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SENSOR FUSION IN WEARABLE IoT HEALTH MONITORING SYSTEM

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ПОЄДНАННЯ ДАТЧИКІВ В ІОТ-СИСТЕМІ МОНІТОРИНГ У ФІЗІОЛОГІЧНОГО СТАНУ

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Wearable IoT-based systems are used for health state monitoring. Monitoring includes several parameters of the health state received from the device. Many simultaneous measurements of the health status obtained from several sensors are integrated into the wearable body area network (WBAN). The important task that directly effects to monitoring system performance is a data fusion from several heterogeneous sources. The effective approach for sensor fusion is currently an actual task. The article presents the design, development, and implementation of the IoT-based wearable system for biomedical monitoring. The stages of research include (1) development and implementation of the wearable device, so-called wearable body area network (WBAN) of biomedical sensors for health state monitoring; (2) data acquisition and collection technique of biomedical physical activity parameters; (3) Bayesian approach for sensor data fusion.

Keywords*: wearable health monitoring system, IoT-based system architecture, sensor fusion, Bayesian approach*

1 Introduction

Activity detection and classification using different sensor modalities have emerged as actual technology for real-time and autonomous monitoring in behavior analysis, ambient assisted living, the activity of daily life, elderly care, rehabilitation, entertainments and surveillance in smart home environments.

Information technology and IoT development allow monitoring of a human health state using inexpensive, wearable devices. Health monitoring systems are the most common among of IoT systems. It's been designed for the acquisition, processing, collection, and analysis of human health state data.

Current trends in the development of vital sign monitoring technologies demonstrate that the future points in the direction of the introduction of sophisticated diagnostic devices that integrate several diagnostic measures into one all-purpose instrument or probe.

There are several challenges associated with data sensing. A few of the challenges are:

- A distributed environment of the wearable sensors networks which are the subset of IoT.

- The highly heterogeneous nature of IoT due to various heterogeneous devices and data.

- Nonlinearity and tracking issues like multi-target tracking, cost-effectiveness, error mitigation, asynchronous and track-to-track problems.

There are many trends in the implementation of fusion strategies to combine sensors data, extract features and apply classifiers to different issues, offer higher generalization, and tackle challenging problems.

Heterogeneity in the IoT environment is a challenging issue to handle during system integration due to disparate sources of data. These data sources cannot be combined as it is, methods are required to transform heterogeneous data to homogeneous space. Further heterogeneous datasets add uncertainty. Complex multivariate relationships among the datasets. However, fusing data from heterogeneous observations promises to find complex multivariate relationships among the data sets.

In this paper, the IoT wearable system for health monitoring with data acquisition and data management is described. The proposed system presents new contributions since it introduces the use of a novelty sensor data fusion for data management, the application of Bayesian approach, which allows one to detect and classify different kinds of physiological state of people.

In this paper: Section 2 presents a techniques overview of health monitoring systems. Section 3 describes the proposed health monitoring systems. In Section 4 present biomedical data acquisition techniques. Section 5 provides a brief description of the data fusion technique and present the result of biomedical data fusion.

2 Related work

The information technology modern innovation is a reason for the development of the health monitoring system using wearable devices. In article [1] present introduction to wearable medical sensor-based systems, components that constitute such systems, challenges associated with their design and development. The

authors described various services, applications, and systems that have been developed based on wearable medical sensor-based systems and discussed their design goals and challenges systems. In research [2] the technology trends of wearable body sensor networks and some key techniques of future wireless health care services based on wearable body sensor networks are discussed. The authors [3] present the development of a wearable heart rate monitoring system. They have developed the wearable device for real-time acquisition and analysis of heart rate signal. Data is stored on the server and it's available for viewing status. Data transmission is carried out using a smartphone. In research [4] mobile health monitoring application is described, that includes a real-time signal receiver, ECG signal processing, and visualization, data management.

Wearable health monitoring systems are most often represented several sensors that record various parameters of the user's physiological state. The obtained sensor signals are heterogeneous, measured by different units. It's can affect the correctness of data analysis.

Data fusion of human health feature for knowledge discover provides excellent means to combine heterogeneous sensor data. Features extracted from sensor data are combined using some methods.

Data fusion techniques classified [5] based on the mathematical methods as follows:

- Probability-based methods including Bayesian analysis, statistics, and recursive operators.
- Artificial Intelligence based techniques including classical machine learning, fuzzy logic, and genetic evaluation.
- Theory of Evidence-based data fusion methods.

