Web-Based Architecture for At-Home Health Systems

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Abstract. Technologies are revolutionizing the way health care is managed and delivered, especially in the areas of telemedicine and home care. Many at-home e-Health products are being developed and brought to market, but one of the factors that prevent widespread adoption is the need for customized solutions that result in lack of economies of scale. In this paper, we describe our Web-ENabled Devices and Instruments (WENDI) platform that addresses this challenge, utilizing technologies that promote low-cost and rapid development of web-based applications.

Keywords: e-Health, telehealth, web-based architecture.

1 Introduction

Advances in information and communication technologies are revolutionizing the way health care is delivered and managed. One of the greatest areas of expansion in e-Health is in telemedicine and home care, which delivers personalized health systems and services to the home. A number of factors have contributed to its growth: the consumers' desire for greater involvement in their own health care, and their desire for more high tech products, diminishing levels of family care [1], the rise of chronic diseases [2], etc. In many developed countries, the increase in the aging population relative to the size of the workforce in the health sector is the major contributing factor.

While innovation in this field has continued and home e-Health products have proliferated, there are a few challenges that prevent widespread adoption and integration of at-home health systems. One is that the fragmentation of public demand and the need for customer-individualized solutions result in technological delay and lack of economies of scale [3].

In this paper, we describe a web-based architecture and platform for at-home health systems that partly addresses this challenge. Our solution utilizes web technologies that promote low-cost and rapid development of customized applications. We also present an example implementation of a customized system using this platform that provided heart rate variability (HRV) biofeedback for stress management.

2 Web-Based Architecture

Web architectures for e-Health systems generally follow a three-tier architecture [4], shown in Figure 1.

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Fig. 1. General three-tier web-based architecture for e-Health systems: (1) data tier, (2) logic tier, (3) database and presentation tier

Tier 1 is the data tier, consisting of sensor networks that collect and pre-process physiological data, usually located on the body, but may also include ambient sensors around the home, such as temperature and humidity. It may also include actuators or other devices that provide feedback to the user. Tier 2 is the logic tier, which consists of a personal server or home gateway that manages the sensor networks and performs additional data processing or analysis if needed. It may also temporarily store data for later viewing or transmission to tier 3. Tier 3 is the database and presentation tier, which provides long-term data storage and presents the data through a web browser for web-based applications. For systems with telemedicine functions, tier 3 consists of a web portal or web application hosted by a server located at a hospital or health institution. For local systems, the web application and database may be hosted by the home gateway.

2.1 Tier 1: Sensor and Actuator Networks

Sensor and actuator networks are often heterogeneous, consisting of sensors used for different purposes such as ECG sensors, pulse sensors, blood pressure sensors, and temperature sensors. They may be wired or wireless, and may use different types of communication technologies -- general purpose technologies such as USB, Wireless USB, Wi-Fi, Bluetooth, and Zigbee, or proprietary technologies such as ANT, Sensium and Zarlink. To some degree, some technologies such as USB, Bluetooth and Zigbee provide integration mechanisms to promote interoperability. For example, Bluetooth has a Serial Port Profile, which sets up virtual serial ports between two devices using serial port emulation. To achieve higher levels of interoperability, a number of standards have been proposed, such as ISO/IEEE 11073 and Health Level 7. These standards may be complementary with each other [5].

2.2 Tier 2: Personal Server or Home Gateway

A personal server is usually a smartphone or mobile device that has constant connection to the body sensor network, supporting patient mobility. However, it has power and energy limitations, and higher cost of data transmission. On the other hand, a home gateway, although not always connected to the patient, can support more communication channels, can have wider network bandwidth and lower-cost data transmission to the next tier. Examples of home gateways include desktop computers, mini computers, and set-top boxes [6].

2.3 Tier 3: Database and Web Application Server

The server on tier 3 hosts a database server for storing data and a web server for hosting web applications, which a web client can access. The main advantage of using a web-based architecture is that the resulting client-server system is platform-independent. By using service-oriented architectural styles such as RESTful and SOAP- or RPC-style architectures, a loosely-coupled distributed system can be built. For example, data processing and analysis can be performed on the server-side while data visualization is implemented on the client-side. The client exchanges information with the server using well-defined messages – for RESTful services, using a uniform interface based on simple and universal HTTP operations such as PUT, POST, GET and DELETE, and for SOAP- or RPC-style services, using an application-dependent programming interface that supplant HTTP operations. In both types of services, clients connect to servers using techniques that are native to the web, but are limited to request/response type of communication. Other web technologies that support bi-directional data streaming, such as Comet or websockets, complement these services [7].

Using a web application or a web portal as a front-end brings several advantages. First, it ensures universal access, as every modern computer, laptop, netbook, tablet and smartphone has a browser. Second, installing and deploying the user interface is almost instantaneous. Third, managing, maintaining, and modifying applications is easier, since only the web application on the server-side needs to be updated [4]. Lastly, with more reusable components, developing web applications is a low-cost and rapid process compared to traditional client-server applications. With the advent of HTML5 technology, running media-rich interactive web applications on browsers is possible.

