A Smart Early Warning System for Disease Outbreak with a Case Study of COVID-19 in India

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***Abstract*—In this paper, we propose a circular, smart system involving participation of the government, health services and citizens, via a mobile application, with the analysis of the collected data being performed in a hierarchical manner in Cloud Storage. We performed a case study on the COVID-19 India dataset to validate the system. The proposed system will aid early detection of infectious disease outbreaks thus reducing the ultimate size of the outbreak, with lower overall morbidity and mortality.**

***Index Terms*—Cloud Computing, Disease Outbreak, Early Warning System, IoT, Mobile Application, Smart Healthcare, Time Series Analysis.**

I. Introduction

Started at the end of the year 2019, a novel infectious disease outbreak rapidly spread worldwide, crippling the public-health architecture of the unprepared. This pneumonia-causing disease was later identified as COVID-19, which raised a lot of attention internationally. In the initial stages of the pandemic, limited patient data was available, making predictions uncertain. Lack of early identification and action facilitated the rapid transmission of the virus within a highly mobile population [1].

Looking at the various infectious disease outbreaks from throughout history, it is evident that early identification and rapid but correct information sharing have always played a key role towards bringing out effective disease prevention and reducing mortality and morbidity rates in the human population. Usually, however, epidemics and outbreaks are well past the early look-out stage before the authorities are notified and the preventive and controlling responses are in effect [2]. In India, poor sanitation conditions, overcrowding, poor air quality due to pollution and other factors are responsible for the transmission of harmful diseases at a faster rate. A circular system involving the participation of the government, health services and most importantly, the citizens, is the need of the hour to prevent disease outbreaks and to tackle non-availability of first-hand medicines [2].

II. Current Status and Challenges

A. Current Status

An epidemic is an actively spreading disease in a community, at a particular instant in time, which is more than normal expectancy. Epidemics are best monitored at a large scale and controlled locally [3].

Standardization of disease diagnosis, networked patient databases and centralized citizen identification has allowed swift monitoring of disease occurrence. Advancements in monitoring data of environmental parameters from ground-based and satellite systems have helped in finding the potential link between epidemics and climate. The use of data analysis techniques and prediction mechanisms such as Artificial Intelligence, Cloud computing and Machine Learning and the widespread use of Mobile Applications has vastly improved the accuracy and reach of such Early Warning System. It is fair to say that the health-care sector is in a potent position, due to the above-mentioned reasons [4]. Thus, it is important to implement here-with proposed circular Early Warning System.

B. Challenges

With probable epidemics, there will be some initial delay in recognition, adverse effects on trade and travel, panic and anxiety among the population and exaggeration by the media [3].

The challenges in forming a circular system involving the government, healthcare centres and the general population are as follows:

- To strengthen the outbreak surveillance system, long term data and analysis will be needed for developing the model. This system should be able to produce high-quality data with reasonable accuracy.

