BEAT: Bio-Environmental Android Tracking

Michael Mitchell, Frank Sposaro, An-I Andy Wang, Gary Tyson
{mitchell,sposaro,awang,tyson}@cs.fsu.edu

Department of Computer Science, Florida State University, Tallahassee, Florida 32306, USA

***Abstract* — We introduce BEAT (*B*io-*E*nvironmental *A*ndroid *T*racking), which provides methods for collecting, processing, and archiving one's daily vital and spatiotemporal statistics using off-the-shelf wireless devices and biologic and environmental sensors. BEAT can operate in a self-contained manner on a mobile device and analyze vital information in real time. It uses statistics such as heartbeat variance and range thresholds to issue alerts. Alerts are propagated in a tiered fashion, so that the end user and his/her social contacts have a chance to detect false alerts before contacting medical professionals. BEAT is built on the open Android platform to support a diverse class of mobile devices. The framework can be extended to a full-fledged personal health monitoring system by incorporating additional biosensor data such as blood pressure, glucose, and weight.**

***Index Terms* — Biosensors, Context-aware services, Medical information systems, Mobile computing, Sensor systems and applications, Telemedicine.**

I. Motivation

Heart disease is a leading cause of death in most developed nations. In the U.S., cardiac-related fatalities rank first, being responsible for 26% of all deaths [1]. The most common sub-group of this category is coronary heart disease, attributable for 17.5% of all fatalities [1]. Coronary heart disease is the decreased or diminished ability to provide circulation to the cardiac muscle, which can lead to cardiac attacks and arrests. Each year, there are 1,255,000 coronary attacks, with 1/3 of them fatal [1]. However, 20% of mortalities can be prevented with personal monitoring systems [2].

Traditional personal monitoring systems typically use laptop computers and/or external storage media later connected to a desktop computer for analysis. Newer personal monitoring systems incorporate smaller mobile computing units (e.g., cell phones). However, many systems are not interactive [8]; gathered sensor information lacks real-time feedback from the monitored users. Others tend to rely on third-party service for data storage and analyses, which impose unnecessary constraints on the deployment model and associated power consumption.

The advent of smartphones, with their continual increase in computing power, storage capacities, and built-in sensors, offers a unique opportunity to address the above constraints. We introduce BEAT (Bio-Environmental Android Tracking), which exploits the increasing capabilities of smartphones to support local storage and analyses of data, as well as real-time monitoring, feedback, and emergency response.

II. Current Systems

Several systems have been developed to bring medical-grade data gathering and analysis out of the hospital and into the home. The system presented in [3] incorporates mobile devices and uses threshold-based algorithms to detect life-threatening arrhythmias. Others have used sensors to monitor medical conditions such as obstructive sleep apnea [4]. Even detection of stress levels [5] has been proposed using threshold-based personal monitoring.

Wireless body-area networks: Wireless body-area networks are intended to be composed of passive sensor nodes, active actuator nodes, and a wireless personal device [6]. The passive nodes collect data (accelerometer, heart rate, etc.), and the active nodes perform operations (dispense medicine, release insulin, etc.). Both communicate with a personal device for more complex operations. However, the focus has been on system architecture and service platforms for extra-body communication [7]. Larger challenges are how to engage patients in a dialog about their health, and how to make it easy for patients to manage their chronic care.

m-Health: The MobiHealth system has developed a way to transmit vital signals over public wireless networks to health-care providers. It relies mostly on an m-health platform that connects medical professionals with end users [8]. The use of third-party monitoring services may be problematic due to the lack of bandwidth and coverage in the current network. The high power consumption required for transmitting large data files wirelessly also highlights the need for processing data on the mobile device whenever possible.

Fitness: The fitness industry has also adopted personal monitoring systems that track weight and physical activity levels. Other devices have been created that use accelerometers as pedometers and as well as various wrist-watch-like devices to display heart rate. Several of these systems operate with an external storage device, allowing additional processing, user inputs, and other communications.

III. The BEAT Design

BEAT provides methods for collecting, processing, and archiving one's daily vital and spatiotemporal statistics by integrating an Android device with commercially available biologic and environmental sensors.

With all the capabilities of modern smartphones, data can be processed and analyzed locally, to alleviate network bandwidth overhead [9]. This approach not only saves power, but also allows real-time interactions with the user to further tune system behaviors.

