An IoT based Real-time Data-centric Monitoring System for Vaccine Cold Chain

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***Abstract*—Vaccination is the assured way of gaining immunization against many life-threatening diseases. However, the vaccine outreaches in developing and undeveloped countries are very limited due to lack of proper management of the cold chain system. This paper presents a real-time data–centric cold chain monitoring system for the continuous monitoring of the vaccine distribution and transportation process. The proposed system provides the unique feature of creating and managing individual trips for vaccine transportation process along with the regular supervision of temperature and humidity of the carrier. Moreover, the hardware and software components for the system also track the location of the carrier. This proposed system can be particularly highly effective in increasing vaccine coverage in the remote regions. This is because the proposed system enables the remote monitoring of the entire process and ensure transparency in the distribution process.**

Keywords— IoT, Monitoring System, Vaccine Cold Chain.

I. Introduction

Immunization by vaccines is widely acknowledged for controlling and eliminating a large number of infectious diseases and is also one of the most cost-effective public health interventions. According to UNICEF, vaccines are saving 2-3 million lives every year. However, vaccine outreach is still very limited in the developing and undeveloped countries. In 2018 alone, 13.5 million children did not receive routine immunization and 1.5 million lives are lost every year from diseases that can be prevented by vaccines [1].

Even though different factors are responsible for this low outreach of vaccines, breach of the vaccine cold chain is the biggest contributing factor [2]. Vaccines are extremely sensitive to temperatures. The World Health Organization has fixed the temperature range for vaccine storage and transportation as 2-8°C and vaccines completely lose potency if they are exposed to temperatures beyond this range even for short durations. This is why maintaining the cold chain system from the point of manufacture till the point of administration is very important. However, various physical, geographical and socio-economic factors in the developing countries hamper the smooth management of the vaccine cold-chain system resulting in the loss of almost 50% vaccines annually [3]. WHO has a number of standardized devices and guidelines for monitoring the cold chain; but in the undeveloped countries, about 31% of these devices were non-functional and several of the units were too old for use [4]. Most of the people in the undeveloped and developing countries are not sufficiently trained for using these devices and often times there is no transparency and no routine monitoring in the cold chain system. This leads to the wastage of almost 39.54% vaccines at the session sites. Moreover, while transporting, the vaccines are mostly carried in cold boxes using ice packs and cold water packs. The vaccines often freeze below the necessary temperature range rendering them useless and even harmful. Again, because of the lack of accountability, vaccines even get lost or stolen during the journey to the health centers. All these contribute to the loss of almost 30% vaccines during transportation [5].

Considering these existing problems in maintaining the cold chain, this paper introduces a real-time, data-centric vaccine cold chain monitoring system, which monitors the temperature and location of the vaccine carriers and sends necessary notifications and text messages to the healthcare supervisors accordingly. The corresponding hardware designs for the system have been previously developed which consists of a thermoelectric based vaccine carrier, a monitoring module containing the necessary temperature and humidity sensors and a communication unit which is responsible for providing the location information as well as for sending text notifications and sharing data on the web server [6]. This system ensures that transparency is maintained and that the vaccines are monitored routinely throughout the transfer process. Unlike traditional

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systems, the entire monitoring process is carried out automatically, hence there is no space for human errors or negligence. The different design aspects and features of the system are described in details in this paper.

This paper is organized as follows. The background study and the limitations and strengths of the existing systems are mentioned in section II. The different features of the proposed system is presented in section III. Section IV contains the implementation framework of the system and the conclusion and future scopes are highlighted in section V.

II. Background Study

Over the years, numerous researches have been carried out to develop web and mobile based applications which can assist in increasing vaccine coverage and monitoring the cold chain. Among the various works done, most of the mobile applications that have been developed are largely responsible to collect data about vaccine coverage in the hard to reach areas of developing countries and are concerned with monitoring the routine administration of vaccines [7, 8, 9]. However, as previous discussions indicate, the proper coverage of vaccines in these remote regions can only be ensured when the cold chain of the vaccine supply system performs properly. So even though these applications can successfully determine the rate of vaccine outreach, they do not work to increase this coverage rate.