Probabilistic techniques are the most classical, are less complex and the most widely used for data fusion. The some of the most widely used probability-based methods for data fusion in recent times are Bayesian theory, Markov Chain and the Monte Carlo method. The Bayesian approach constitutes a prior definition, its specifications and posteriors computations. Several Bayesian approach-based data fusion methods are proposed in [6, 7, 8]. Bayesian approach for multi-channel data fusion of heart rate used in [9].

In the health status monitoring system authors [10] also applied the analysis based on Bayesian probability theory.

3 IoT-based wearable system for health monitoring

3.1 System Design

In this section the stages of wearable IoT-based health monitoring system design are present.

WBAN is a subset of wearable biomedical sensors for control, stimulation, treatment, substitution of the biological and physical functions of the human organism [11]. The biomedical sensors are directly integrated into a wearable device, thus forming a wearable body area network (WBAN). WBAN controls the physiological parameters of the human body and is used for data acquisition, collection, and transmission [1].

IoT wearable system for health monitoring includes following components.

Health monitoring device

The wearable device is responsible for data transmission and then transmitting to the gateway through a wireless network.

Transmission and storage of health monitoring data

The power supply of a wearable device is limited and it's using for continuous data storage and analysis is beside the purpose. Data collection and transmission can be carried out in real-time or packet data transmission to the remount server. It provides fast and convenient storage of user's physiological data. Complete user's monitoring data, processed data is available through a web application. Information is available for the user or person who has the appropriate access can get information to user's personal data.

Web-application for remount health state monitoring

The user can access the cloud storage and health state data through a web application. In addition to real-time signal data visualization, there is also a possibility the user's historical data, selecting of the health state data period.

The architecture of the developed wearable health monitoring system is present by three main components as shown in Fig.1.

Device level is present by WBAN, that includes the next sensors: accelerometer, heart rate sensor, body and environmental temperature sensors. WBAN receive the physiological signals of the user's organism, environment, and directly represents as a wearable device.

Data from the device is transmitted in real time or as the packet data to the remount server for further processing and analysis.

Data access is carried out through a web application.

3.2 Wearable device level

The wearable device is responsible for health monitoring data acquisition, collecting and it transmitting to the gateway through a wireless network. The device location is the forearm. This device location will make it possible to use more sensors and obtain more accurate data, to find hidden patterns using same additional sensors in the future.

As shown in Fig. 2, the health state monitoring node of the developed system includes: 1) sensors module, 2) controller module with a wireless adapter, and 3) power module.

1) *Sensors module* - is the basis of the monitoring device. It is responsible for the user's health state data obtaining. Module presented by the following sensors: accelerometer, heart rate sensor, body, and environmental temperature sensors. Through sensors certain parameters of the user's and the environment physiological state are collected:

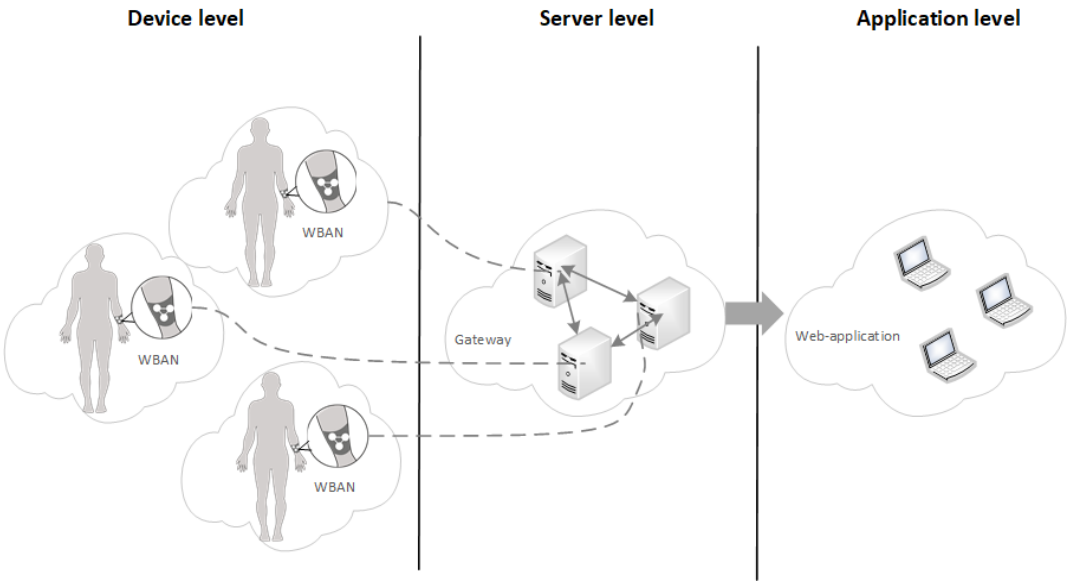

Fig. 1. Health monitoring system architecture

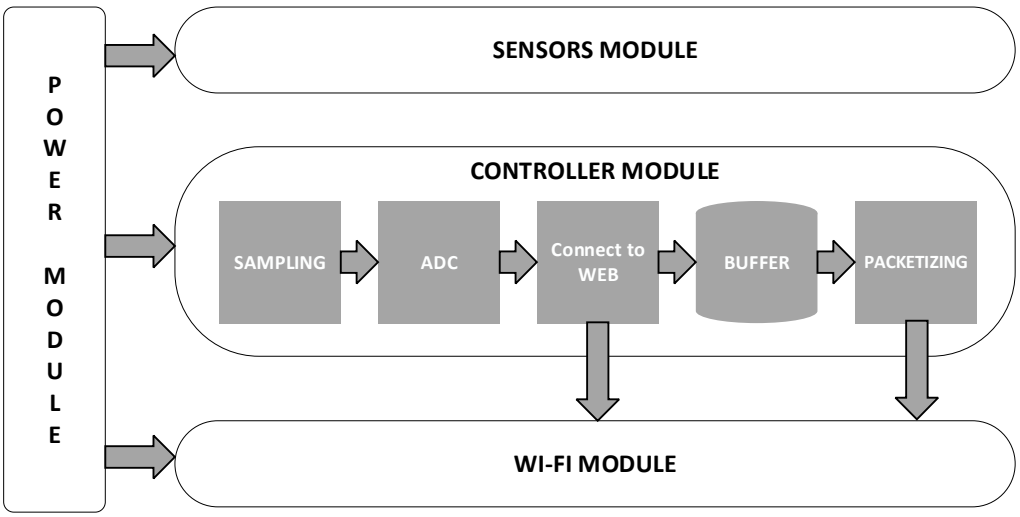

Fig. 2. Wearable device configuration

a) Accelerometer. It determines the days distance, measure user's motions and identify the user's activity during the day.

b) Pulsometer. It is used to determine the user's heart rate.

c) Body temperature sensor. Since the temperature sensor is located on the arm, and the arm temperature is different by body temperature, it is necessary to collect enough data for the normal body temperature index knowledge. For each user it is individual.

d) Environment temperature sensor. Information about the environment temperature helps us to obtain additional information about the user's health status. For example, if the environment temperature is low and user's body temperature begins to fall, it can be concluded that we deal with hypothermia.

2) *Controller module with wireless adapter* is using for preprocessing and transmission of user's health state signal data. The controller module is possible to determine the necessary parameters for additional signal processing, buffering, signal data packet for further transmission through a wireless network. It provides fast and convenient access to the Internet for transmitting real-time user's physiological data to a remount server.

3) *Power module* - provides a reliable power supply of each module of wearable health state monitoring device. As a stand-alone power source, a power bank of 20,000 mAh is used. The source of autonomous power supply is selected with a large energy capacity supply, sufficient for long-term continuous monitoring.

3.3 Server level

The second component of the system is presented by the remount server. Since the developed health state monitoring device has a limited energy resource, the data processing and analysis cannot be implemented by the device. It requires many computational resources and, as a result, many power energy, thereby reducing the device work time. The collected data is sent to the remount server for processing and long-term storage. The necessary data processing and analysis are carried out by data warehouse instruments. This is solving the problem of limited energy resources. The advantage is a significant permissible data volume and a short time of data processing.

3.4 Application/Service level

The third component will be present a web-application. The web application is currently developing.

4 Data acquisition techniques

For the experiment, the accelerometer and body temperature sensor are placed on the forearm. The forearm is located on the finger. The environment temperature sensor is on the prototype board at a sufficient distance from the body temperature sensor.

During the experiment the data acquisition, collection, and processing were carried out in the next states:

1. User's physical resting state.
2. User's physical activity state.

The duration of the signal acquisition was 5 minutes with a step time equal to 1 second.

As a result of the experiment, the transmission of data from the signals of the physiological state of the user was carried out through a packet, and the data were stored in the data warehouse.