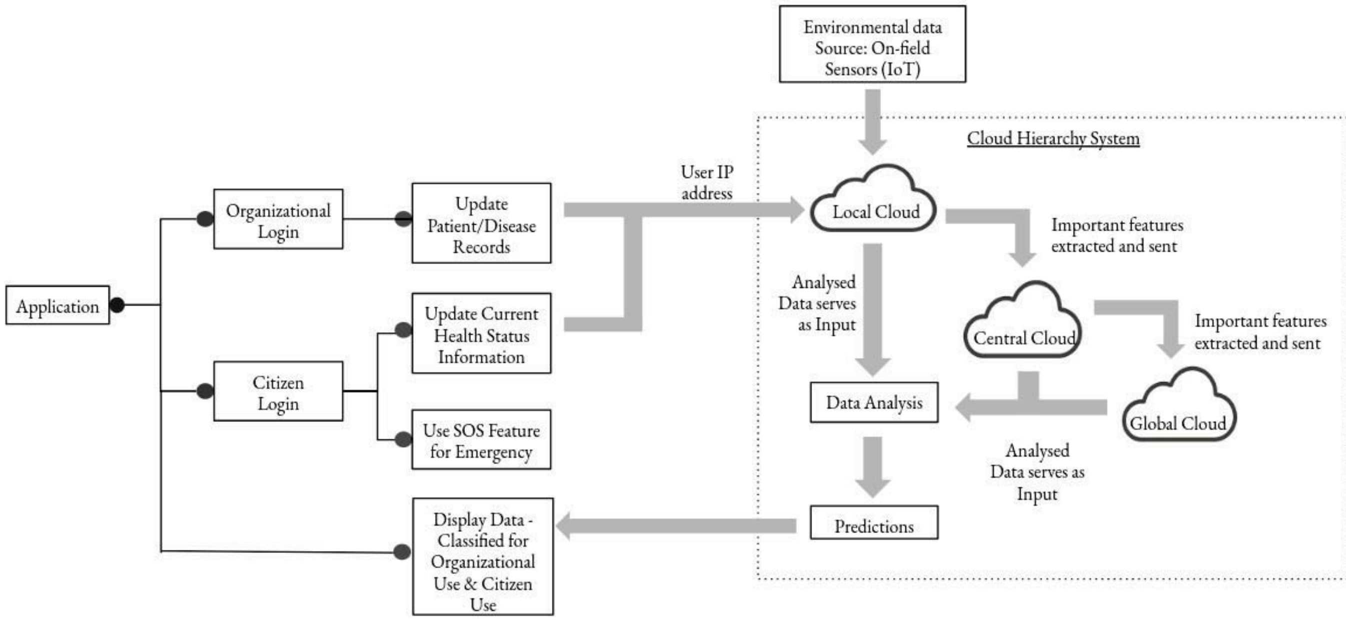

Fig. 1. Overview of the Proposed System

- The system involving data collection nodes should undergo analysis of cost-effectiveness.
- This preventive Early Warning System (EWS) will be effective only when it is not undermined by poor organization at the local level. A feedback component is necessary for checking the functioning at each level.
- Training of personnel for epidemic preparedness.
- Simplifying results of the data analysis for ensuring readability for the policymakers, and to ensure necessary response.
- Determining the most appropriate response actions.
- Epidemics of rumours: With expanded reach and available data, there's a risk of self-diagnosis and panic among the public. The spread of false rumours and misinformation should be contained by ensuring that the functioning and response systems exist locally as well as at the top levels [3].

III. Need Of Circular System

Human population dynamics and behavior is one of the major factors that allows viruses to cause epidemics. Since the world population is growing at an exponential rate, there is more probability of viruses spreading via human contact. Migration adds another layer of complexity to our problem, as viruses find their way to other human bodies more rapidly [4].

An important step to curb the spread of infectious diseases is to identify its origin at a preliminary stage. The current system in place does not inculcate a circular system and effective practical use of latest technologies.

India, in particular, is a breeding ground for communicable diseases [5]. What we require is a solid organizational structure with its local and top layer of authorities in place, along with responsible healthcare and citizen contribution. This can be our much needed impetus towards establishing a secure system to handle disease outbreaks.

With this background, our proposal is to develop a circular system that will turn into an EWS, which benefits the society where we live and ultimately to the Indian population as a whole. The proposed system aims at prevention of epidemics at the source, rather than the current approach of control after metastasis. The proposed application will update and connect neighborhood residents and healthcare centers, issuing a warning in case of unusual health-scares. Additional features provide means to report and efficiently deal with emergency medical situations.

Drug wastage or over/under-utilization will be controlled as drug manufacturers will be informed of disease outbreaks beforehand. Weaker sections of the society that lack access to basic health care facilities will be informed not just about possible health scares, but also about possible risk factors in their environment.

IV. Methodology: Design Approach

In this section we describe the design approach of the proposed system. Our proposed system is an amalgamation of a network between a Mobile/Web Application, User Interface, Internet of Things (IoT) Devices (On field), Sensors and Cloud Computing technology.

Fig. 1 shows a model of our circular system wherein the above-mentioned elements are illustrated. It consists of both climatic and non-climatic factors. Climatic factors under consideration are temperature, humidity, amount of rainfall,

