

# An Automated Vital Sign Monitoring System for Congestive Heart Failure Patients

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## ABSTRACT

Congestive heart failure (CHF) is a cardiovascular disorder that affects approximately 4.6 million Americans and is a leading cause of death in the United States. Current research shows that strategies to promote early recognition and treatment of symptoms and enhance self-care management behaviors reduce unnecessary hospitalizations. However, mechanisms to monitor patients' health status and behaviors are limited by constraints imposed by the patient's geography, infirmity, or resources. Remote monitoring supports a more dynamic connection between healthcare providers and patients, improves health promotion and patient care through monitoring of health data, communicates health reminders, and makes provisions for patient feedback. This paper will describe two versions of Weight and Activity with Blood Pressure Monitoring System (WANDA [22]) that leverages sensor technology and wireless communication to monitor health status of patients with CHF. The WANDA system is built on a three-tier architecture consisting of sensors, a web server, and back-end database tiers. The system was developed in conjunction with the UCLA School of Nursing and the UCLA Wireless Health Institute to enable early detection of key clinical symptoms indicative of CHF-related decompensation in a real-time automated fashion and allows health professionals to offer surveillance, advice, and continuity of care and triggers early implementation of strategies to enhance adherence behaviors. The small study has enabled patients to reduce or maintain the number of readings which are out of the acceptable range. For diastolic, systolic, and heart rate values, the t-test results show that the WANDA study is effective for patients with CHF.

## Categories and Subject Descriptors

C.2.4 [COMPUTER-COMMUNICATION NETWORKS]: Distributed Systems - Distributed applications, Distributed databases ; H.2.7 [DATABASE MANAGEMENT] : Database Administration - Data warehouse and repository, Logging and recovery, Security, integrity, and protection

**General Terms:** Design, Experimentation, Measurement

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**Keywords:** Health monitoring, Congestive heart failure patients monitoring, real-time feedback, telemedicine, wireless health, data integrity, database backup

## 1. INTRODUCTION

Congestive heart failure (CHF) is a condition in which heart function is inadequate to supply oxygenated blood to the patient. During the past several decades, incidence and mortality rates from CHF have been increasing, and CHF has become increasingly become an important public health problem. Approximately 4.6 million Americans have been diagnosed with CHF, with 43,000 annual deaths due to CHF and with 400,000 new cases reported each year ([1]). The sequelae of CHF are well known, with frequent decompensation of the chronic state resulting in recurrent hospitalizations. CHF experts agree that these costly incidences of decompensation can generally either be avoided or lessened in severity. In cases where hospitalization is unavoidable, experts believe that inpatient time can be reduced. Therefore, the importance of maintaining an optimally compensated state in patients with CHF is critical. For decades the scientific community has been engaged in investigations to ascertain associated events and contributing factors that significantly impact the progression and outcomes of CHF. Data shows that patient adherence and clinical management strategies aimed at maintaining an optimally compensated state may decrease the need for CHF readmissions, shorten hospital length of stays, reduce costs, and improve quality of life.

Remote monitoring programs provide a potentially feasible option for dealing with the expanding population of patients that have CHF but are unable to access clinics due to either a lack of resources, location, or infirmity. Care facilitated by technology has the potential to enable early detection of key clinical symptoms indicative of CHF-related decompensation and allows health professionals to offer surveillance, advice, and continuity of care and triggers early implementation of strategies to enhance adherence behaviors. However, there had been a paucity of data to support the use of remote monitoring in patients with CHF. Additionally, current mechanisms to monitor health status in patients' homes are limited. As a result, it seems prudent to develop a wireless health device for daily tracking and recording of patient vitals for care and rehabilitation purposes.

As compared with subjects with a normal body-mass index, obese subjects have a doubled risk of heart failure ([1], [5]). Due to the high prevalence of obesity in the United States, Kenchaiah [5]

suggests that strategies to promote optimal body weight may reduce the population burdened with heart failure. In addition, an increase in weight indicates the retention of excess fluid, which requires increasing the dosage of diuretic medication to counteract fluid accumulation. Therefore, close monitoring of patient weight has been shown to decrease the need for hospitalization, thus improving patient quality of life.

In [1], the authors suggested several risk factors for CHF. One of these factors is the indication that low physical activity accounts for 9.2% of population attributable risk. The results of [6] suggest evidence that long-term aerobic exercise training in patients with CHF restores function of the skeletal muscle microvasculature of the lower limb. Therefore, monitoring weight and daily activities is important for CHF patients.

