Management of Streaming Body Sensor Data for Medical Information Systems

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Abstract

Data retrieved from body sensors such as ECG machines and new-generation multi-sensor systems such as respiratory monitors are varied and abundant. Managing and integrating this streaming data with existing types of medical information such as patient records, laboratory results, procedures, medical documents, and medical images in a logical and intuitive way is a challenge. Not only is the management of such data difficult but so is the visualization and presentation of the data to physicians, specialists, and patients. Using a new generation of lifeshirts embedded with real time monitors for respiratory and heart functions as a testbed, we propose and have initiated development of a data management system for dealing with such streaming body sensor data, under the framework of an extensible architecture that will support easy visualization of such data.

Index Terms—*Data Management, Streaming Data, Medical Sensors, Information Systems, PACS.*

1. Introduction

Data retrieved from body sensors such as ECG machines and new-generation multi-sensor systems such as respiratory monitors are numerous and abundant. Managing and integrating this streaming data with existing types of medical information such as patient records, laboratory results, procedures, medical documents, and medical images in a logical and intuitive way is a challenge. Not only is the management of such data difficult but also is the visualization and presentation of the data to physicians, specialists, and even patients [1]. Using the VivoMetrics™ LifeShirt [2][3] as a testbed, we have proposed and developed a data management system for dealing with such streaming body sensor data in addition to an extensible architecture that would allow for easy visualization of such data.

Section 2 highlights the VivoMetrics LifeShirt, its capabilities, the types of data generated, and the challenges in managing such data. Section 3 presents a database schema for managing such streaming data and how it is integrated with the existing medical information. It also presents a streaming database architecture that will provide access (possibly real-time) to streaming medical and conventional data

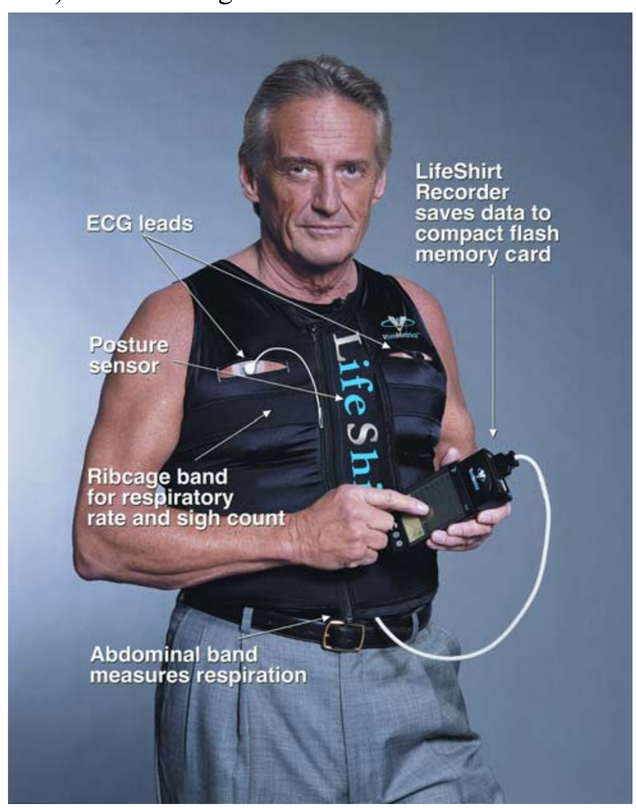

Figure 1. LifeShirt System (Courtesy of VivoMetrics).