The choice of mobile operating system*:* The choice of operating system (OS) is critical when designing an open framework that will be deployed on multiple device types. While Symbian and RIM devices continue to dominate the global smartphone market [12], their market shares, along with Windows Mobile, have experienced declines, while Android and iPhone are gaining rapidly. Android and iPhone have sophisticated application marketplaces, which provide easy access to both software distribution and maintenance channels. Though the iPhone platform is more mature, Android has been gaining considerable momentum, with 70,000 applications and over 1 billion downloads as of July 2010 [13].

There is a major distinction between the two promising OS options. In contrast to Apple's proprietary source code, Google's Android is open-source, which provides developers access to OS code. This paradigm enables rapid development of prototypes that can utilize system resources. Programming the device at both the application and OS levels provides superior customization and functionality over the iPhone OS. Android also utilizes the Java programming language at the application layer, which enables applications to be run in a Java Virtual Machine. This allows applications to behave consistently on every device, reducing platform dependencies and backwards compatibility problems [14].

Real-time monitoring: BEAT performs analyses of both short-term and long-term patterns and provides notifications to the user. Threshold-based algorithms are used for real-time monitoring. If the beats per minute detected deviate from user-defined thresholds, the unit invokes a pre-defined handler function to raise an alarm. For example, if the user is exercising and their heart rate exceeds a desired range, BEAT will notify the user to slow down. The data is also stored at user-specified granularities for inspection and trend analysis. Optionally, the data can be uploaded to health professionals.

Emergency response: In the event of an emergency, notifications are first issued to the user, who may identify a false positive (e.g., monitoring strap removal, adjustment). If there is no response within a defined time, communication to the user's pre-specified social contacts is attempted. If contact is made, social contacts can evaluate the situation further and alert emergency personnel. By using this multilevel-flow, emergency alerts can be canceled by the user. All threshold values can be customized based on individual needs [15].

Contextual data analyses and user interactions: BEAT categorizes events by processing the collected data. Based on the current state and patterns of the biologic and environmental sensors, BEAT can prompt users to enter additional data. To illustrate, if the heart rate monitor detects an increase in pulse rate, the accelerometer detects movement, and the GPS detects a frequent change in location, it can be inferred that the user is exercising. Threshold parameters are then adjusted automatically to minimize interactions with the user.

In cases where only heart rate may spike, with no accelerometer and GPS activity present, the user is prompted to provide simple feedback on his/her physical symptoms and whether BEAT has raised a false alarm. This feedback is stored to be used in machine-learning algorithms for guiding future interactions, to reduce false alarms and unnecessary interactions [11]. This design is comparable to similar emerging systems such as automated wandering detection for dementia patients [10]. For such cases, the data set can be flagged for further analysis by medical professionals.

Long-term analysis: Long-term patterns can be extracted from incremental base-line data checkpoints over time. Even gradual changes can be tracked, thus enabling the earliest possible detection of an emerging condition. With the user's permission, health history and analysis can be uploaded from the device to health professionals periodically or on demand.

Power management: Another requirement of the BEAT framework is low power consumption. This relates to both the collection of external sensor data as well as the transmission of this data to third parties, as needed. User-tunable parameters can also help reduce the polling frequency if verbose data is not required.

Uploading sensor data to medical-care providers also influences the power overhead of the system. Data compression can help limit the size of the required transmission, thereby reducing power to transmit. Unfortunately, the compression process itself requires power to perform. To sidestep this constraint, compression, analysis, and transmission can be deferred until the mobile device is connected to an external power.

IV. IMPLEMENTATION

Hardware: The BEAT framework uses the Zephyr Bluetooth HxM monitor - a small, lightweight sensor, with embedded power supply worn across the chest. It utilizes the conductive Zephyr Smart Fabric strap and embedded ECG electronics to calculate heart rate.

The HxM monitor provides ~24 hours use per battery charge, with a Bluetooth operating radius of ~30 ft.. In addition to ECG electronics, the monitor is equipped with a 3-axis solid-state accelerometer, which can additionally calculate strides, distance covered, and speed data. The monitor operates in Bluetooth slave mode. Once a connection is established with an Android device, the monitor will continually broadcast transmissions at one second intervals through the duration of the connection.

Software: BEAT was developed using the Android Framework API level 6, targeting device platform versions 2.0 and newer. The Linux kernel versions varied between devices tested, ranging from 2.6.29 to 2.6.35. Initial prototypes of the BEAT system required customized kernel builds; however, with the Android 2.0/2.1 release (API level 5) this requirement was removed. The release provided BEAT native access to the Java Bluetooth API, enabling enhanced functionality such as service discovery and the ability to create the necessary Bluetooth serial (RFCOMM) channel with the Zephyr device. Removal of the custom kernel requirement allows the BEAT system to be deployed on any existing Android device 2.0 and newer.