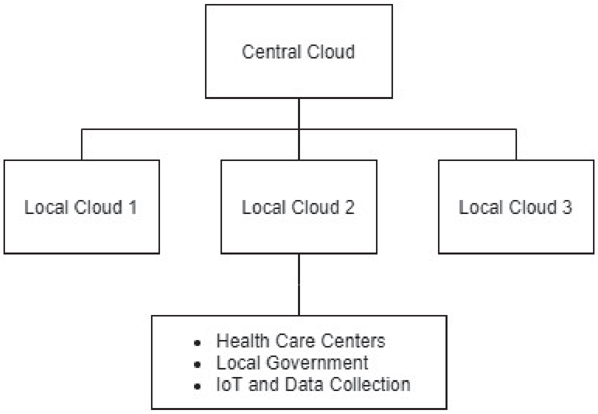

Fig. 2. Grouping of users from a local area to form a local network

and likewise. Non-climatic factors such as population density, and health history of an area will be included in the analysis for accurate predictions. Such data is specific to local regions and thus, a system rooted locally is preferred. Therefore, we aim to scale down and concentrate this system onto Local areas, rendering it to act like a local area-based system. However, through the Application and Cloud Network, data from different local areas is linked together. There are many direct and implicit advantages of concentrating this system on a smaller area, the main one being the accuracy of the predictions for that particular area. This could only be possible if the on-field IoT devices/sensors are dispatched in a particular area, and the Application has users in that area. However, the accuracy of the predictions would reduce if any one of the above data collection methods is absent. This is because the response and preventive models must be made relevant to the particular needs and limits of the local government.

The proposed application will host the local residents, doctors and healthcare centers' databases, and the local environmental conditions data. It will make predictions about infectious disease outbreaks and other health scare situations beforehand, forming an Early Warning System (EWS). This will be useful in updating and warning citizens by enabling them to access and view their local area's Non-Classified Electronic Health Records (EHR), Analysis and Predictions. In a broader sense, a city will be divided into numerous local areas, with further scope for scaling the model.

All the users located in that particular area will be able to view that area's local environmental data, EHR, analysis and predictions.

The displayed databases, analysis and predictions would change according to the user's location. This could effectively tackle the problem of Human Migration in the domain of contagious diseases. The Application (ML algorithm) would be able to determine the origin/source by analyzing the data from users, hospitals, government organizations, and the environmental data. On the application platform, citizens, healthcare centers and government organizations would be grouped together from a particular local area based on their IP addresses and other location services. This would enable the networking of people from a particular local area with each other and with their neighborhood hospitals/clinics, etc. as can be seen from Fig. 2.

With an ultimate aim of improving health, the EHR is a tool that can empower and allow the users of a system including the patients to exchange effective and high-quality information in a confidential and secure environment [6]. The data obtained directly from the environment and the data received from the users on the application, together would serve as an appropriate dataset for analysis and predictions. Accuracy would be ensured since the algorithm would take into account environmental, climatic factors and also the population density, human migration, and health history of an area.

A. *The On-Field Process*

Transmission of many infectious diseases is influenced by climatic conditions. Some of these infectious diseases are the most significant causes of elevated mortality and morbidity rates in many developing countries. In many environments, these diseases occur as epidemics, which are generally triggered by changes in the climatic conditions leading to higher transmission rates [2].

An array of sensors and IoT devices will be placed strategically in a designated local area to collect environmental data. As shown in Fig. 1, these devices and sensors will be connected to the Cloud forming a network. The data is sent to the Cloud for storage, and appropriate existing Machine Learning algorithms are applied on it for prediction and analysis. These predictions/results would be visible on the application. The stakeholders (healthcare centers and the government) will decide the course of further action based on the result.

B. *The Application Process and Features*

Users of the application: Citizens and Organizations such as medical facilities or government agencies, as can be seen from Fig. 3.a.

- Citizen Login : Data Input (Refer to Figure 3.b) - Personal Details for identification of citizens, such as their name, age, sex, address, and medical history are required. They can update their personal details at any point in time, and view their medical history too. This would create an EHR for that user.
- Citizen Login : Dashboard (Refer to Fig. 3.c) - Citizens update their symptoms regularly, and can also view their past usage history on the application. The Emergency feature is present to alert nearby medical facilities in case the user faces any emergency medical situation. They can also view the environmental conditions on the Dashboard. The non-classified Analysis results will be displayed in the form of Warnings to ensure citizens are aware of their proximity to potentially dangerous locations. Notifications from the application will indicate alarming proximity to infected persons/areas.