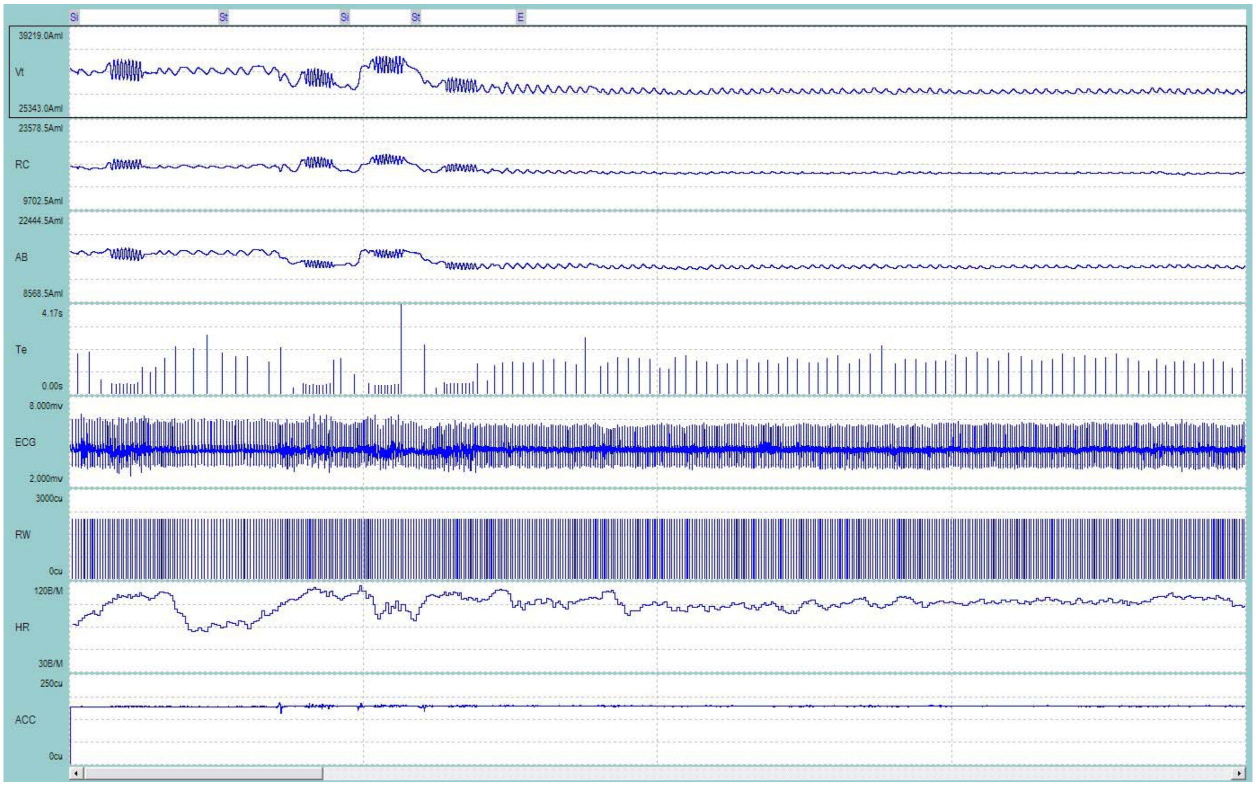

Figure 2. LifeShirt waveforms, a sample of a variety of sensor data streams

(e.g., medical images, laboratory results, medical documents). Section 4 presents future uses for the VivoMetrics LifeShirt in our research.

2. Multisensor systems, The LifeShirt

2.1 Description

The LifeShirt System [2] is an example of an innovative ambulatory multi-sensor continuous monitoring system for collecting, analyzing and reporting health data, capturing an ongoing "movie" of physiologic data rather than episodic "snapshots" collected during periodic office visits. A method of respiratory monitoring called inductive plethysmography [4] enables clinicians to capture a highly accurate view of patients' breathing.

The LifeShirt System is able to collect body data through various sensors, including respiratory bands, which measure pulmonary function (tidal volume, respiratory rate, etc; currently numbering about 24 parameters) as well as electrical activity of the heart (EKG); as is shown in Figure 1. An on-board PDA (currently a Handspring Visor) continuously encrypts and stores the patient's physiologic data on a compact flash memory card. Posture and activity information is also tracked and recorded, and the PDA has an electronic patient diary to record subjective patient data about mood, symptoms and activity. The LifeShirt vest is easy to wear, weighs 8-oz and is machine washable. Sensors are woven into the shirt around the patient's chest and abdomen. A two-axis accelerometer records patient posture and activity level.

VivoLogic, a proprietary PC-based software, decrypts and processes recorded data, and provides viewing and reporting features for researchers and clinicians to view the full-disclosure, high-resolution waveforms (see Figure 2) or look at trends over time. Summary reports can be generated that present processed data in concise, graphical and numeric formats.