3 System Architecture and Design

For e-Health systems, the solution usually includes both hardware and software to provide a platform that collects, processes and presents data from sensors, and/or transmit data for further analysis or storage [8]. In this section, we describe our Web-ENabled Devices and Instruments (WENDI) platform, a hardware and web-based software solution for at-home systems.

Figure 2 shows the hardware components of an at-home system. It consists of a sensor and actuator network that is connected to a home gateway, a Linux-based mini-computer with standard interfaces such as USB and Bluetooth. The home gateway is connected to a router, which provides a local wireless network for the at-home health system. Client devices such as laptops, tablets and smartphones or any other device with a web browser can connect to the home gateway through the Wi-Fi network. For telemedicine or social networking functionality, the router can be connected to the internet.

Fig. 2. Components of an at-home health system using the WENDI platform

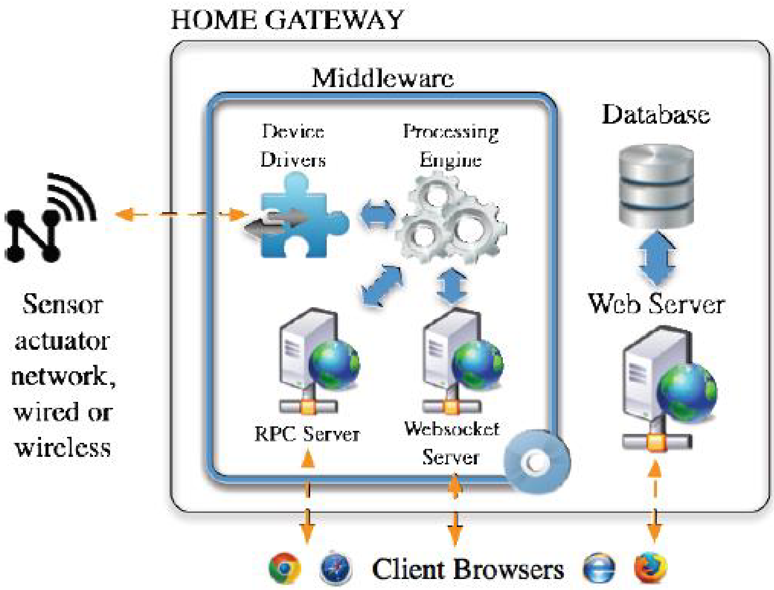

Fig. 3. Components of WENDI home gateway

The sensor and actuator network may include any device with serial port emulation, such as USB-serial and Bluetooth device with a serial port profile. Support for other types of devices may be added in the future.

The home gateway is an off-the-shelf mini-computer (Asus EEEBox 1007) running a Debian Linux-based operating system (OS). It contains middleware that collects, processes, and transmits data from sensors, as well as a database where data is stored, and a web server that hosts web applications. The components of the home gateway are depicted in figure 3.

The middleware on the home gateway was written in Python. The middleware hides the complexity and heterogeneity of underlying hardware, allowing programmers to focus on the retrieving data from sensors without knowing how to communicate with individual sensors, actuators, or other devices. It has a petrinet-based processing engine for analyzing data. It also includes an RPC server, which has basic commands to start and stop data acquisition, and a websocket server, which streams sensor data to client browsers. The middleware can be easily extended and customized to provide additional functions for applications.

A javascript client library was created to facilitate communication with the server. It has functions for creating a socket to communicate with the RPC and websocket servers, and functions to send commands / receive responses from the RPC server as well as process messages from the websocket server.

Figure 4 shows the deployment diagram for WENDI. On the home gateway, the platform relies on OS drivers and components for data acquisition and control of sensors, actuators or devices, such as the USB and Bluetooth device managers. A standard web server and relational database management system packaged for the OS are included for building customized web applications. The middleware consists of several modules: wendi_sources.py, which receives incoming data from sensors and devices, wendi_sinks.py, which sends outgoing data to actuators and devices, wendi_pn.py, which is the petrinet-based processing engine that takes the input data, processes the data, and produces output data, wendi_server_wamp.py and wendi_server_websocket.py, which handle RPC and communication over websockets, respectively. Libraries for RPC and communication over websockets are provided by the Autobahn Python package [9]. On the client device, a corresponding javascript library is provided to send requests and receive commands to the RPC server, and to send/receive streaming data over websockets. The wendi.js client library uses a library provided by Autobahn JS [10].

