A Novel Health Monitoring System using Patient Trajectory Analysis: Challenges and Opportunities

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***Abstract*—Continued advances and cost reduction in mobile devices such as smart phones made them widely used in our daily-life practices such as en route navigation and vehicle tracking. Health applications utilizing these battery-powered devices continue to grow, and so does the demand for effective modeling and analysis tools to support data collected by these devices. Health monitoring applications in particular became very popular these days. However, researchers must overcome many challenges, such as data acquisition, data scales and data uncertainty, in order to develop such applications. In this paper, we propose a novel health monitoring system that can interact with the patient and analyze the patient's moving trajectories combined with data of environmental conditions. We present a system architecture, and discuss ideas and challenges in developing the health monitoring system for asthma patients. This system can provide a better understanding of the effect of environmental factors on triggering health attacks and hence support individual-based health care.**

***Index Terms*—health monitoring, uncertain trajectories, environmental factors, asthma, road networks**

I. Introduction

Relations between negative health effects like asthma and lung cancer and elevated levels of the environmental factors, such as air pollution, tobacco smoke and humidity, have been detected in several large scale exposure studies [8]. Thus, public health care and service systems often require the ability to track, monitor, and analyze patients' trajectories and their relationships with several environmental factors in order to derive conclusions that will help in preventing and treating diseases. Health applications dealing with large volume of continuously moving data objects, such as humans and vehicles continue to grow. However, these applications present significant challenges in terms of data size, data scales, complex structures and relationships, uncertainty, and space and time constraints. Tracking moving objects has been a hot issue recently due to the large number of applications that depend heavily on it. However, individual monitoring of exposure to environmental conditions did not follow the same pace despite its great impact on public health; the general effect on earth has more been the concern. Limited research has been done on techniques for retrieving, storing and analyzing real-time data of patients along with the environmental conditions patients are exposed to.

The main objective of this research is to improve public health care through proposing ideas and directions to develop an effective and efficient real-time health monitoring system that can report potential health threats (e.g., asthma attacks) associated with environmental conditions, support individual's long-term health care management, reduce the cost, effort and time spent in traditional health visits to hospitals, and provide intelligent information that might be useful for improving public health care plans and strategies. Although we are targeting asthma in this paper as it is well known that asthma is highly affected by surrounding environmental conditions [2], [13], our proposed system can be used in improving the general well-being as well as targeting other diseases that are affected by the environment.

This paper focuses on the two main components in developing our proposed system that takes into account the correlation between the time and location of a patient and the level and time of exposure to negative environmental factors; these are patient trajectory tracking and environmental exposure measurement. The first component can be obtained by location tracking devices such as the GPS. The second component not only includes air pollution level but also other measurements, such as humidity and temperature levels, that can be normal to healthy people but not to asthma patients. Finally, we discuss challenges and opportunities to develop the proposed system and conclude the paper.

II. Motivation

A. Health and the Environment

According to the World Health Organization, asthma is now a serious public health problem with over 100 million sufferers worldwide. It continues to be one of the major causes of hospitalization of children in many countries. The number of reported adults and children diagnosed with Asthma in the U.S. in 2009 was 17.5 million and 7.1 million, respectively [17], [6]. Moreover, the number of visits (to physician offices, hospital outpatient and emergency departments) with asthma as primary diagnosis in 2007 was 17.0 million in the U.S. only [19]. In the same year, the number of discharges with asthma as first-listed diagnosis was 456,000 with an average length of stay being 3.4 days [14]. Although scientific advances have led to effective medical interventions to prevent morbidity of the disease, the burden in prevalence, mortality and health care use remains high.