Moreover, there exists a few web based systems as [10, 11] which allows to monitor the cold chain performance by reporting the refrigeration status of the various vaccine refrigerators, cold rooms and boxes. However, these systems are only suitable for use in vaccine cold rooms and vaccine refrigerators at the session sites. These are not adapted for use during the transportation period of the vaccines where the cold chain breach is most common. In [12] a cold chain monitoring system is devised based on FonAstra which a sensing system that uses cellular network to send temperature and location data via text messages. This data is then stored in a database which is accessible through a web browser. A similar work has also been done in [13] where the system sends the data through WI-FI transmitters to the monitoring authorities who can check this data through Sensor cloud. It does not send any separate SMS notification. Both of these systems are only online based applications and these also have a basic limitation that these do not include the function of allocating separate IDs to the large number of vaccine carriers that are often sent out together on different trips and also cannot identify from which carrier or which vaccine delivery trip the definite data is being sent from. So these in practice can only be used for individual carriers or single trips at a time. The system discussed in [14] is a slightly improved version of the two previous systems. This monitoring system, sends the temperature and location data to the supervisor as SMS and also sends to a cloud based web service. The cloud application receives acknowledgements from the supervisor's mobile phone and marks the vaccine carriers as safe or unsafe accordingly. Unlike the previous systems, this monitoring system can identify individual boxes by separate IDs but do not have the ability to differentiate between the various delivery trips being made at the same time.

This system thus have been designed considering the limitations of the existing works. Unlike the previous works, the monitoring system is based on both a web server and a mobile application. The mobile application has a user friendly interface which allows easy access to the health care workers. Moreover, this work has a number of distinctive features which were absent in the previous works; most important of these being: assignment of individual ID numbers to all the vaccine carriers and creating and tracking every individual trip that is made to the remote health centers.

III. Proposed Model

A general idea about how the monitoring system functions is depicted in the block diagram in Fig. 1.

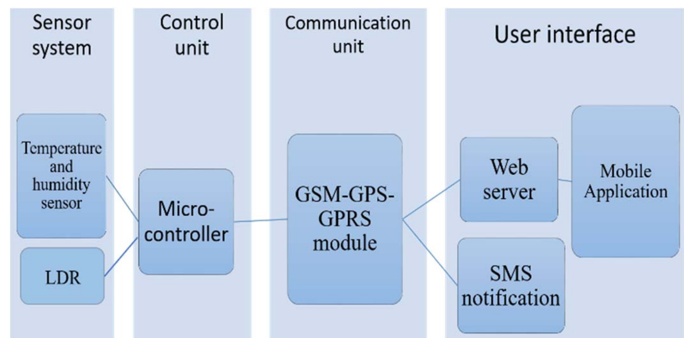

Fig. 1. Monitoring system block diagram

A. *Trip details and vaccine carrier information*

The first feature that sets this system apart from the previous works is that at the beginning of any vaccine transportation trip, a new trip is created through the web server of the system which can be accessed by the healthcare supervisor. This contains all the necessary details about an individual trip, including the current status of a trip, the trip route, the details about the type and amount of vaccines being carried and details about the healthcare workers on the trip. The entire trip can also be tracked by the healthcare supervisors or admin while it is active. While tracking an individual trip, the admins can access information about the current location of the carrier, the current temperature and humidity readings of the vaccine carrier chamber as well as the general information about the healthcare worker and the vaccines being carried. However, while tracking there is no provision for selecting the best route for the vaccine transfer, rather, the carrier will follow the route pre-defines before the journey. Algorithm 1 describes the process of searching and tracking an active trip.

