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Real-Time Cyber-Physical System for Healthcare Monitoring in COVID-19

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ABSTRACT

The cyber physical system (CPS) is used to integrate physical processes with computation and communication. Recent advances in internet of things, cloud computing, and machine learning are making the cyber physical system an emerging technology in the healthcare system. This paper presents a real-time cyber physical system framework for healthcare monitoring system that plays a major role in pandemics such as COVID-19. The system processes real-time patient critical data such as blood sugar, blood pressure, and temperature used to save the lives of patients. The real-time processing is done at the sensor node using real-time tasks scheduling. The sensor node data gets analyzed on fog nodes taking time-critical actions. The healthcare data is then sent using Kafka real-time streaming using Kafka pipeline. The processing of healthcare data using Spark in real time is done using the Hadoop distributed file system (HDFS) on the cloud.

KEYWORDS

Cloud Computing, Cyber Physical System (CPS), Fog Computing, Hadoop Distributed File System, Real-Time System, Spark

INTRODUCTION

As of now, the world is confronting the most genuine worries in human services including the ascent of human services costs, the development of maturing populace and the rise of new chronic and pandemic decease such as Covid-19. Recent advancement in computation and communication technologies Cyber physical system plays an important role in healthcare system. Cyber physical system also called as smart system connects physical world with the computational component i.e. cyber world using communication technologies which result in smart services and improve quality of life. Cyber physical system is used variety of application including medical and healthcare system, automotive, transportation, emergency response system, intelligent manufacturing and production, sustainable development and many more(Alamri et al., 2013).

Role of Cyber Physical System in Medical and Healthcare Services

Research of cyber physical system in healthcare is requiring for implementation of smart medical and healthcare service. Cyber physical system research in healthcare is in its starting phase. Cyber physical system in smart healthcare system consist of patient monitoring and real time control and feedback system, patient and doctors digital record storage and real time analytics for decision making . Cyber physical system in healthcare system used to coordinate and management of adaptive medical

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devices(Hackmann et al., 2014)[3]. Many cyber physical system architecture is presented past but very few presented in the field of healthcare application. Cyber physical system using service oriented architecture. Cloud and wireless sensor network based integrated architecture for cyber physical healthcare system. Cyber physical system for patient healthcare using artificial intelligent is proposed in several research article(Jindal & Liu, 2012)[5]

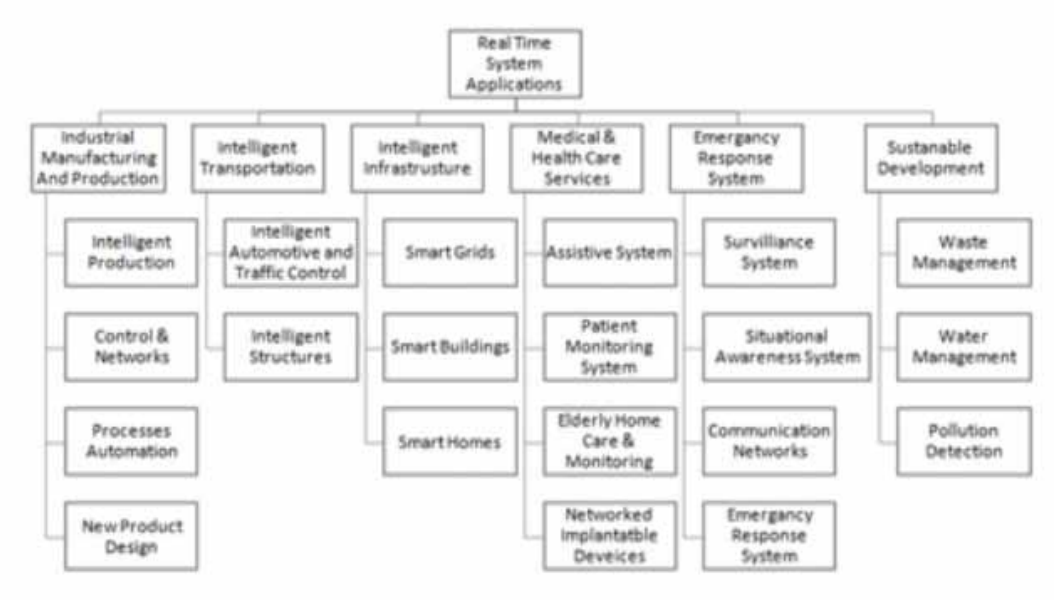
Real Time Cyber Physical System in Healthcare