Research has identified several factors associated with the development of asthma, such as exposure to traffic exhaust fumes, tobacco smoke, pesticides and changes in the weather, but none have proven to be the causative agent [2]. Rather the development is a combination of underlying susceptibility with environmental exposures [2], [13]. In addition, these environmental factors associated with asthma have been measured on a general basis, i.e., they are based on summarized data collected in large scale areas (e.g., city), and not based on individual exposure which would more accurately reflect the exposure to such factors at a specific location and time. Moreover, asthma triggers vary and can be very different from one patient to another. Thus, individual-based measurement of exposure is needed to be able to develop more accurate conclusions on causes of asthma attacks.

B. Health Monitoring

There exist some powerful health monitoring systems in this advanced era of information technology. These systems range from smart homes [9] that consist of several intelligent devices built in homes which are able to monitor and provide help to elderly and disabled people, to very tiny sensor chips that can be implanted in the body of patients to provide continuous monitoring of blood pressure, sugar level and other measurements [7], [21]. These types of health monitoring systems are very useful but limited to some conditions. For example, smart homes are useful for patients who spend most of their time at home (e.g., elderly). On the other hand, implanted sensor chips are able of continuously monitoring patients regardless of their locations. However, they are limited by high cost, patients' willingness for a device implant and patients' health condition. In addition, health monitoring may not work for some diseases using these sensors since the development of their attacks may not be measured by sensors. In the case of asthma, for example, it is not enough to depend on physical measurement of implanted sensors as many other factors play a role in triggering an attack. For example, it can be a result of environmental factors as stated earlier.

III. Asthma Monitoring System

This section proposes a health monitoring system that can track the trajectories of an asthma patient in a geographic region and various environmental factors associated with that region, and analyze these data along with the patient health level (peak flow level, for example). The system will be able to retrieve individual patient's location data and several environmental resource data through mobile phones or sensors. Integration of these spatio-temporal data can support the calculation of the patient's exposure to certain levels of the environmental conditions. Using statistical analysis and efficient data mining algorithms to retrieve intelligence information from relations between the patient's locations within time and various environmental conditions, the system can identify the potential asthma attack and provide useful information to the patient that may prevent asthma attacks. The main advantages of the proposed system can be summarized as follows: (1) Continuous monitoring and early attack detection, (2) Data analysis on individual-level to provide risk alerts, (3) Long term treatment based on spatio-temporal data analysis, and (4) Reducing time, effort and cost spent on emergency visits to hospitals and clinics.

A. Architecture Overview

The context and overall architecture of the proposed system are illustrated in Fig. 1. The system consists of data acquisition to acquire data and data integration from different sources to provide user and environment profiles. The internal reference data consist of maps, road networks, etc.

The system enables collecting data from users by various sources. For example, the user's mobile device connected to the GPS is a good source of user location and trajectory. In addition, the user's interaction with social networks or communication via mobile phone (phone number tied to business) etc., are possible data collection methods. The communication via mobile and sensor networks will provide other information of the user such as the current health condition of the user (e.g., users post that they are feeling difficulty in breathing or chest wheezing). These unstructured data can be used to predict the environmental conditions such as traffic, congestion, smoke level, etc. Environmental data, such as air pollution, tobacco smoke, temperature and humidity, can be obtained from standard sensors. Moreover, the user profile tied to user mobile devices provides intimate profile of the user.

Based on the input, area of interest, reference data trajectory and trend analysis, the system computes the interesting output based on the rules configured in the system. The system will provide the output to external systems such as health awareness broadcast systems, public safety systems, pollution control systems, etc. Several rules of filtering and inference provide specific configurations to change the system's behavior without having to change the entire system. Specifications on data acquisition and data analysis parts of the system will be discussed further in the opportunities section.