**Table 1.1. Acceptable range of each measured value**

Values	Range
Systolic	> 90
Diastolic	> 50
Heart rate	< 90 and > 40
Weight	< +2 ( lb./ day)

Based on Haider [3] and Redfield [4], the prognostic significance of systolic and diastolic blood pressure is well known. CHF is often caused by systolic dysfunction where the heart muscle cannot pump or eject the blood out of the heart adequately, or by a diastolic dysfunction where the atrium does not fill up. As this pumping procedure stops, blood may back up in other areas of the body, producing congestion in areas such as the lungs, the liver, the gastrointestinal tract, the arms, or legs. Heart rate is an additional factor that predicts the risk for CHF in an elderly person. Heart rate may help identify patients at high risk for overt CHF who are candidates for aggressive blood pressure control. Table 1.1 shows acceptable range of each measured value for CHF patients. Based on suggested values, monitoring a patient’s vital signs and alerting caregivers can help prevent hospitalization.

**Table 1.2. WANDA B.’s daily SMS questions**

Questionnaire Items
I could feel my heart beat faster
I could not breathe when I laid down
I felt pain in my chest
I had an upset stomach
I had a cough
I was tired
I could not catch my breath
My feet were swollen
I woke up at night because I could not breathe
My shoes were tighter than usual
I gained 3 or more pounds in the past week
I could not do my usual daily activities because I was short of breath

The Heart Failure Somatic Awareness Scale (HFSAS) in table 1.2 is a 12-item Likert-type scale to measure awareness and perceived

severity of signs and symptoms specific to CHF. The HFSAS is limited to 12 items to reflect the most common signs and symptoms of CHF. A 4-point Likert-type scale is used to address these symptoms, and if present, to ascertain how much the patient is bothered by them (0: Not at all, 1: A little, 2: A great deal, 3: Extremely). Scores range from 0 to 36, with higher score showing higher perceived somatic awareness and symptom distress. According to Jurgens [2], this HFSAS is shown to be reliable with content, discriminate, and construct validity without gender bias. Additionally the HFSAS is useful in studies designed to improve symptom recognition and self-management. Fostering awareness of the early CHF symptoms of decompensation averts repeated hospital admission for symptom management.

This paper will describe the components of the Weight and Activity with Blood Pressure Monitoring System (WANDA B), a wireless health device that leverages sensor technology and wireless communication to monitor the health status of patients with CHF. The WANDA B system was developed in conjunction with the University of California Los Angeles Wireless Health Institute (WHI) and School of Nursing. The WANDA is built using a three-tier architecture. The first tier is a sensor tier that measures patients’ vital signals and transmits data to the web server tier. The second tier consists of web servers that receive data from the first tier and maintains data integrity. The third tier is a back-end database server that performs backup and recovery jobs. The small study has enabled patients to reduce or maintain weight, and to reduce the number of blood pressure values which are out of the acceptable range (Table 1.1). For diastolic, systolic, and heart rate values, the t-test results show that the WANDA study is effective for congestive heart failure patients.

## 2. RELATED WORK

Baker [8] discusses five wireless health prototypes for purposes such as infant monitoring, alerting the deaf, blood pressure monitoring, and fire-fighter vital signs monitoring. The five prototypes use two sensor network mote technologies. One is the Tmote Sky, the latest derivative of the Berkeley Telos motes from Moteiv. The other one is the Corpand SHIMMER, Intel’s Digital Health Group’s platform for Sensing Health. In their Heart@Home blood pressure monitoring project, a SHIMMER mote is located on the wrist cuff which is connected to an electronic pressure sensor, which then broadcasts these time-stamped readings over a radio network. The prototype’s PC-based software application then provides a graph of the user’s blood pressure and pulse rate over time.

Accelerometers are useful for wireless health monitoring because they are able to record intensity, frequency, and duration of activity, along with the total volume of accumulated activity. Accelerometers are also able to assess movement with minimal hindrance to the user, which makes them ideal devices for motion monitoring. Sherrill [9] previously developed a wearable sensor network which helps remotely monitor the activity of patients with chronic obstructive pulmonary disease (COPD). This system manipulates 2-axis or 3-axis accelerometers which are attached to the arms and legs in order to monitor a person’s activity in their own home and community, allowing lifestyle flexibility.