Real time operation and scheduling required in different monitoring and control tasks in cyber physical healthcare system. Implementation of timing constraint in cyber physical healthcare system is challenging because of following:

- The real time tasks in cyber physical healthcare system having different release time and deadline as the computing nodes location and physical movement is different
- The real time tasks having hard deadline, missing dealing will be result in loss of lives

Figure 1. shows the real-time cyber physical system application domains.

Figure 1. Real Time Cyber Physical Systems Domains

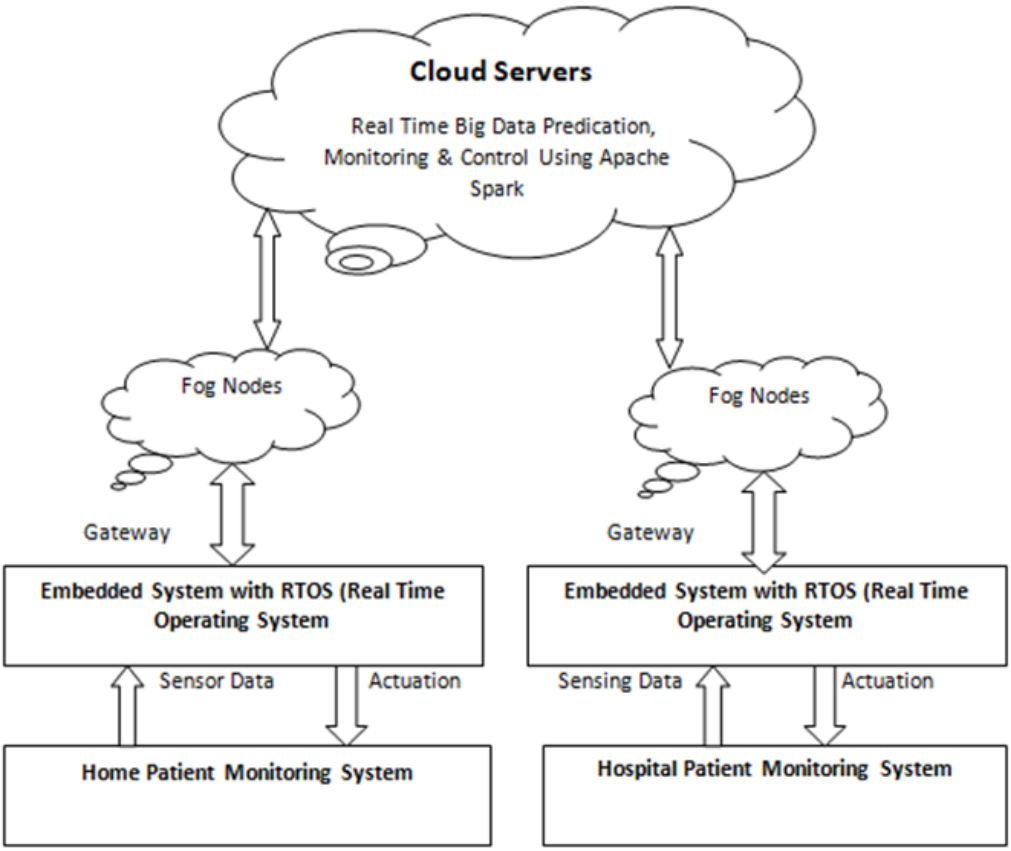


The organization of paper is as follows: The first section presents the real time cyber physical healthcare system. The second section describes the real-time sensing for cyber physical healthcare systems, The third section illustrates the role of fog computing in cyber physical system. The Fifth section presents the use of Kafka for real-time data-streaming in remote healthcare systems The sixth section describes the Spark for healthcare big data processing. The last section gives the conclusion of the overall research study.