B. Challenges

A number of challenges exist in developing an online health analytical infrastructure that matches the proposed health monitoring system. The main challenge is the large scale of the proposed system; It requires major public participation/outreach efforts in order to (a) obtain active participation

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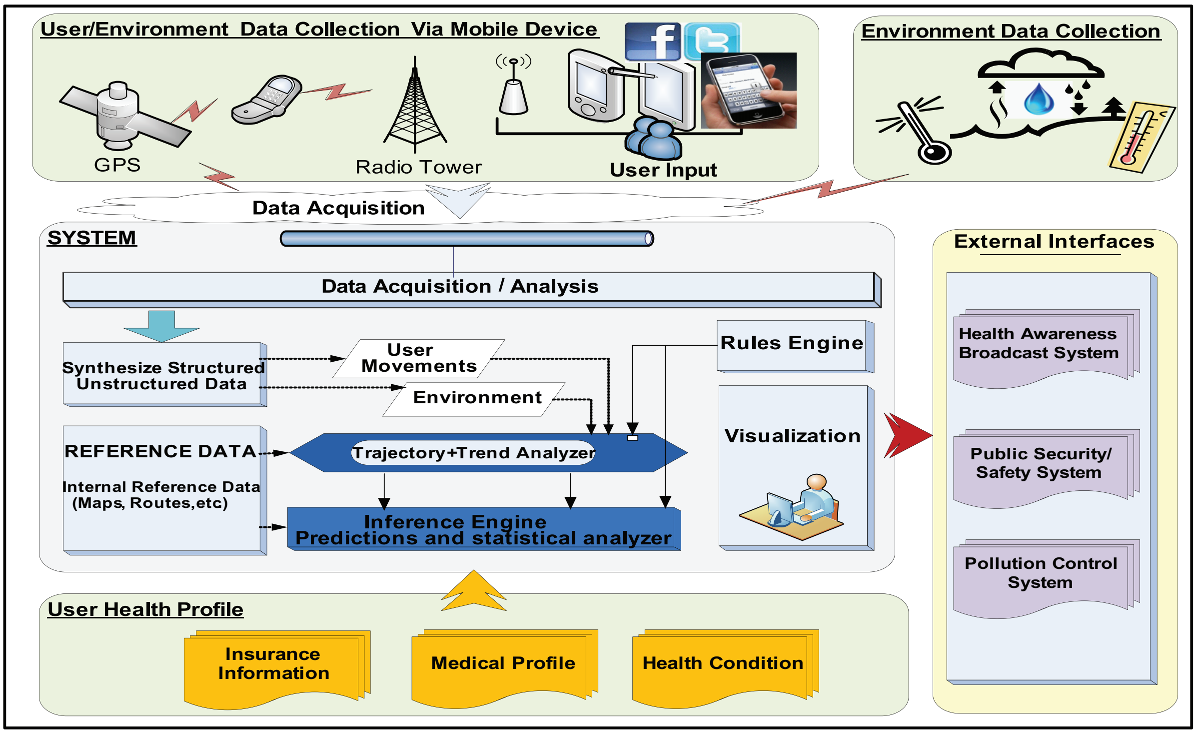

Fig. 1. A health monitoring system using patient trajectory and environmental factors

of the users and (b) limit data distortions. The first can be addressed by providing a high quality human-machine interface to the system with user friendly options to interact with the system. In addition, patients need to be educated about the advantages of such a system and its potential role in saving their lives. The second challenge necessitates providing a lot of training to overcome the expected highly biased data collected. Methods of data training and testing exist and will be tested in the future phases of this project.

Many other technical challenges exist, we only list major ones here:

- Continuous tracking of data with limited resources (e.g., sensor cover radius, mobile device life time, etc.).
- Measuring environmental conditions with a fine scale.
- Accounting for uncertainties because of errors in device measurement and data sampling.
- Integrating different representations of spatio-temporal datasets (e.g., environmental data and trajectories).
- Capturing individual exposure to a certain environmental condition.
- Designing novel spatial join and search algorithms, and accessing methods to improve query performance.
- Developing visualization tools that can be used for data analysis.
- Developing data mining tools that are useful in making conclusions about integrated data
- Protecting and securing medical data of patients.