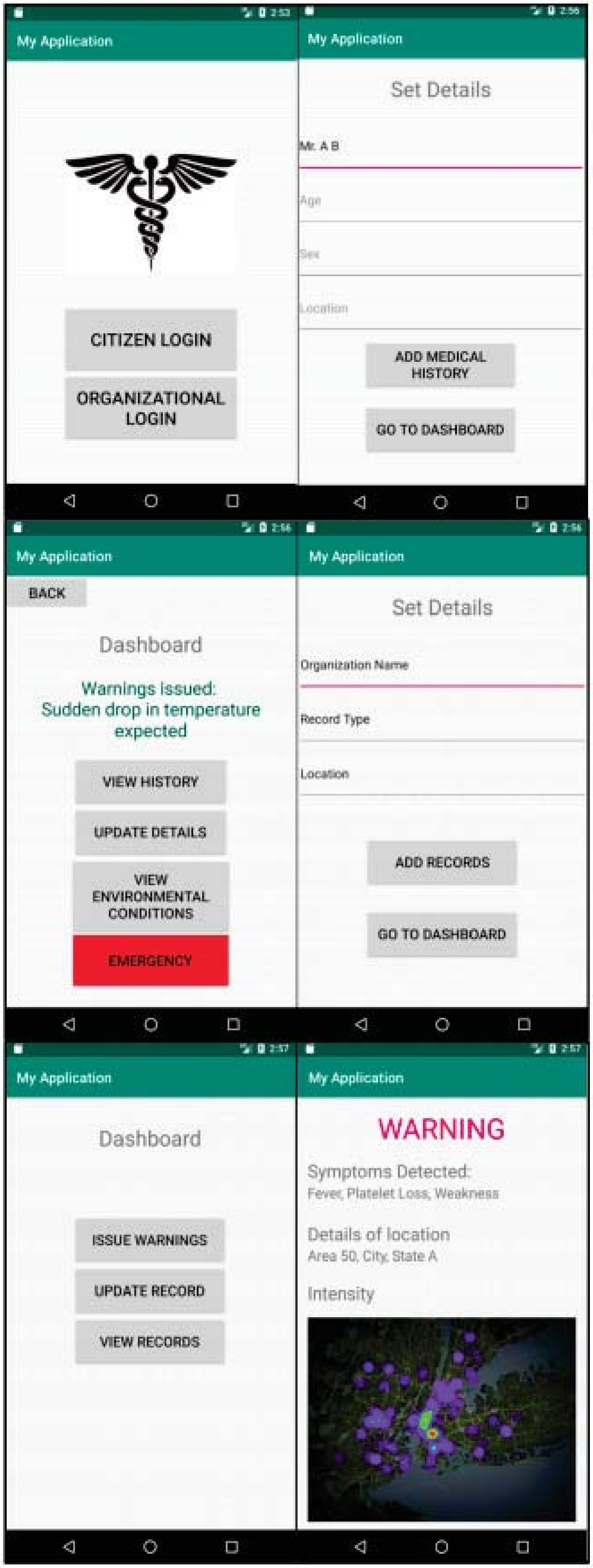

Fig. 3. a) Home Page, b) Citizen Login, c) Citizen Dashboard, d) Organizational Login, e) Organizational Dashboard, f) Display of Data

- Organizational Login : Data Input (Refer to Fig. 3.d) - Basic details such as name, location, and contact information are required as data input. Hospitals update records of their patients as well.
- Organizational Login : Dashboard (Refer to Fig. 3.e) - Organizations can update and view classified information as well as analysis reports, as can be seen in Fig. 3.e. Organizations can issue warnings as well, after viewing classified Data Visualizations. As shown in Fig. 3.f, the warnings may include observed surge in symptoms, concerning areas and visualisations like heat-maps for better understanding for the user.

Features of the EHR (database) will be classified to determine visibility for the type of user, thus maintaining different levels of abstractions for users (citizens, hospitals, government organizations, etc.). This would ensure security of sensitive information.

All users can view weather data fed to the application after being collected on-site and sent to the Cloud Management System.

All the data from the mobile application is input to the Cloud Management System for analysis at three levels - Local, Central and Global. The Data Analysis results including, common symptoms observed, intensity of symptoms and the concerned area, in turn, are displayed on the interfaces for select users.