Real Time Cyber Physical Healthcare System

Real time cyber physical healthcare system is as shown in Figure 2 where different types of sensors used to collect health information from patients from doctors and medical staffs including doctors, nurses and others, medical devices(Tabish et al., 2014).

Figure 2. Real Time Cyber Physical Healthcare System



Real time physical healthcare system consist of following modules:

- Sensing: Different sensors used to monitor various health parameters
- Embedded Real Time Operating System: Sensor data is processes by embedded processing unit in real time using real time operating system. Real time scheduler is used to schedule different concurrent tasks in real time
- Fog computing: Sensor data first processes by the fog nodes in real time. Fog nodes processes data real time analytics and decision making and control
- Kafka pipeline for real time processing of healthcare data.
- Spark framework for real time processing of healthcare data

Real Time Sensing for Cyber Physical Healthcare System

Cyber physical system used in various healthcares and medical service which helps to take corrective actions in real time. The summary of such application and different types of sensor used for collection of data for these applications is mentioned in the Table 1 (Shi et al., 2015).

Table 1. Real Time Cyber Healthcare Application (Rahmani et al., 2015)[9](Haque & Aziz, 2013)

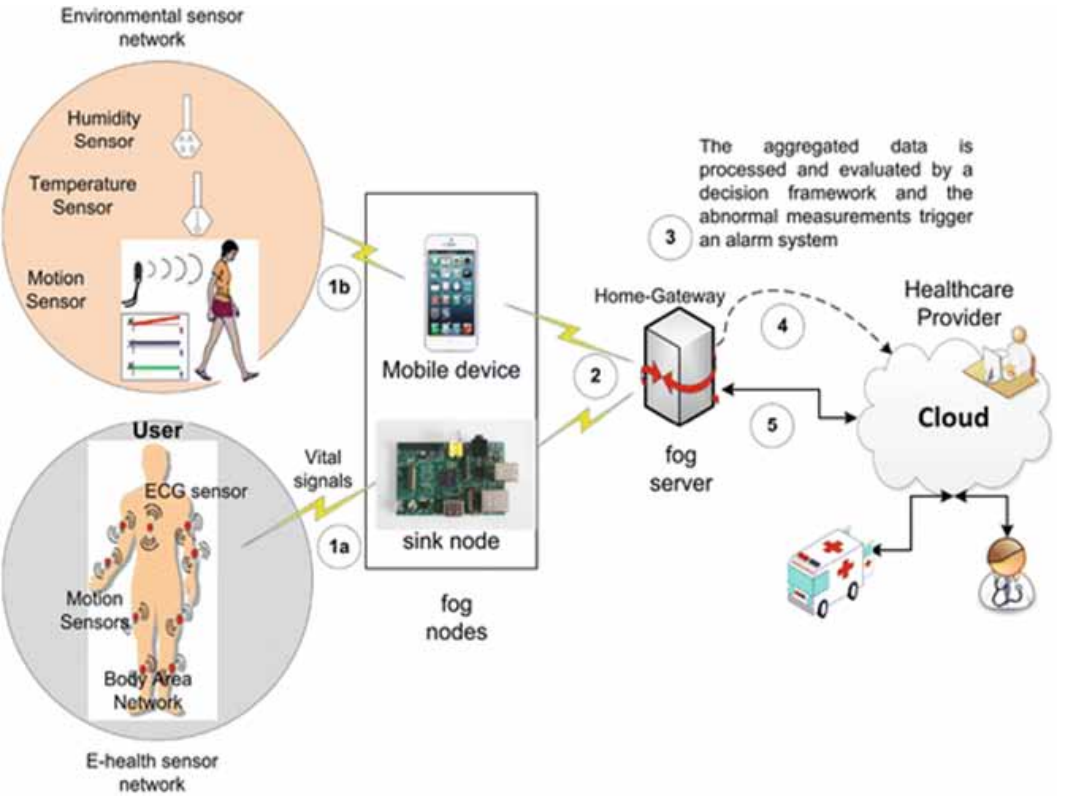
Sr.No	Healthcare Application	Sensor and Operations
01	Monitoring and Control of Heart rate	Heartbeat sensor:is used to track changes in volume of blood in body. If the changes goes up to a threshold them alarm is send to doctors and patients to take corrective actions
02	Diabetic Patient Monitoring	Glucose Sensor is used to monitor level of sugar in body and real time alert system is developed
03	Wound Monitoring and control system for critical diabetics patient	Smart camera is used to take picture of wound. Mobile app software is used to take real time images of wound and send the processes image to doctors for action
04	Asthma Patient Monitoring	Asthma Tracker is used to track the patient asthma level and updates the real time information to cloud
05	Skin Disease Monitoring and Control	Smart camera take images of skin, processes and updates if any skin disorder
06	Eye Monitoring and Control	Smart camera takes picture of eyes. Mobile app processes images of eyes and send real time eye information to doctors
07	Pulse Rate Monitoring	iOximeter is used to monitor pulse rate
08	Temperature Monitoring System	Temperature sensor used to monitor temperature of patients and store information in the cloud
09	Blood Pressure Monitoring	BP sensor is used to monitor the real time value of blood pressure
10	Cough Monitoring system	Microphone is used to processes cough sound and voice processing is used track the real time cough analysis
11	Remote Surgery	Robot surgical system and Augmented reality sensor used to perform remote surgery on real time