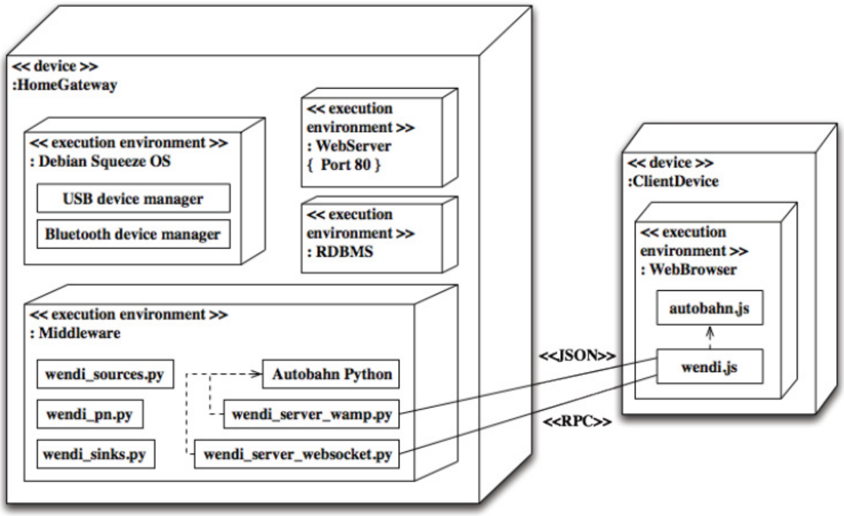

Fig. 4. Deployment diagram for WENDI

4 Example Application: HRV Biofeedback for Stress Management

In this section, we present an example application utilizing the WENDI platform. The objective in this application was to present heart rate variability (HRV) data from a pulse sensor to the user for biofeedback in stress management. A healthy heart is influenced by multiple factors that result in variations in heart beat intervals (HBIs), called HRV, at time scales ranging from less than a second to 24 hours. Ideally, the HRV waveform should contain strong sinusoidal components. However, when one is experiencing feelings of anger or frustration, the HRV waveform shows a disordered, jerky waveform [11]. The change in HRV is one of the body's secondary physiological responses to stress. The body also has natural tools for combatting stress, one of which is breathing at a slow rate in synchrony with your nervous system. Previous research has shown that by using the body's feedback loop, this breathing technique enhances the state of your nervous system, and induces feelings of calm and relaxation [12].

A web application was built to educate users in using breathing exercises as a stress management tool and provide HRV biofeedback for patients to monitor their progress. On the server side, pulse data was collected from a plethysmographic sensor located on a glove. A microcontroller on a hand glove acquired pulse data from the plethysmographic sensor positioned on the index finger, pre-processed and transmitted the data via Bluetooth to the home gateway, which performed further data processing and analysis. Processing involved detecting peaks in the pulse waveform,

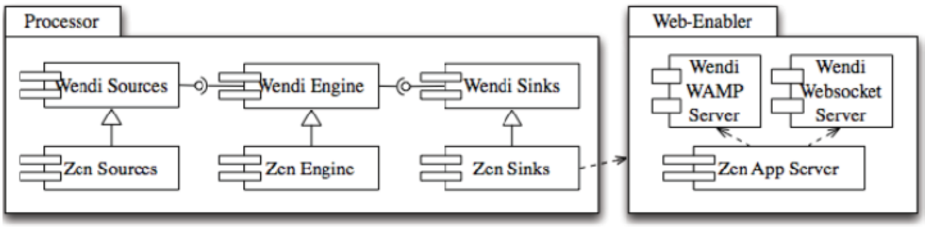

Fig. 5. Component diagram of extended middleware

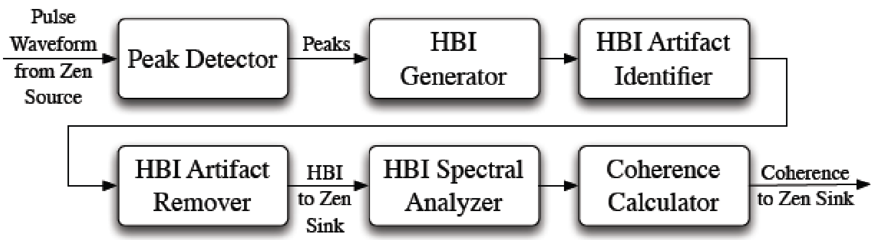

Fig. 6. Block diagram of Zen Engine for HRV biofeedback

extracting the HBIs, and calculating coherence. Coherence was a number between 0 to 100 that reflected the relaxation state of the user over a period of time; a higher figure indicated that the user was more relaxed. HBIs and coherence data were delivered to a client browser on a tablet, where data was visualized. Figure 5 shows a high-level component diagram that illustrates how middleware on WENDI was extended to provide other application-dependent functions. Figure 6 shows the block diagram of the Zen Engine.

On the client-side, a standard web application was built to educate and train patients on breathing techniques for stress management. The client communicated with the web server and database server as part of its standard web application, and used the javascript client library for WENDI platform to control data acquisition through RPC and obtain streamed data from the server through websockets.

5 Summary

In summary, we have presented a web-based platform for at-home health systems that utilizes web technologies that enable low-cost and rapid development of customized applications with rich user interfaces. The platform is modular and extensible, allowing programmers to extend the functionality of the platform with user-defined components such as sensor drivers and signal processing modules. The platform also provides an easy way to add the ability to acquire, process and stream data to existing web applications.

Currently, the platform is designed to be used by systems integrators, who have the ability to extend the functionality of the platform with plugins. More work is needed to transform the platform into one that can be used by domain experts, who may have basic IT skills, but need higher-level abstractions that simply the configuration of the system. Other areas for future work include utilizing existing standards such as IEEE 11073 and Health Level 7 for interoperability with other devices and systems, discovery of sensors, actuators or devices, management of devices and network resources, etc. Future work will address these issues.

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