2.2 Testbed usage

In our research, we have been using the LifeShirt to generate significant amounts of data. Recently, we have been testing and experimenting with the

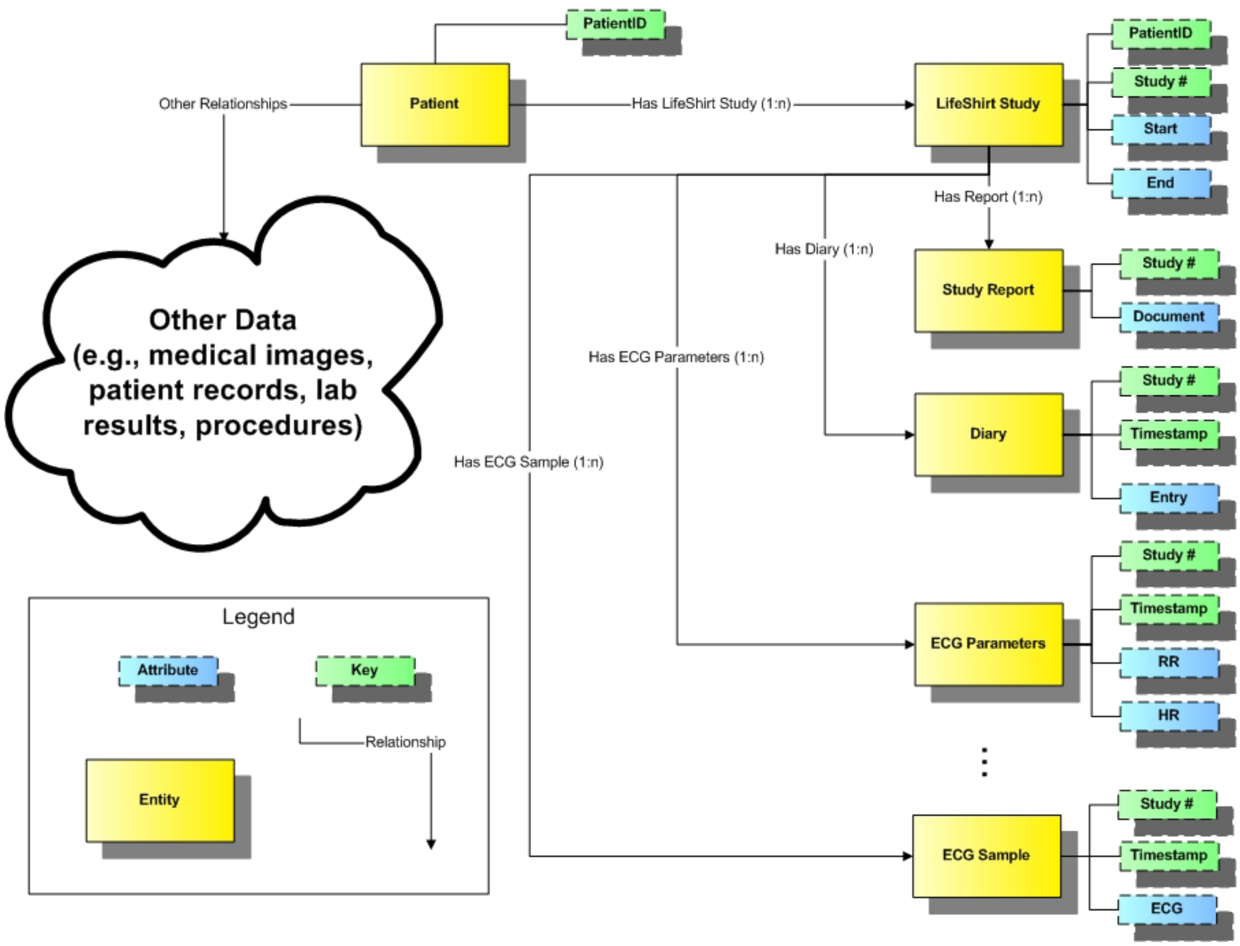

Figure 3. Database Schema.

LifeShirt, through a collaborative effort with VivoMetrics R&D. Five members of our research group in addition to a surgical resident have worn LifeShirt systems and have generated over 25 hours of body sensor data, totaling 1 GB of data. The amount of data generated by the LifeShirt is overwhelming, making storage, management, and visualization of such data challenging. The issue of how to relate and integrate these streams of data with conventional patient information is another challenge.

In collaborative efforts with VivoMetrics, we have also modified the diary feature of the LifeShirt, which allows wearers to enter their current activities while using the LifeShirt. We have developed a database schema using IBM's Universal Database DB2 [5].