Approximately 95 percent of all mobile phones in the U.S. today are capable of sending and receiving SMS text messages. As of

2007, more than 100 million of the 250 million mobile phone subscribers in U.S. have used text messaging, and more than 41 million people send text messages every day. Mobile phones may provide an opportunity to improve behaviors like self-monitoring through means such as SMS. For example, Obermayer [10] shows that sending text messages to mobile phones increases the effectiveness of smoking cessation intervention among college students. Another study among young adults in New Zealand revealed that participants who received text messages were more likely to quit smoking in 6 weeks than those who used controls [11]. In a program conducted among youth with type 1 diabetes by Franklin [12], daily text messages were helpful for disease self-management, increased self-efficacy, and treatment adherence and achieved high satisfaction among participants.

The WANDA B project involves the unique integration of a home-based wireless health and activity status monitoring platform coupled to a SMS health-monitoring and usability questionnaire system, especially designed for patients with CHF.

### 3. SYSTEM ARCHITECTURE

WANDA is built using a three-tier architecture as shown in Fig 3.1. The first tier is a sensor tier that measures patients' vital signals and transmits data to the web server tier. The second tier consists of web servers that receive data from the first tier and maintains data integrity. The third tier is a back-end database server that performs data backup and recovery jobs. Additionally, data in the third tier is used for data analysis such as linear regression, and clinical data security projects.

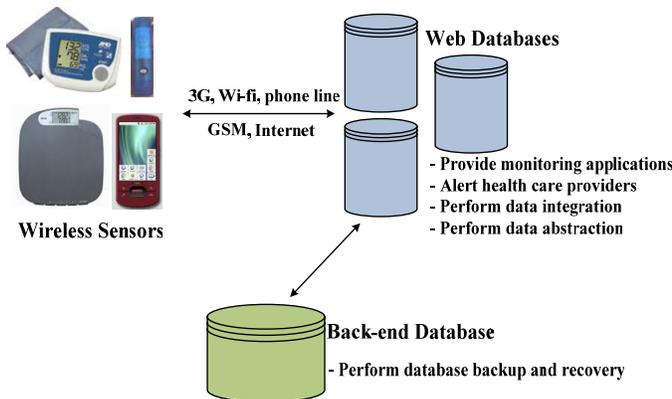


Fig 3.1. WANDA system architecture

#### 3.1 Sensor Tier

The first tier is comprised of the wireless sensors and the mobile devices. Sensors in this layer monitor patients and transfer data to web servers. The first iteration of the WANDA B is designed for elderly CHF patients who are not accustomed with smart phones or computers, and thus it only uses devices that look and function like standard weight scales and blood pressure monitors. The second version of WANDA, Mobile WANDA, uses a smartphone to collect and transfer data. This mobile version also allows patients to view their own health data through a smartphone interface.

#### 3.1.1 WANDA B.

In the WANDA B. sensor tier, we use Bluetooth-based weight scales, blood pressure monitors, WHI [13] Personal Activity Monitors (PAMs), cell phones, iPhones, and an SMS message server system in order to monitor heart failure patients. As previously mentioned, patients generally are unfamiliar with computers or smartphones, thus the WANDA B. interfaces with the second tier through a phonenumber system that sends updates every two weeks.



Fig 3.2. Devices used in WANDA B.

WANDA B. collects weight, blood pressure, activity, and takes daily SMS surveys. Whenever patients measure their weight and blood pressure, values are transmitted to the web-server via Bluetooth and a phone line connection. Answers to daily SMS questionnaires and calorie expenditure data values are also stored in the database. This data is accessible through a custom-built web application (the WANDA B. web application) or through an iPhone application. These means allow physicians to monitor patients in real-time.

The Ideal Life system [14] is a part of the first tier system. It includes the Body Manager™ body weight scale and the BP Manager™ blood pressure monitor device ( which quickly and accurately measures diastolic blood pressure, systolic blood pressure and heart rate). The Body Manager™ and BP Manager™ systems collect weight and blood pressure data and send it to the Ideal Life Pod™. Since the system supports Bluetooth, the components can communicate in a range up to 300-400 feet. When the Ideal Life Pod™ receives data, it transmits data to the database system through a standard phonenumber via a long-distance phone service plan.



Fig 3.3. Ideal Life Body Manager™, BP Manager™, and POD™

The WHI Personal Activity Monitor, or PAM, shown in Fig 3.4, is a small, light-weight, triaxial accelerometer-based activity recorder. The WHI PAM's has a small form factor, which allows

it be easily carried in a patient's pocket. The sample rate as well as the minimum acceleration threshold can be adjusted to ensure that data resolution requirements are met while also optimizing for longer battery life. Time-series acceleration data is stored using an on-board flash memory card. Data transfer is achieved via USB on an internet-enabled PC, but future designs will support wireless communication. Using a patient's age, gender, height, and weight, the WHI PAM system calculates daily caloric expenditure based on the metabolic equivalents (METs) associated with approximations of the patient's activity levels throughout the day.