Algorithm 1: Algorithm for searching and tracking a trip

```
start
tripData = getTripInformationFromRoute();
trip = getTripDetailsById(tripData.id);
if trip == null then
    trip = makeTrip(tripData);
    trip.locationList=tripData.locationList
    trip.userList=tripData.userList
end
allLocation = trip.getAllLocation();
allUser =trip.getAllUserList();
```

```
isAllLocationVisited = true;
for every location in a allLocation
    if notlocation.isVisited() then
      isAllLocationVisited = false;
    end
endfor
if isAllLocationVisited then
   trip.isCompleteTrip = true;
else
   trip.isCompleteTrip = false;
end
end
```

Also, each of the vaccine carrier in the trips are assigned a unique ID which allows them to keep track of all the carriers individually as well.

B. *Continuous monitoring*

The vaccine carriers used in the system are equipped with a temperature and humidity sensor that continuously monitors the temperature and humidity of the carrier chamber and the monitored data is sent to a microcontroller unit which records the temperatures and sends the data at a regular interval to the communication unit. Moreover, an LDR is placed in the carrier that helps to determine if the vaccine carrier has been opened anytime during the journey. If the carrier is opened, the LDR value crosses a threshold level which causes the communication unit to send urgent notifications regarding opening of the carrier. This ensures that no vaccine can be stolen or removed from the carrier during the transportation process.

C. *Location Tracking*

In this system, the communication unit consisting of the GSM-GPS-GPRS module is responsible for providing the location information of the vaccine carrier along with determining the date and time of the trip being made. The module determines the GSM location of the carrier and this enables the supervisor to locate the position of any vaccine carrier at any given time to ensure that the pre-defined route for vaccine transportation is being followed.

D. *Regular and Urgent Notifications*

In the proposed system, at definite regular intervals, notifications about each individual box are sent to the supervisor as well as to the health care individual assigned to the particular trip. These notifications contains the carrier temperature, humidity and location information along with the time stamp. Apart from the regular notifications, some urgent notifications are also sent out whenever the carrier temperatures fall beyond the range of 2-8°C or if the carrier has been opened during the trip. Both the regular and urgent notifications are sent to the users via SMS as well as through the mobile application, because these carriers are designed to be used even at the most remote areas. Due to the lack of proper infrastructure, it is possible that at any point of the transportation process, internet connections might not be available or might be weak which can cause a delay in receiving notifications from the mobile application. However, basic mobile networks are mostly available in all areas and SMS notifications are more likely to be received.

IV. Framework Implementation

A. *Architectural Design*

The architectural design of the proposed system is based on a three-tier approach where the first tier is the client tier or presentation tier, the second tier is the middle tier followed by the database tier. This three tier architecture allows to integrating the different users and their functionalities on one platform. This enables the proposed system to provide more flexibility to its applications.

1) The Client Tier: The first tier in the architecture is the client tier which allows the users to interact with the platform. In this case, the web browser and the smart phone's touch screen and display interface act as the client tier which is utilized by all users connected to the system. The graphical user interfaces of the application operates in this tier and it allows the users to perform the different functions like creating an account, logging in, tracking a current trip and so on. This proposed system provides a very simple and user friendly GUI, which will allow the healthcare workers with minimum training and education to easily operate the application. Fig. 2 and Fig. 3 presents the mobile and web based interfaces of the proposed monitoring system respectively.

Fig. 2. Mobile user interface

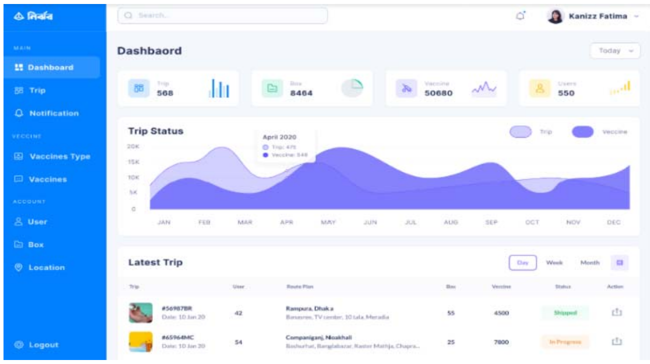

Fig. 3. Monitoring system homepage

2) The Middle Tier: In this system, the middle tier consists of the core logic of the application. As mentioned before, the client tier assembles and diplays data from the user, while the database performs the storage and retrieval of data. Most of the remaining functions are performed by the middle tier where it determines the content and structure of the data to be displayed to the users and processes the user input. This middle tier acts a merger between the other two tiers. The inputs generated by the users are formed into queries and interpreted by the data base as read or write functions. In this proposed system, the web server is a core component of the middle tier.