Fog Computing for Real Time Healthcare System

Sensors collect information from patients and send the sensor information to fog nodes for real time analysis(Hackmann et al., 2014) as shown in Figure 3. Embedded microcontroller gets information from sensor and processes the real time sensor data to fog nodes. Medical applications are different from other cyber physical system in which remote monitoring requires reliability and security and all operations must be performed in real time which is not possible with cloud computing(Kamal et al., 2017). So to implement real time analytics for time critical application such as healthcare fog computing plays an important role. Fog computing in real time health care system provide following advantages(Gu et al., 2017).

- Fog computing architecture is distributed which helps to provide reliability to healthcare application
- Communication is directly with edge devices to provide real time communication service for healthcare application
- Data processing in fog computing is done very close to source of information to take quick corrective action.
- Large nodes can be connected in fog computing which helps in formation of cyber physical system for healthcare system
- Fog computing provides less latency require for real time analysis of healthcare system
- Fog computing provide various protocol standards and higher security as compare to cloud computing.

Figure 3. Use Case of Real Time Healthcare Monitoring Services using Fog Computing (Gu et al., 2017)



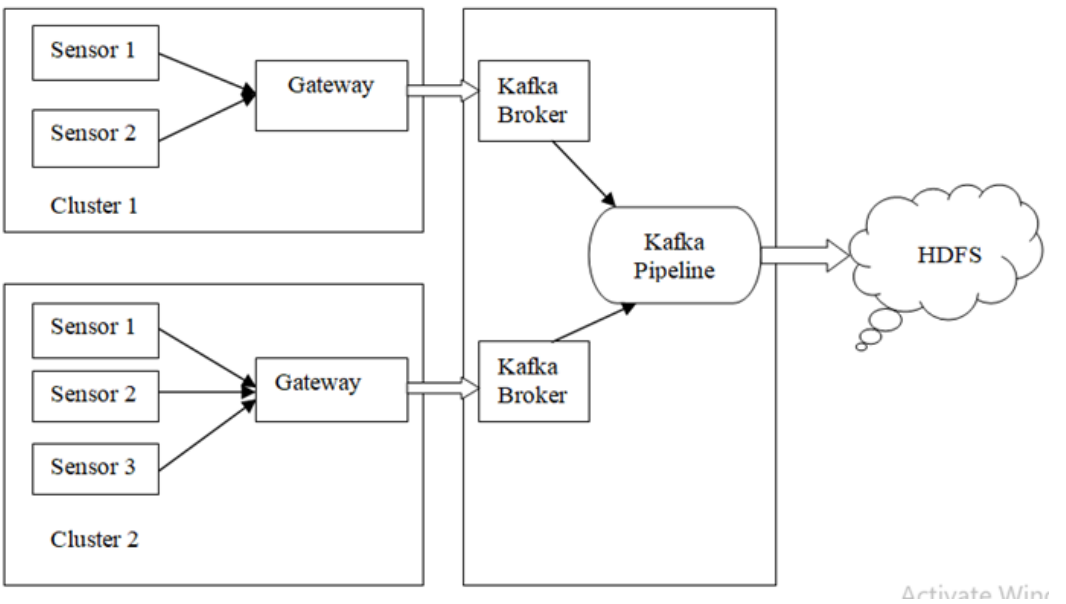
The above use case of real time monitoring services using fog computing is used for real time monitoring of patients under critical medication such as covid-19 patients monitoring. The critical sensor data get transfer from fog node to fog server as shown in step 1 and 2. The data get analyzes on the fog server using complex data analysis algorithm and if there any abnormal events then actuator get activated at fog nodes to take corrective actions as shown in step 3(Banerjee et al., 2011). Abnormal events means any kind of medical emergency like fall of elderly person, blood sugar, blood pressure increases to higher value or symptoms of some pandemic diseases. Whenever there are no any abnormal events, then the data get transferred to cloud server for further storage and analysis as