C. *Opportunities*

In this section, we discuss available opportunities as well as specifications about potential solutions to some of the raised challenges that are of high concern to us at this stage of our work. Two main data sources are required for our proposed system; measuring environmental factors using sensors and calculating the location/time of the patient using his/her trajectory data obtained by the GPS. The goal is to find some rules that will help in identifying meaningful relationship among these datasets that would be useful in measuring the effect of environmental conditions on the health of asthma patients. To achieve this goal, a geostatistical model of spatial autocorrelation need to be developed that would capture the correlation between a patient's trajectory dataset and the environmental factor datasets.

Improvement in technology has been greatly witnessed recently. For example, the development of sensors as well as GPS devices has more and more improved in terms of the miniaturization of the sensing/tracking devices and in terms of the battery life time. In addition, there is a great improvement in the wireless communication including Bluetooth, WiFi and 3G. Different wireless technologies address different system requirements such as coverage; the wireless infrastructure of the system should allow the use of diverse wireless and sensor devices in order to provide a complete support of the system's requirements.

Researchers have very recently proposed algorithms and models that allow the tracking of moving objects without consuming a lot of the tracking device's energy by adapting

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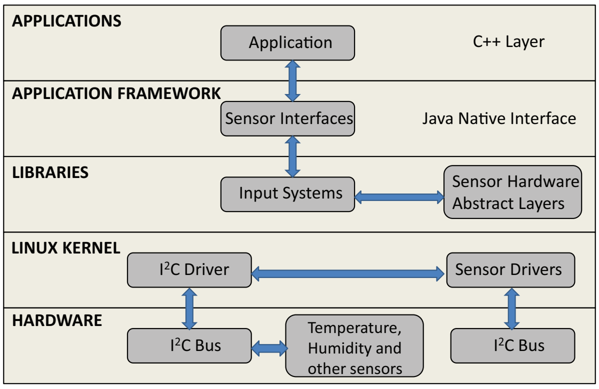

(a) Android sensor network

Component	Hardware
Processor	ARM Processor
Storage	NAND Flash, Micro SD
Communication	Bluetooth
Sensor interfaces	I^2C
Battery life	10 hours
Operating system	Linux, Android, and WINCE
Location based sensors	GPS, GPRS/GSM

(b) Sensing devices

Fig. 2. Android sensor system architecture

to the movement and other parameters of the moving object [11]. The experimental results showed that their proposed system helped in acquiring trajectories of moving objects, yet consuming less battery energy of the tracking device.

D. SpatialGPSLogger: A Data Acquisition System

We now present our ongoing work towards the development of the presented system. We propose a location based data acquisition system called SpatialGPSLogger that uses the GPS on a smartphone device. Environmental data such as air pollution and tobacco smoke cannot be obtained by the smart phone device without proper wireless sensors. Most smart phone systems do not allow users to modify the internal structure and interface sensors. Therefore, a more flexible system than a smart phone is required to continue our study to collect environmental data. The embedded system and sensors as shown in Fig. 2 are used to implement our SpatialGPSLogger. The embedded system runs on an ARM processor and Android operating system and is capable of interfacing various types of sensors through its serial ports. We use this system to interface sensors to retrieve temperature, humidity, and biological signals of patients.

In our approach, SpatialGPSLogger selects a set of sensor data, which retrieves individual's location data through a mobile phone connection to GPS. We plan to port sensor drivers to the embedded system under the Android platform and create applications through the use of Linux kernel to retrieve temperature, humidity, orientation, accelerometer, light, magnetic field, proximity of patients, etc. The platform allows programmers to access raw data from the sensors through the Android sensor network to the application layer on the Android system as depicted in Fig. 2 (a). The application communicates with C++ layer through sensor Java native interfaces. The input system is a Linux framework for all sensors data that defines a standard set of events and it also interfaces to user space through Java native interface. I^2C is a two wire serial interface connection for sensor data to be accessible under Linux kernel. Fig. 2 (b) summarizes the sensing devices that are used to retrieve environmental data.