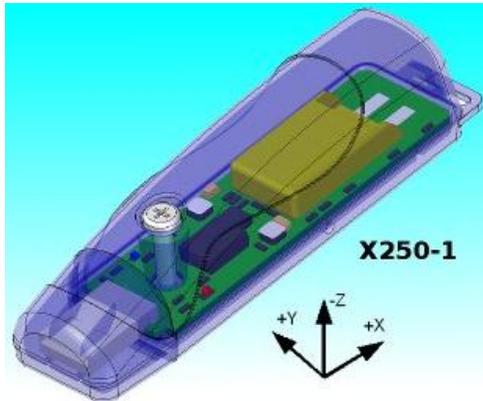


Fig 3.4. WHI PAM (Personal Activity Monitor)

Table 3.1. Activity levels and METs values

Physical Activity	MET
<b>Light Intensity Activities</b>	< 3
Sleeping	0.9
writing, desk work, typing	1.8
walking, less than 2.0 mph (3.2 km/h), level ground, strolling	2
<b>Moderate Intensity Activities</b>	3 to 6
bicycling, stationary, 50 watts, very light effort	3
sexual activity (position dependent)	3.3
calisthenics, home exercise, light or moderate effort, general	3.5
bicycling, <10 mph (16 km/h), leisure, to work or for pleasure	4
bicycling, stationary, 100 watts, light effort	5.5
<b>Vigorous Intensity Activities</b>	> 6
jogging, general	7
calisthenics, heavy, vigorous effort	8
running jogging, in place	8

Based on activity information detected by the PAM device, it calculates the METs value (Table 3.1). Calories burned by each activity, are calculated by the following equation ([15])

$$\text{Calories} = ((\text{METs} * 3.5 * \text{weight (kg)}) / 200) * \text{duration (min)}$$

Based on a schedule set by doctors, WANDA B.'s daily SMS survey system sends a SMS questionnaire (see Table 1.2) in order to check for heart failure symptoms. The corresponding user responses are collected and recorded by the WHI SMS database.

This SMS system also sends a text message to the users to which they can reply to in the same way as they would reply to texts from friends. The WANDA B. platform also sends 25 usability questions via text message every month to obtain input from patients' on the system's usability (e.g. ease of use, usefulness). This information will be used to evaluate patients' perspective of the WANDA B.'s feasibility as a health monitoring device.

### 3.1.2 Mobile WANDA

The Mobile WANDA utilizes an assorted collection of health monitoring devices from different companies in order to implement a mobile version of WANDA B. The Mobile WANDA not only has all the functions of the original system, but also gives developers great customizability. The weight scale is a Tanita BC-590BT body composition scale, which measures body weight, body fat, body water, bone mass, and muscle mass. With the additional body data, doctors can make an even more thorough analysis of patients' symptoms. A blood pressure monitor used in the Mobile WANDA is a UA-767PBT Bluetooth blood pressure monitor from AND. This blood pressure monitors measures systolic, diastolic, and heart rate values.

The software application is implemented on the Nexus One, which is a Google Android based smartphone with a 3.5 inch multi-touch display and 480-by-320-pixel resolution. Since the Nexus One contains an embedded accelerometer, the WHI PAM is not necessary for the Mobile WANDA platform. The Mobile WANDA can also automatically upload users' activity data to a server, so users will not be burdened with having to make a manual data upload with a USB port.

In terms of the Bluetooth device-smartphone interface, all of the devices act as masters that initiate Bluetooth communication with an Android phone. Since the Android phone acts as a slave node, only one connection can be established at each time and Piconet is not possible. This is not really an issue in the Mobile WANDA system since patients will not be operating two sensing devices simultaneously. The Bluetooth protocol has a range of approximate 10 meter and provides secure data transmissions. The communication between the phone and the medical server is through a Wi-Fi or 3G network. Data measured from a sensing device is uploaded to the Android phone within 5 seconds. The Android phone transfers this data to a networked server and also stores this data on a local SDCard. Thus, a user can visually view a graph of historic health data on the phone. If an upload procedure fails due to a problem with the network, the application will retry the upload when the network is available. Upon each new measurement, the application validates the data in real time according to an ideal range (see Table 1.1) provided by doctors. If any irregular trend is observed, the system phone will pop up a warning message and give suggestions to users. A simple regression analysis is used to detect abnormal data trends.