shown in step 4. In step 5 data get stored on cloud permanently for further analysis using machine learning algorithms to get the status of patients health. Real time communication protocol ensures timely action. Let suppose the sensor accelerometer and gyroscope detect the fall then blood pressure sensor and EEG sensor value cross the threshold, real time images transferred and processes on fog sensor where the severity of fall is detected and corrective actions taken in the form of information to doctors, hospitals, relatives and ambulance (Hackmann et al., 2014).

Real Time Healthcare Data Streaming Using Kafka:

In cyber physical real time healthcare system can be many to one or many to many system where at regular interval messages are exchanges at regular interval. Kafka is a pipeline architecture used to store large amount of data to database on real time. It can be configured as many to many and many to one mode for real time healthcare system (Rajkumar et al., 2010). The Kafka gets configured and runs on Zookeeper server. The Kafka topic is used to create pipeline. When Kafka topic is in running mode then lot more number of sensor nodes can send data to Kafka topic and lot more number of actuator nodes can read data from Kafka broker. Kafka has the ability to store data for some time in buffer storage and processes the data in real time within the pipeline itself (Raghupathi & Raghupathi, 2014). The cyber physical real time healthcare system architecture consists of sensor within cluster send messages over MQTT cluster for communication (Haque et al., 2014). Gateway is used to receive data from sensor nodes. Gateway is used to write data to Kafka topic. Kafka pipeline worked as real time injection layer that inject data into the HDFS (Hadoop Distributed File System) as show in Figure 4.

Figure 4. Kafka Based Data Pipeline Architecture for Cyber Physical Healthcare System



Real Time Big Data Processing of Health Data Using Spark

Healthcare data analysis is done using machine learning algorithms. Existing hadoop system to run machine learning algorithm incur practical difficulties(Hu et al., 2012). Machine learning and deep learning algorithms take long time to produce output. It is executed with multiple stages which used MapReduce program in back end(Papageorgiou et al., 2015). The problem with map reduce is that it