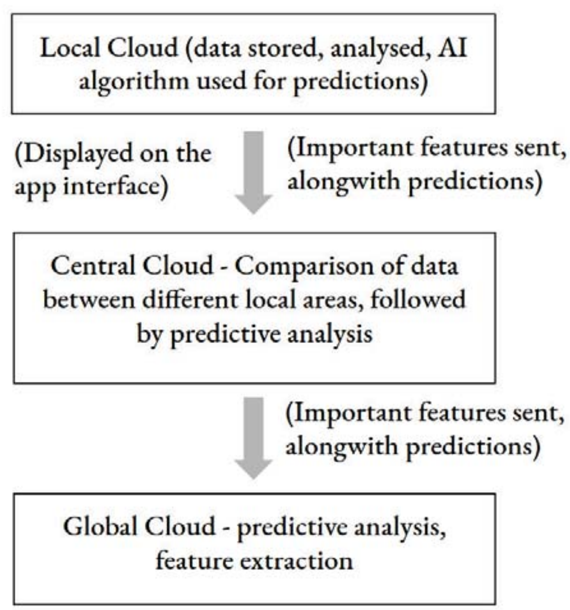

Fig. 4. Cloud Hierarchy System

The hierarchy is established as the data is first sent to the cloud containing only the local data (therefore called the local cloud). At the local cloud level, the data is analyzed for appropriate results and the important insights from the data are extracted. Results obtained are displayed on the application interface and the extracted data along with the results are sent to the next level's cloud network (called the Central cloud). Here the results and extracted data from several Local Clouds are stored and analyzed, connecting and forming a relation between different local areas, thus also giving us city/state wise predictions and not just local area wise predictions. A similar procedure is repeated for the Global cloud.

V. Case Study : Covid-19

We have performed a Case Study on the COVID-19 pandemic data. The integration of digital technology into pandemic policy and response could be one of the several characteristic features of countries that have flattened their COVID-19 incidence curves and maintained low mortality rates. Countries that quickly deployed digital technologies to facilitate planning, surveillance, testing, contact tracing, quarantine, and clinical management have remained front-runners in managing disease outbreak burden. The comprehensive responses of countries that have been successful at containment and mitigation can provide insight to other countries that are still facing a surge of cases [7]. We analyzed the COVID-19 data to check the applicability of the proposed system. This analysis extends to other infectious diseases with outbreak-causing potential as well.

The COVID-19 dataset is openly available for download and usage on Kaggle [8]. Out of the six extensively collated datasets, we worked on the dataset with state-wise details on the number of confirmed COVID-19 cases. The attributes in the dataset include - Number of confirmed cases, deaths and cured persons, with a division of Indian and foreign nationals, for every state since 30 January, 2020.

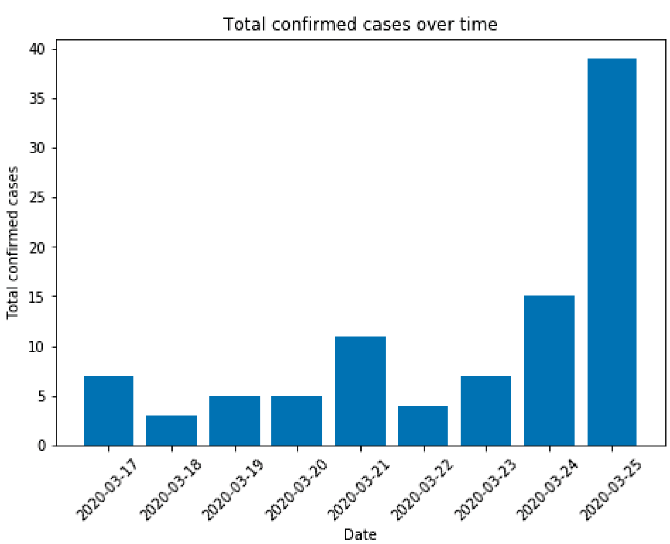

Fig. 5. Time Series Analysis of COVID-19 dataset

Our primary objective was to demonstrate how our system would respond to this data, assuming it collects and processes it real-time. Thus, we focused on a Time-Series Analysis (TSA) of the data in the preliminary stages of the outbreak i.e. February - March. Fig. 5 is indicative of a gradual increase in the cumulative number of confirmed COVID-19 cases recorded in a duration of 9 days. This data would be recorded by our system, through the data collected via the application. The analysis would be performed in the Cloud Hierarchy System, with a display similar to Fig. 5 being generated on the application's dashboard. The inferences from the analysis would indicate an abnormal rise in cases and thereby, the corresponding threat would be realized sooner.

An extrapolation of the Time Series Analysis shows an alarming exponential rise in certain states, such as Kerala and Maharashtra, as is now apparent. Thus, the system can predict a possible outbreak with enough time for preparation for the concerned authorities.

