors and provide an emergency alert system in case any abnormalities are detected. This data is relayed to a MySQL database for storage which can help the doctors to access the patient's records through the server.

Mudiyanur et al. [4] have implemented an inexpensive healthcare system that continuously monitors the patients health which is achieved via a raspberry pi module that is interfaced with an ECG module, GSM module, buzzer and utilizes MySQL database for storage of the patient's records. Since the raspberry pi is interfaced with a GSM module, during the processing of data, if any aberrancy is detected, a buzzer is raised and an emergency alert is dispatched to the medical personnel.

TABLE I. SURVEY COMPARISON OF SENSORS

Microcontroller Unit/Papers	D. A. M. Budida et al.	Mudiyanur et al.	Siam et al.	P. Singh et al.	Akhila V et al.	M. Pereira et al.	Banka et al.
Heart rate	✓	×	×	×	✓	✓	✓
ECG	×	✓	×	✓	×	×	×
Temperature	✓	×	×	×	✓	✓	✓
Blood Oxygen Saturation	×	×	✓	×	×	×	×
Blood Pressure	×	✓	×	×	✓	×	✓
Body fat	×	×	×	×	×	✓	×
Vibration	×	×	×	×	×	×	✓

Siam et al. [5] have designed a smart and secure IoT system that records the vital signs of patients. The system consists of the MAX30102 sensor which senses the blood oxygen saturation and measures the heart rate and the DS18B20 sensor that is used for detecting the temperature of the patient. This system is based on a 3-tier architecture consisting of the patient layer, cloud layer and the doctor/medical unit layer. The data transmitted by the NodeMCU to the cloud is encrypted using the Advanced Encryption Standard protocol for the secure and safe transmission of private data. The healthcare personnel can access this data through the server using a dashboard for further treatment.

P. Singh. et al.[6] have developed an IoT based healthcare system for the re- mote monitoring of patient healthcare information like heartrate readings using a Raspberry pi interfaced with an Arduino UNO which acts as an ADC for the raspberry pi. An AD8232 ECG Sensor is used for the measurement of the heart rate of the patient. The data is transmitted using BLUEMIX which is an IoT cloud platform that works on the MQTT protocol. This data can be accessed by the medical staff with valid authorization, this helps secure the data more efficiently.

Akhila V et al.[7] have designed a Patient Health Monitoring System (PHMS) based on Internet of Things utilizing the Arduino Uno which acts as an aggregator that collects data from various sensors for health monitoring like temperature, heart rate and blood pressure sensor. An ESP8266 module is interfaced which facilitates the Arduino board with Wi-Fi capabilities. The acquired data is processed and sent to THINGSPEAK, which is an IoT cloud platform for data storage and analytics. This enables the healthcare personnel to maintain and visualize the patient's biomarkers.

M. Pereira et al.[8] have proposed an IoT healthcare monitoring system that utilizes the AD8232 heart rate sensor, a temperature sensor that are connected to an ARM7 LPC2129 microcontroller. They have uniquely implemented a body fat measurement sensor, comprising of optical isolator and a control amplifier, which can further aid the healthcare professional to know about the physique of the patient and provide treatment accordingly. The data from the sensors is processed by the ARM LPC2129 microcontroller that is displayed on an LCD screen and exported to a MySQL database for further monitoring by the medical professionals.

TABLE II. SURVEY COMPARISON OF MICROCONTROLLERS

Microcontroller Unit/Papers	D. A. M. Budida et al.	Mudiyannur et al.	Siam et al.	P. Singh et al.	Akhila V et al.	M. Pereira et al.	Banka et al.
Arduino	✗	✗	✗	✓	✓	✗	✗
Raspberry Pi	✗	✓	✗	✓	✗	✗	✓
NodeMCU	✗	✗	✓	✗	✗	✗	✗
ESP8266	✗	✗	✗	✗	✓	✗	✗
Atmel	✗	✗	✗	✗	✗	✗	✗
ARM7	✓	✗	✗	✗	✗	✗	✗
Arduino	✗	✗	✗	✗	✗	✓	✗

Banka Et al.[9] have designed developed a healthcare monitoring kit that can be used in remote areas that lack healthcare services. The kit consists of a temperature sensor (LM35), heart rate sensor, Blood Pressure sensor that sends data to the raspberry pi microcontroller that is integrated with an ADC(MCP3008) for the conversion of data from Analog to Digital. The system is interfaced with a GSM module that enables it to access the database over the air even in remote areas. The data is sent to a MySQL database where it is analysed and stored. Data mining techniques can be employed which can help in the early detection of ailments that can then be treated accordingly.

TABLE III. SURVEY COMPARISON OF DATABASE SERVICES

Database Service/Papers	D. A. M. Budida et al.	Mudiyannur et al.	Siam et al.	P. Singh et al.	Akhila V et al.	M. Pereira et al.	Banka et al.
MySQL	✓	✓	✓	✗	✗	✓	✓
Bluemix (IBM)	✗	✗	✗	✓	✗	✗	✗
Thingspeak	✗	✗	✗	✗	✓	✗	✗

V. CONCLUSIONS

The prevailing research in the field of IoMT acknowledges the necessity for more efficient and personal solutions that could improve the overall wellbeing of the patients and help the medical personnel by streamlining the process. The field of IoMT has an influx of various proprietary solutions leading to a market of non-interoperable systems and services despite utilizing similar communication standards. This survey provides an analysis of the rising field of low-cost IoMT solutions and their application scenarios by studying different architectures of systems and networking protocols that provide a platform for the exchange of medical data. The healthcare industry is continuously evolving and this paper offers an insight into the ongoing research in this field consisting of various systems and technologies in order to provide affordable and proficient IoMT devices with healthcare services with a limitless potential due to the advent of IoT.

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