Our research efforts will interface with the LifeShirt as well as other future multisensor systems through the PDA and related software that process the sensor signals into clinically meaningful information. The intent is that our innovations be considered by all body sensor vendors as precursors for eventual commercialization and widespread deployment.

3. Database design

3.1 Schema design

Figure 3 shows how the LifeShirt streaming data can be integrated with conventional medical data (e.g., medical images, patient records, laboratory test results, procedures, etc). A patient may have multiple LifeShirt studies, or uses of the LifeShirt. Each study is identified by the ID of the patient that it belongs to and a unique study ID in addition to start and end timestamps. Each study contains a

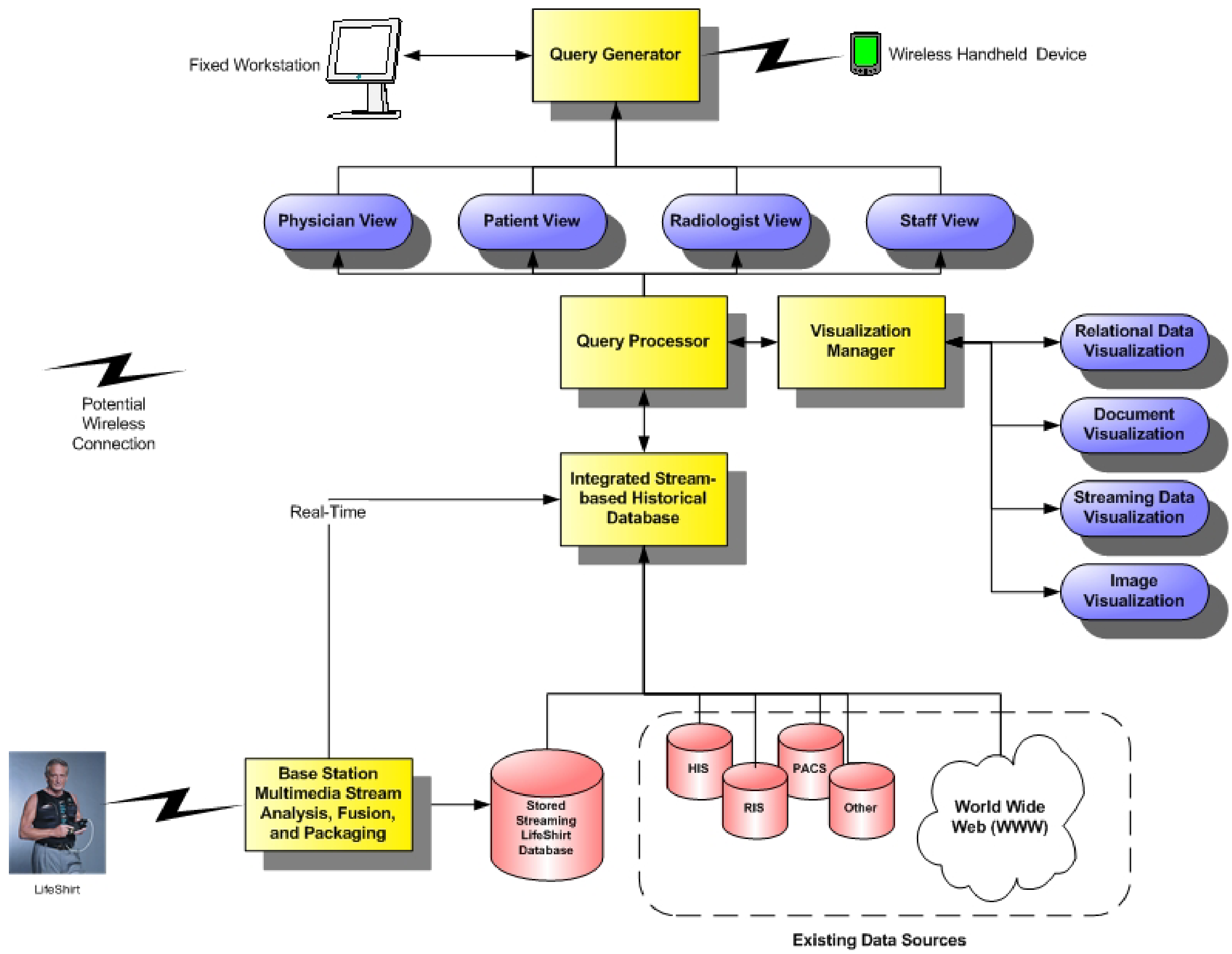

Figure 4. Streaming Database Architecture

study report, a diary, statistics of the study, and numerous data stream signals. Every time a patient wears a LifeShirt, he generates a series of data streams for various body measurements, such as ECG, lung tidal volume, and respiratory rate. Available for exporting out of the LifeShirt and importing into the database schema defined in Figure 3 are: all waves (cut by breath), all trends (cut by minute), raw respiratory waves (cut by sample rate), ECG (cut by sample rate), and ECG Parameters (cut by RR trigger). A cut is the frequency by which data is available for a signal. For example, the ECG cut by sample rate data set has a tuple describing ECG activity for every time the ECG sensor takes a sample (i.e., 200 times a second). A table is defined for each type of export.

After the data has been processed and calibrated using the VivoLogic software included in the LifeShirt system, all these data streams are stored in an IBM DB2 database whose schema we have designed with highlights of it shown in Figure 3. Diary entries are generated and stored in the database in addition to a PDF document containing the automatically-generated study report/summary. The goal of the database is to have the flexibility of storing every possible type of information generated by the LifeShirt system in the database so that it is available for clinician use and study later.

By using the patient identification number, we can easily relate these LifeShirt studies to other conventional medical data.

3.2 Streaming database architecture

Figure 4 shows the proposed architecture for integrating the LifeShirt with a medical information system. Currently, we have defined the *Stored*

Streaming LifeShirt Database (SSLDB) as presented in the previous section. The current implementation of the *Base Station Multimedia Stream Analysis, Fusion, and Packaging (MSAFP)* module is the VivoLogic software that handles data analysis and exportation into the *SSLDB*. The World Wide Web, HIS, RIS, PACS [6], and other existing data sources along with the *SSLDB* will connect to an *Integrated Stream-based Historical Database (ISHDB)*, which will provide a single integrated view of all the available data sources to all the layers defined above it.