3) The Database Tier: The final tier of the architectural design is the database tier which is responsible for the storage and retrieval of all data from the system. The database of the proposed system is designed based on the entity relationship diagram during the system design phase and it consists of seven database tables.

B. Role of the Users

The proposed system comprises of two types of users: the healthcare supervisors who are responsible for creating the trips and monitoring the entire transportation process of the vaccines and the healthcare workers who are assigned for individual trips to transport the vaccines to the centers. All the users are required to be registered in the platform to use it. Next based on the type of the user, they are directed to the respective dashboards where they can perform their individual functions as depicted in Fig. 4.

1) Healthcare Supervisors/ Admin: The first role of the supervisors or admins is to create an account and log into the account using their emails. Supervisors are allowed to login both to the web and mobile applications. Next the user can access a number of features on the system as depicted in Fig. 4. This includes creating, updating, viewing or deleting trips and vaccine information and tracking the locations and access details about all ongoing trips. During an ongoing trip, the supervisors also receive routine notifications through the mobile app about the temperature conditions of the carrier and whether the carrier has been opened or not and can take actions accordingly.

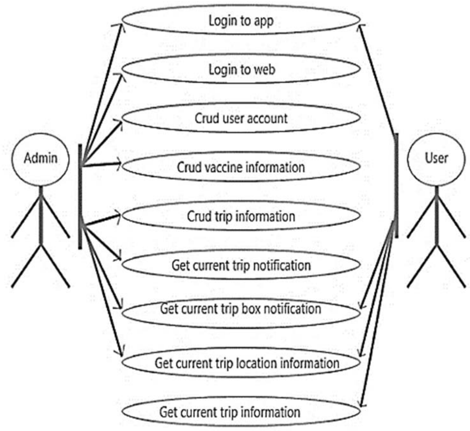

Fig. 4. Use case diagram

2) Healthcare Workers: Similar to the supervisors, the first role of the workers assigned to the trips is to create and log in to their respective accounts. The workers have access only to the mobile applications and they can view the details about their current trips only. They receive regular notifications about the temperature conditions and can view the location and route information of their current trips.

3) Physical Design: After completing the system analysis and understanding the role of each user, the logical designs of the systems are created. Each process in the system was modeled using Data Flow Diagrams (DFD) and to get better understanding of the flow of data through the system Entity Relationship Diagrams (ERD) were constructed. Moreover, sequence diagrams were utilized to determine the roles and functions of each user. The main concerns of this design level was thus to determine the work flow of the entire system and how the outputs will be presented.

C. Data Flow of the Application

1) Sign in and Sign up: Irrespective of the type, all the users must go through the process of signing up and logging in. The process of creating an account and logging in is very simple. For creating an account, the user is required to click on the Register button. This will prompt the user to create an account by providing the necessary information and click submit. This sends the details of the user to the database. Once the sign up process is successful, the users can login to their accounts by entering the necessary credentials. After logging in the different features can be accessed based on the type of the user.

2) 4.3.2 Creating and Searching for a Trip: One of the features of the system is the ability to create individual trips before a specific vaccination transfer process is started. For this purpose the user who is admin or supervisor is required to access the feature by clicking on the "create new trip" button on the dashboard. This provides a form requesting different information regarding the trip and the vaccines being carried.

Similar to creating a trip, only an admin can search for both current and previously completed trips by using the search option on the dashboard. The trip name entered by the user is matched against the database to retrieve and present the details of that particular trip. The dashboard of the admin also by default contains a list of ongoing trips and the details of a trip can be viewed simply by clicking on the list item. Similar processes are also to be followed by the healthcare workers, the only difference being that they are allowed to view only the trip that they are currently assigned in.