Fig 3.5. Devices used in Mobile WANDA

The method for estimating the activity level is based on the algorithm proposed by Panasonic ([24] and [25]). It is proven that the value calculated by this algorithm has high correlation ( $R^2 = 0.86$ ) with the Doubly Label Water method, which is one of the most accurate methods for evaluating total energy expenditure under free living condition. Using this algorithm, metabolic equivalent intensity (MTE) levels of physical activities and approximate calories burned can be calculated by an equation that is also applied to the WANDA B.'s PAM device.

$$K_m = \sqrt{\frac{1}{n-1} \left[ \left( \sum_{i=0}^n x_i^2 + \sum_{i=0}^n y_i^2 + \sum_{i=0}^n z_i^2 \right) - \frac{1}{n} \left\{ \left( \sum_{i=0}^n x_i \right)^2 + \left( \sum_{i=0}^n y_i \right)^2 + \left( \sum_{i=0}^n z_i \right)^2 \right\} \right]}$$

Fig 3.6. The  $K_m$  value has a high correlation with actual TEE. The MTE level can be found by the first order linear regression fit.  $n$  is the number of data for a time window,  $\sum x$ ,  $\sum y$ ,  $\sum z$  are the sum acceleration in X, Y, and Z direction. In our application, the accelerometer sampling rate is 10Hz, the period is 1 minute, and the  $n$  is 600

Mobile WANDA also implements the patient questionnaire feature that is done by the WANDA B.'s SMS system. Patients are asked via the smartphone interface to answer twelve daily, and the responses are sent to physicians for reference. If the patients forget to take vital measurements or answer the questions, the application has a built-in alarm to remind the user. The questionnaire answers are also both stored locally on the SD Card and uploaded to the medical server via WiFi or 3G.

### 3.2 Web servers

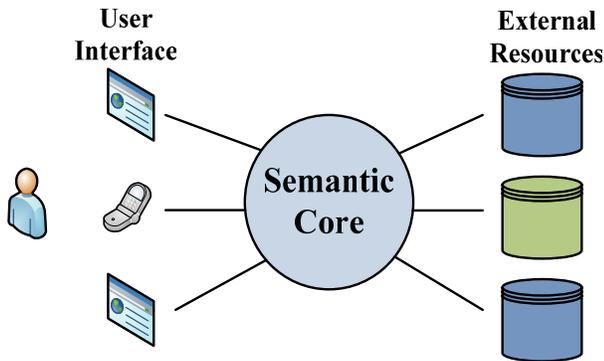


Fig 3.7. The WANDA B. web server architecture

Data collected from the first tier are sent to several web servers to store data and provide monitoring applications mentioned in Section 4. Unlike the Mobile WANDA, the WANDA B. draws data from several different web servers. Since IdealLife, PAM, and the WHI SMS system use incompatible data types and different databases, analysis of WANDA B. data involves drawing data from different databases. Incompatible data formats in different databases are solved through usage of an abstraction of file formats and a shared ID table. In addition, when the obtained values are out of the acceptable range (see Table 1.1), the system sends alert messages to health care providers via text message or e-mail.

#### 3.2.1 Abstraction of data formats

The objective of abstraction in programming is to separate behavior from implementation. In other words, the main objective of abstraction is to separate what an abstraction is from how it is implemented so that implementations of the same abstraction can be substituted freely. To allow changing implementations without affecting users, we should change the representation without having to change all programs by encapsulating the representation. If an implementation is encapsulated, other modules don't have to depend on its implementation details [7].

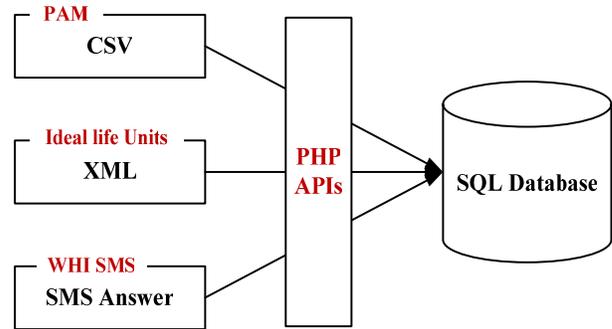


Fig 3.8. Data abstraction in WANDA B.