The BEAT framework consists of a set of interoperating applications including a system service, a data viewer, a data logger, and emergency alert (Figure 1). Communication among the separate entities of BEAT is achieved through the use of a shared data channel called a ContentProvider and through Intents, which are messaging structures used to launch Activities (user interactions), initiate services, or broadcast communications. Modular BEAT components register BroadcastReceivers that respond when specific Intents occur. The ContentProvider contains an embedded SQLite database and provides a common interface to all Android packages.

At system initialization, BEAT first connects the phone with the heart-monitoring device. A dedicated user Activity allows the phone to scan, pair, and connect with the device using the Android Bluetooth API. The Bluez kernel sub-system utilizes the hciattach daemon to connect to the hardware-specific UART driver. Once paired with an Android device, a RFCOMM channel is established, and prior to Activity termination, a dedicated thread is spawned to maintain this communication channel.

When the thread detects an incoming packet, it first performs a CRC check to ensure data integrity. Data packets that fail the check are discarded. Acceptable packets are parsed and packaged into an Intent object. The Intent is assigned a HEART_BEAT action and is broadcast to the system. Multiple components of BEAT register BroadcastReceivers responding to this Intent, including the data viewer and logger.

On receipt of a HEART_BEAT Intent, the live data viewer application updates its values to reflect the latest received heart-rate data. The gathered data can be viewed both numerically and in time-series graphs within this interface. The BEAT logging component also contains a BroadcastReceiver registered to listen for the same HEART_BEAT Intent. Once received, the logger stores the data from the Intent in an internal buffer. A user configurable parameter (default 60 sec/write) determines the write frequency from this temporary storage into the BEAT ContentProvider and underlying SQLite database.

If BEAT identifies that heart-rate exceeds predetermined thresholds, it initiates the Alert process by broadcasting an Intent of ALERT action. This Intent starts a dedicated Alert Activity that waits for user feedback for dismissal of a false positive. This time window was selected to be 10 seconds (configurable). If response is not made within this interval, the alert Activity retrieves emergency contact information from the BEAT ContentProvider and issues a CALL Intent and enables speakerphone via the system's AudioManager.

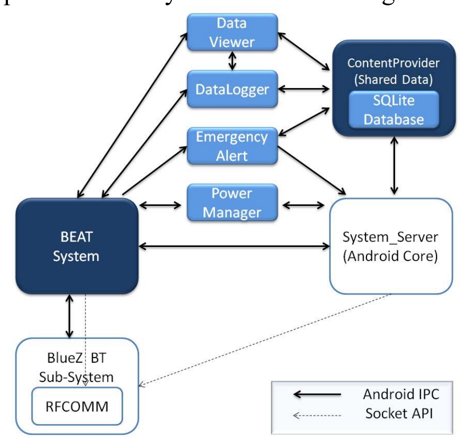

FIGURE. 1. VARIOUS BEAT COMPONENTS (SHADED BOXES).

V. EVALUATION

Evaluation of the BEAT framework was performed by measurement of the storage consumption rate of logging data from multiple sensors, and power consumption due to local data analyses and transmissions.

Storage: While short-term monitoring and archival of data may require a trivial amount of storage space, long-term storage necessitates additional design considerations. The data storage requirements (Tables I and II) are well within the range of today's devices, even without employing filtering techniques or data compression. LempelZivWelch compression was used, however, to reduce the amount of data required to be transferred.

Power overhead: Power consumption of the BEAT framework was measured using PowerTutor [16]. Also tracked were the Android Dalvik log and active applications. This additional data ensured that the power overhead accurately depicted the incremental draw of the BEAT framework and Bluetooth sub-system.

The Android devices used for power profiling included the HTC G1, Nexus One, Droid Incredible, and EVO 4G. At present, the BEAT system requires ~550 mW for operation. This is largely due to the Bluetooth sub-system and remains a major issue for the BEAT system. However, with the upcoming release of Android 3.0, we expect improved power efficiency.

TABLE I: PROJECTED NUMBER DATA POINTS FOR EACH SENSOR.