Fixed workstations and wireless handheld devices will send queries to a *Query Processor* through a *Query Generator* module, which uses the *ISHDB* to answer the queries issued by terminals and handheld devices. Working with the *Query Processor,* a *Visualization Manager* module will help determine how each query-issuing device will visualize the requested data using handlers defined for each data type. The data may be alphanumeric database data, a document, streaming data, images, or any other types of data for which handlers may be developed later in the future.

Furthermore, views for physicians, patients, and staff will be defined to help control what types of data are available and how they are to be visualized for each audience type. Other types of views for other audiences may also be added to the proposed architecture.

In the future, it is expected that the LifeShirt will be able to transmit data on a real-time basis wirelessly for analysis [7]. As a result, the *MSAFP* module will need to be extended to be able to accept data from the LifeShirt wirelessly on a real-time basis and to be able to package and send data to the *ISHDB* for immediate viewing or to the *SSLDB* for archival purposes.

Although, the LifeShirt is used in the above-defined architecture, the architecture is extensible enough so that other types of data generated by other body-sensors can be used.

4. Future testbed and evolution

A plan is being formulated to explore the use of the LifeShirt in monitoring a small test bed of volunteers and eventually patients undergoing lung operations, obtain daily snapshots (several hours a day) of their respiratory and heart conditions (not possible in today's medical practice), and investigate what measured body parameters may be the most pertinent in anticipating complications frequently encountered (such as pneumonia and arrhythmias). The hypothesis is that the measured parameters may lead to the ability to anticipate and thereby prevent, alleviate or at least mitigate such complications. This tested will exercise our technical thrusts and innovations, and lead us to the needed evolution in the information technology proposed herein and to exploit the evolving body sensor advances to improve health-care.

We are also building a real-time wireless emulator using the data gathered by the LifeShirt to test applications (e.g., *ISHDB*), since current technology that would allow for this type of transmission of medical information is not readily available.

5. Conclusion

We have presented database system architecture and a database schema that will allow for easy integration of large volumes and types of streaming body-sensor data. The extensible architecture proposed will not only provide a single view of all available data, but also allow for the use of various types of multimedia data, which are already numerous and are expected to grow in the near-future. It is anticipated that this information is to be continuously (real-time) and wirelessly transmitted at high frequencies.

We are progressing with further development and implementation of the data model and architecture proposed, while keeping in mind that future developments in wireless body-sensor technology will provide faster and more volumes of continuous data on a real-time basis.

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