VI. Results

Fig. 6 depicts the algorithmic process of the EWS, which we obtained as a result of our proposed methodology.

VII. Conclusion

Our proposed Early Warning System will be important in the coming years of increased climatic fluctuations and decreased air, water and food quality [5].

It is important for this system to be sustainable, encouraging participation at all levels to expand the reach and efficiency of the health-care system in India. This circular system will fulfil both of these requirements as more data will accumulate over time, promoting reinforcement learning and thereby, the accuracy of prediction.

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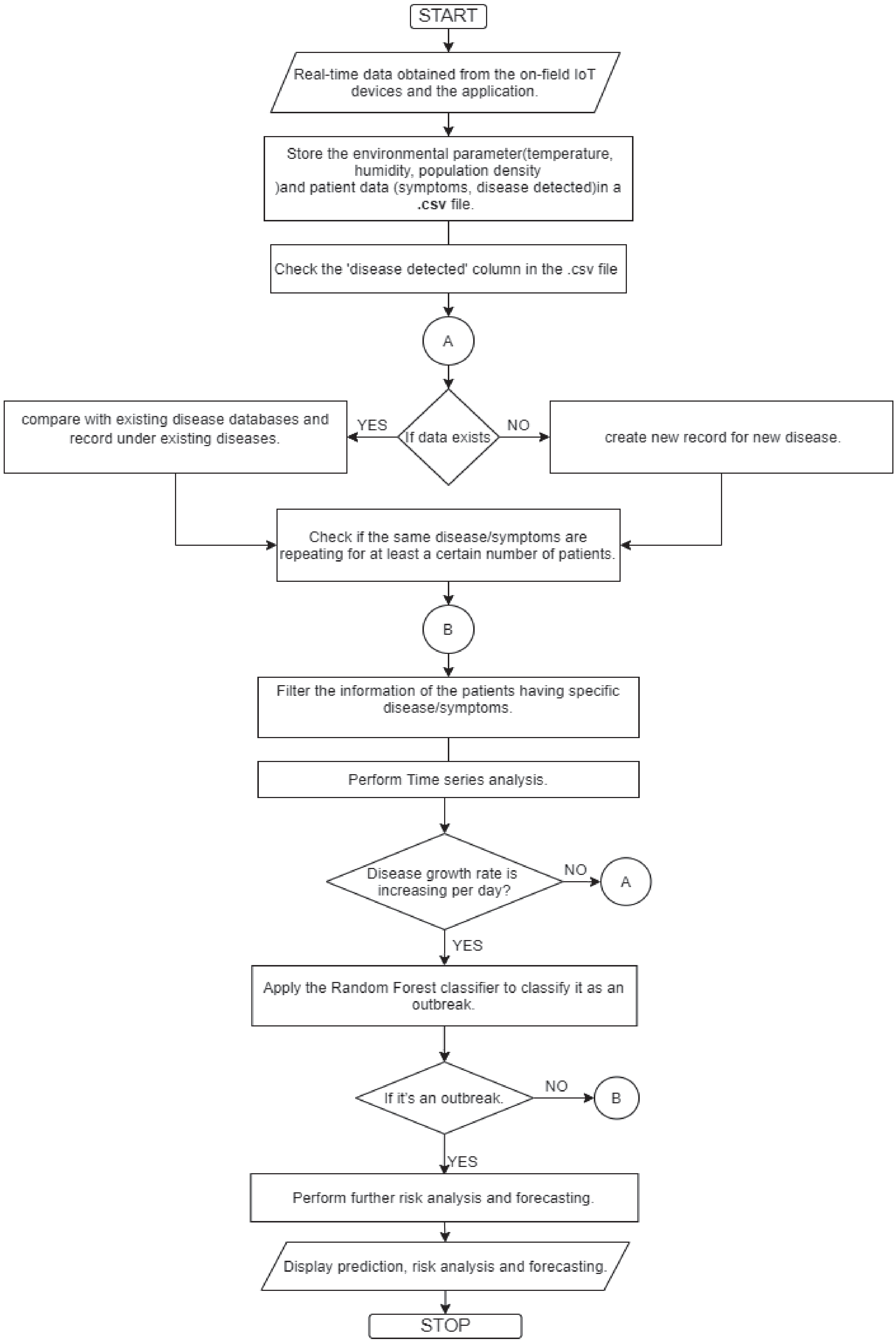

Fig. 6. EWS Process flowchart