3) Adding New Vaccine types: For adding details about new vaccines to the database, a similar process is followed as creating a trip. The admin accesses a form by clicking on the "create new vaccine" button and by providing the necessary information in a form, the details of the vaccine are saved in the database. The unique vaccine ID assigned to each vaccine created in this process is utilized later in creating a trip.

V. Conclusion and Future Works

An app based monitoring system for vaccine cold chain is proposed in this system. The proposed system ensures that the vaccine cold chain is monitored continuously during the entire transportation process to health centers and as the system is completely automated, it ensures transparency and efficiency in the whole process. The system can be extremely beneficial when utilized to track and monitor the vaccine transfer processes in the remote areas in developing and undeveloped countries where the vaccine outreach is minimum due to lack of proper management of the cold chain systems. Even though there are no visible drawbacks of the system, there are still some future scopes in improving the overall efficiency of the application by making it as user friendly as possible to be easily usable by the untrained field workers and add features as necessary.

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References

[1] Unicef and World Health Organization, "Progress and Challenges with Achieving Universal Immunization Coverage : Estimates of Immunization Coverage," no. July, pp. 1–18, 2019.

[2] A. Ashok, M. Brison, and Y. LeTallec, "Improving cold chain systems: Challenges and solutions," *Vaccine*, vol. 35, no. 17, pp. 2217–2223, 2017.

[3] World Health Organisation, "Monitoring vaccine wastage at country level," *World Heal. Organ.*, pp. 21–27.

[4] Federal Ministry of Health Ethiopia(FMoH), "Ethiopia National Expanded Program on Immunization, Comprehensive Multi - Year Plan 2016 – 2020.," pp. 1–115, 2015.

[5] A. PEEPLIWAL, "Cold Chain: A Lynchpin of National Immunization Program," *J. Pharm. Technol. Res. Manag.*, vol. 5, no. 1, pp. 77–104, 2017.

[6] R.T. Hasanat, N. Mansoor, M.S. Rahman, M. Rasheduzzaman, 2020. Development of Monitoring System and Power Management for an IoT based Vaccine Carrier. In *ICED 2020.*

[7] A. Katib, D. Rao, P. Rao, K. Williams, and J. Grant, "A prototype of a novel cell phone application for tracking the vaccination coverage of children in rural communities," *Comput. Methods Programs Biomed.*, vol. 122, no. 2, pp. 215–228, 2015.

[8] M.J. Uddin, *et al.*, "Use of mobile phones for improving vaccination coverage among children living in rural hard-to-reach areas and urban streets of Bangladesh," *Vaccine*, vol. 34, no. 2, pp. 276–283, 2016.

[9] D. Hansen, Niels, et al., "Time-Series Adaptive Estimation of Vaccination Uptake Using Web Search Queries." Proceedings of the 26th International Conference on World Wide Web Companion. International World Wide Web Conferences Steering Committee, 2017.

[10] R. Anderson, *et al.*:"Supporting immunization programs with improved vaccine cold chain information systems," *Proc. 4th IEEE Glob. Humanit. Technol. Conf. GHTC 2014*, pp. 215–222, 2014.

[11] R. Anderson, J. Lloyd, and S. Newland, "Software for national level vaccine cold chain management," *ACM Int. Conf. Proceeding Ser.*, pp. 190–199, 2012.

[12] R. Chaudhri, G. Borriello, and R. Anderson, "Pervasive Computing Technologies to Monitor Vaccine Cold Chains in Developing Countries," *IEEE Pervasive Comput.*, vol. 11, no. 3, pp. 26–33, 2012.

[13] A. Mohsin, and S.S. Yellampalli, "IoT based cold chain logistics monitoring," *IEEE Int. Conf. Power, Control. Signals Instrum. Eng. ICPCSI 2017*, pp. 1971–1974, 2018.

[14] A. Parthasarathy, J. Chinnappa and P.S. Ramkumar, "A Cloud-based Vaccine Cold-Chain Monitoring System," *ASCI Journal of Management*, vol. 46, pp. 129-136, 2017.