5 Data fusion

In this work we apply the Bayesian approach for data fusion. The using of Bayesian approach, if we obtained evidence from various sources, the initial hypothesis about the health state is either increased or weakened. The Bayesian approach is an estimate of many hypotheses about various user's states allows us to determine the most probability user's health state. Summarizing the Bayesian approach to determine the state of user's rest or activity state, the data fusion of the sensor signals can be determined as follows. We denote a certain user state as F_i, the user state parameter as K, and y_k as the current value of K. The probability of the certain state y_K at currently step time determining as follows.

$$P(F_j \mid y_k) = \frac{P(y_k \mid F_j)}{P(y_k)} P(F_j) \qquad (1)$$

.

Suppose that the several parameters fusion of the user's state K determined as a set $Y=\{y_1, y_2, \ldots, y_K\}$ indicates a certain user's state F_i, its probability can be determined as follows.

$$P(F_i \mid Y) = \frac{P(Y \mid F_i)}{\sum_{j=1}^{N} P(Y \mid F_j) P(F_j)} P(F_i) \qquad (2)$$

.

where $F_1, F_2, \ldots, F_N$ is the possible user states. Thus, we obtain the probability of the certain state by data values fusion (3).

$$P(Y \mid F_i) = \prod_{k=1}^{K} P(y_k \mid F_i) \qquad (3)$$

.

The Bayesian approach for various sensors data fusion allows more accurately determination the user status in terms of rest or activity states.

Conclusion

This paper outlined the wearable health monitoring system and presents the development and implementation of a wearable device and technology for physical activity data acquisition and collection. The system architecture has been described including following levels: device, server, and web-application. Bayesian approach for sensors data fusion is utilized. Its main advantage is that we can perform data fusion on wearable sensor data easily. The future work will be targeted on the web applications development and research of sensor data mining techniques.

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Білобородова Т.О., Ардель О.В., Дерев'янченко В.С., Бабаєв Ш.О. Поєднання датчиків в IoT системі моніторингу фізіологічного стану

Носимі системи в контексті технології IoT використовуються для моніторингу фізичних станів людини. Такий моніторинг передбачає відстеження декількох параметрів фізичного стану за допомогою одного пристрою, що представляє собою так звану мережу біомедичних датчиків (wearable body area network - WBAN). Використання WBAN передбачає безліч синхронних вимірювань стану організму, одержуваних від декількох датчиків. Об'єднання даних з декількох потенційно гетерогенних джерел є актуальним завданням, яка безпосередньо впливає на продуктивність системи моніторингу. Існуючі технології по об'єднанню даних сигналів фізичного стану не пропонують ефективного вирішення.

У статті представлено проектування, дизайн і реалізація носимої системи моніторингу фізіологічного стану з використанням технології IoT. Етапи дослідження, представлені в статті, включають: (1) розробку і реалізацію носимого пристрою, що представляє собою мережу біомедичних датчиків для моніторингу фізичного стану людини; (2) технологію збору і отримання даних біомедичних показників фізичної активності людини; (3) Байєсовський підхід для злиття даних.

Ключові слова: *носима система моніторингу фізіологічного стану, архітектура системи IoT, злиття датчиків, Байєсовський підхід*

Белобородова Т.А. Ардель А.В., Деревянченко В.С., Бабаев Ш.О. Объединение датчиков в носимой IoT системе мониторинга физиологического состояния

Носимые системы в контексте технологии IoT используются для мониторинга физических состояний человека. Такой мониторинг подразумевает отслеживание нескольких параметров физического состояния с помощью одного устройства, которое представляет сеть биомедицинских датчиков (wearable body area network - WBAN). Использование WBAN предполагает множество синхронных измерений состояния организма, получаемых от нескольких датчиков. Объединение данных из нескольких потенциально гетерогенных источников является актуальной задачей, которая напрямую влияет на производительность системы мониторинга. Существующие технологии по объединению данных сигналов физического состояния не предоставляют эффективного решения.

В статье представлено проектирование, дизайн и реализация системы носимой системы мониторинга физиологического состояния с использованием технологии IoT. Этапы исследование, представленные в статье, включают: (1) разработку и реализацию носимого устройства, представляющего собой сеть биомедицинских датчиков для мониторинга физического состояния человека; (2) технологию сбора и получение данных биомедицинских показателей физической активности человека; (3) Байесовский подход для слияния данных.

Ключевые слова: *носимая система мониторинга физиологического состояния, архитектура системы IoT, слияние датчиков, Байесовский подход*

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