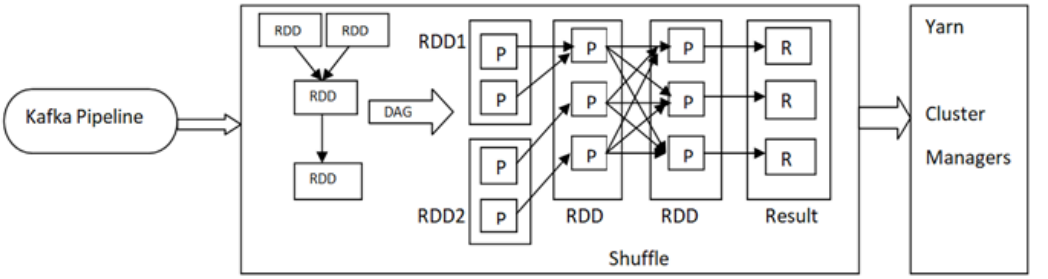
loads the data into memory, processes the data and then store it back. The read and write operation on memory take huge time as comparing to processes data. In healthcare application data must be processes in real time to take corrective action immediately to avoid any risk. Spark is new framework for replacement of MapReduce framework in Hadoop2.0. Table 2 shows the difference between spark and hadoop map reduce based on different parameters(Solanki & Nayyar, 2019)[23].

Table 2. Features of Apache Spark based Real Time Healthcare Data Processing versus Hadoop MapReduce

Sr.No	Metric	Apache Spark Healthcare Data Processing	Hadoop Map Reduce Healthcare Data Processing
01	Speed	Very fast as compare to MapReduce	Less speed than Spark and faster than traditional system
02	User Interface	Compact and easier than Hadoop	Complex and lengthy data processing
03	Data Storage	Memory for Data Storage	Data stored in Disk
04	Language use	Scala	Java
05	Data Processing	Real Time	Batch
06	Fault Tolarence	Fault Tolerance using RDD	Fault Tolerance using Hadoop less efficient
07	Support Machine Learning	MLib on Spark provide fast speed for ML Model	Mahout on Hadoop is less fast for ML Model
08	Latency	Low latency framework	High Latency Framework
09	Scalability	Up to 8000 nodes cluster support	Hadoop support 15000 nodes
10	Caching	Memory for caching data to enhance performance	Don't support caching of data
11	Streaming	Real time data streaming	Processing of data in batch
12	Cost	Higher than Hadoop	Less than Spark

The spark uses resilient distributed dataset (RDD) and directed acyclic graph. The Spark application read data from used code and placed it into the RDD. The RDD are not changeable and each step it creates new RDD(Kumari, Tanwar, Tyagi, & Kumar, 2018). The conversion processes is designated as directed acyclic graph and submitted to cluster. The conversion processes consist of arithmetic, logical and set or map based operation. After conversion process RDD get shuffle, then combined and final result get produced. The advantages of using Spark framework in cyber physical healthcare real time system is shown in directed acyclic graph execution step(Kumari, Tanwar, Tyagi, Kumar et al, 2018). Directed acyclic graph used end to end processes in that first data get read, transformed and then stored in database but in MapReduce there is memory write operation for each transformation of job(Kreps et al., 2011). Yarn is used as cluster management of tasks to produce the result(Singhal & Singh, 2017). The Spark framework store intermediate result into another RDD and combine it during processing which reduce the time require for execution depending upon the job and machine learning or deep learning model as shown in fig 1.5(Armbrust et al., 2015; Alamri et al., 2013; Hu et al., 2012).

Figure 5. Spark framework architecture for handling real time processes



CONCLUSION

This paper proposes the novel framework for cyber physical real time healthcare system for patients monitoring system in pandemic like Covid-19. The proposed framework shows how the real time patients monitoring done at different stages in the healthcare system such sensor node real time data processing and scheduling, real time data analytics at fog nodes, real time streaming of data using Kafka pipeline and real time data processing on cloud hadoop file system using Spark. The proposed framework helps in real time, reliable, fault tolerance and secure patients care and monitoring during pandemic.

In future the framework is implemented using cluster based cyber physical system for embedded sensor nodes using fog computing.

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