IV. Related Work

The progress in technology has inspired many to make use of it in monitoring environmental pollution. The authors in [18] used nanotechnology to develop an air pollution monitoring system. The system provides real-time interpolated maps of air quality using GIS which analyzes and displays data collected by "solid state gas sensors". As more signs show the negative effect of bad quality of the environment on health, more sources of assessing environment condition are developed such as "EnviroFlash" [3] which can notify patients about up to date air quality.

With the rapid development in sensor networks, location tracking devices and mobile networks, health care has made a great progress in utilizing these technologies in order to advance Telemedicine [16] applications as well as eHealth [10] services. Through these services, "virtual visits" of patients to doctors became possible. Some patients are now able to skip actual "face to face" visits with doctors for simple tasks like blood pressure and sugar level measurement assessment. In addition, commercial "emergency alert" systems made use of advances in technology to provide immediate help to patients with severe diseases such as heart problems and diabetes which might tackle patients as sudden attacks. An example is the "Invisible Bracelet" (iB) [1] which is supported by the American Ambulance Association that uses the mobile network technology to get immediate help.

Both environmental conditions and locations of moving objects are spatio-temporal data that are uncertain in nature. For example, the concentrate of a specific air pollutant vary from one region to another and from a given time to another and depends on the accuracy of sensors. Also, a GPS device may report a location of a moving object 2-5 meters away from the actual location. Authors in [12] discussed the spatio-temporal modelling of individual exposure to air pollution using data integration. They presented a case study example that uses a deterministic air quality model and a GPS to analyze collected data over an hour period.

Different technologies are available for located-based data acquisition but they are device dependent. Still data collection relies on manual process and this hinders the analysis of individual trajectories and their relationships with environmental conditions. Hence an integration of different technologies is critical for an efficient and automated data acquisition of moving objects.

A patient's trajectory is represented as spatio-temporal data [20] and can be defined as space-time paths of a moving object constrained to road networks. Due to computation and database limitations and limited battery life of mobile devices, trajectories are modeled as discrete points that represent locations in time. This representation results in uncertainty in the location values recorded in the database of the moving object [4], [23]. Existing methods do not provide effective modeling for uncertainty of moving trajectories to support different types of queries to improve query processing.

An environmental condition (e.g., humidity-30%) is also a spatio-temporal measurement that can be modeled as a raster grid for discrete time stamps. Each cell in the grid represents the average value of the environmental factor at a given time for the area. This average value is associated with positional and temporal uncertainties because of the approximations and interpolations used in modeling [12]. These uncertainties in value and position can be characterized based on their probability distribution functions [15].

Data mining on moving objects is a process of extracting useful and interesting information from large sets of spatio-temporal datasets. Existing data mining techniques do not adequately fit the nature of moving objects that continuously change their properties in time and the complex relationships between them. Therefore flexible and scalable data mining tools are crucial in order to find accurate and sufficient information of moving objects' patterns, behaviors and trends. The integration (spatial joins) [5] between the environmental grid representation and the trajectory representation of a moving object will provide information about the exposure measurement of a patient to environmental factors. This linkage of data from different sources leads to ecological inference that has been classified as a special case of the change of support problem [22].

V. CONCLUSION

Health monitoring systems can be thought of as a natural extension to advances in health services and technology including mobile and sensor networks. Their main objective is to analyze real-time data collected from patients and other sources in order to provide individual-based care to patients. Such a system, if developed successfully, promises to reduce the cost, effort and time put in traditional health visits to hospitals.

In this paper, we proposed a health monitoring system that analyzes spatio-temporal data collected from patients. The system analyzes the effect of various environmental factors, such as humidity level, on the health of patients. The proposed health monitoring system gathers time/location data from patients through location aware devices such as GPS, and collects environmental data through sensors. Then, the system analyzes the data using a spatio-temporal integration model to derive conclusions that will help prevent or treat patients. Several intermediate tools are used such as data mining tools and visualization tools. Main challenges and opportunities in developing such a system were discussed.

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