	Heart rate	GPS	Accelerometer
Minute	3	2	180
Hour	180	120	10,800
Day	4,320	2,880	259,200
Week	30,240	20,160	1,814,400
Month	907,200	604,800	54,432,000
Year	10,886,400	7,257,600	653,184,000

TABLE II: SIZE ESTIMATION OF DATA FROM VARIOUS SENSORS (KB)

		Day	Week	Month	Year
Heart rate	Raw	22	154	4,620	55,440
	Compressed	6	42	1,260	15,120
GPS	Raw	6	42	1,260	15,120
	Compressed	3	21	630	7,560
Accelerometer	Raw	310	2,170	65,100	781,200
	Compressed	150	1,050	31,500	378,000

VI. FUTURE WORK AND BROADER IMPLICATIONS

The addition of context analysis to the BEAT system is currently under implementation. However, early results have shown that even with thresholds alone, BEAT can provide meaningful service. Context analysis can also incur more overhead, but this is not foreseen as a major issue as smartphones rapidly evolve. Other difficulties relate to the measurement of false positives. This evaluation requires interaction with patients suffering from heart conditions. Negotiations with local senior centers are currently under way to further evaluate the BEAT platform.

BEAT is designed to be extensible. Additional sensors can be incorporated to gather other vital readings such as blood pressure, glucose, and weight [17]. Biosensors capable of monitoring these variables can be paired via Bluetooth radio and integrated into the BEAT framework.

The large volume of uniform data collected by the BEAT system from multiple individuals can also be of importance to medical professionals. This enables the use of correlation studies on observed variables. New early warning signs for life-threatening conditions may be identified based on these studies. In addition, there is the potential for more timely and detailed feedback for large-scale medical studies of new treatments or medications.

VII. CONCLUSION

By leveraging the power of Android, the BEAT system provides the short-term information needed for users and caregivers to react in real time to, or even prevent, life-threatening events. It also provides the long-term information needed for health-care providers to make lifestyle and medication recommendations. In combination, these will afford the user a more independent and higher quality of life. The BEAT system can be tailored to the individual, and with the ability to integrate additional sensors, the system has the potential to do even more.

REFERENCES

[1] Xu J, Kochanek KD, Murphy SL, Tejada-Vera B. Deaths: Final data for 2007. *National Vital Statistics Report*, 58(19), May 2010.

[2] Shah NB, Der E, Ruggerio C, Heidenreich PA, Massie BM. Prevention of hospitalizations for heart failure with an interactive home monitoring program. *69th Scientific Session of the American Heart Association*, 1997.

[3] Ledijdekkers P, Gay V. Personal heart monitoring system using smart phones to detect life threatening arrhythmias. *19th IEEE Symposium on Computer-Based Medical System.* June 2006.

[4] Oliver N, Flores-Mangas F. Healthgear: A real-time wearable system for monitoring and analyzing physiological signals. *International Workshop on Wearable and Implantable Body Sensor Networks.* 64-68. April 2006.

[5] Picard RW, Du CQ. Monitoring stress and heart health with a phone and wearable computer. Motorola Offspring Journal, Vol 1. 14-22. 2002.

[6] van Dam K, Pitchers S, Barnard M. Body area networks: Towards a wearable future. *Proc of WWRF kick off meeting*, March 2001.

[7] Latre B, Braem B, Moerman I, Blondia C, Demesster P. A survey on wireless body area networks. 2007.

[8]Van Halteren A, Bults R, Wac K, Konstantas D, Widya I, Dokovsky N, Koprinkov G, Jones V, Herzog R. Mobile patient monitoring: The mobihealth system. *The Journal on Information Technology in Healthcare*, 2(5):365–373, 2004.

[9] Jones V, Gay V, Leijdekkers P. Body sensor networks for mobile health monitoring: Experience in Europe and Australia. *The Fourth International Conference on Digital Society*, February 2010.

[10] Sposaro F, Danielson J, Tyson G. iwander: An android application for dementia patients. *Conf Proc IEEE Eng Med Biol Soc*, September 2010.

[11] Sposaro F. and Tyson G. ifall: An android application for fall monitoring and response. *Conf Proc IEEE Eng Med Biol Soc.*, 1, 2009.

[12] Miller M. Google android smacks down windows mobile in latest gartner data. May 2010.

[13] Zeman E. Android market: 70,000 apps, 1 billion downloads. *InformationWeek*, July 2010.

[14] Google. Android developer's site. July 2010. developer.android.com.

[15] Sposaro F, Tyson G. Geriatric medical application suite on a sweet phone. *First AMA IEEE Medical Technology Conference on Individualized Healthcare*, March 2010.

[16] Zhang L, Tiwana B, Qian Z, Wang Z, Dick R, Mao ZM, Yang L. Accurate Online Power Estimation and Automatic Battery Behavior Based Power Model Generation for Smartphones. *Proceedings of CODES+ISSS*, October 2010.

[17] Agarwal S, Lau CT. Remote health monitoring using mobile phones and web services. *Telemedicine and e-Health*, 16(5), June 2010.