Since WANDA B. draws data from files systems that supports different file formats, a data abstraction procedure is required (Fig 3.8). For example, in order to insert data stored in Ideallife file system (Fig 3.9) into a SQL server, data should be parsed and abstracted. Thus, we developed a PHP API to draw XML data from the file system and insert into the WANDA SQL server system.

```
<ArrayOfBPMReading>
  <BPMReading>
    <ClientUserID>      </ClientUserID>
    <ReadingDate>       </ReadingDate>
    <ReadingTime>       </ReadingTime>
    <Systolic>          </Systolic>
    <Diastolic>         </Diastolic>
    <HeartRate>         </HeartRate>
  </BPMReading>
</ArrayOfBPMReading>
```

Fig 3.9. Blood pressure data format in the Ideallife file system

An algorithm to parse XML data in Fig 3.9 is given in Fig 3.10.

```
<? PHP
$address = /* Ideallife file system address */
$fp = fopen( $address, 'r' );
While ( $ArrayOfBPMReading = fscanf( $fp, "%s" )
{
  $i++;
  list($BPMReading) = $ArrayOfBPMReading;
  if( $i % 9 == 1)
  {
    list($ClientUserID_1) = sscanf( $BPMReading, "<<ClientUserID>%s");
    $ClientUserID = strtok($ClientUID_1,"<ClientUserID>");
  }
}
```

```

/* Do the same procedures for other elements */

/* Execute the following SQL query */
/*
INSERT INTO WANDA_Database
(ClientUserID,ReadingDate,ReadingTime,Systolic,Diastolic,HeartRate)
VALUES
('$ClientUserID','$ReadingDate','$ReadingTime','$Systolic','$Diastolic',
'$HeartRate')
*/
}
?>

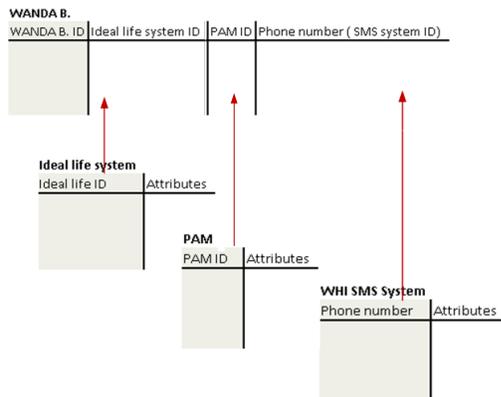
```

**Fig 3.10. PHP API abstracting Ideallife data**

Data abstraction facilities in WANDA B. web servers offer users the advantages of encapsulation. The representation of abstract objects can be changed without requiring corresponding changes in original files that manipulate the objects. In order to update data, the WANDA B. system calls other databases and file systems periodically and extracts data from them.

### 3.2.2 Data integrity

The need to combine records from different systems or healthcare organizations exists for many reasons, such as patients moving or changing health care providers. When the number of available repositories and analyses increases, linking information between them becomes a major concern. Finding the relevant resources and making connections between their content and analysis output poses significant challenges [19]. To make all patients' medical records accessible to care providers, Bell [16] makes electronic medical records linked together using a massively distributed Master Patient Index (MPI). A MPI is a facility that correlates and references patient identifiers and performs matches.



**Fig 3.11. Database structure in WANDA B. and a shared ID table**

The WANDA B. is an integrated architecture of Ideal Life system units, WHI PAM devices, and the WHI SMS system. Each system has its own database, patient ID, and item ID to distinguish the inputs measured by patients. Since the WANDA B. can use different system units and add more devices, finding relevant resources and making connections among them is essential.

The concept of semantic integration comes from the world of business and electronic commerce, where similar problems of legacy software and complicated data exist [20]. In order to interpret the real mining of data from multiple sources, finding,

establishing, and maintaining connections between relevant tools and most up-to-date data is significant. For solving the data integration problem in distributed systems, a shared ID table is used in the WANDA B. system. To join keys used in the Ideal Life systems, the WHI PAM, and the WHI SMS systems, the WANDA B. ID is used. Other input in different system databases are referenced via the WANDA B. ID table and original database tables (Fig 3.11) which enables the linkage of information located in several systems to a specific patient.

For example, when a user tries to access the weight data, the WANDA B. system draws data from the IdealLife system using the shared ID table. Therefore, the system should execute the following SQL query to perform the given task.

```

SELECT weight
FROM WANDA_B, Ideallife_system
WHERE WANDA_B.Id = \* a given ID * AND
WANDA_B.Ideallife_system_ID = Ideallife_system. Ideallife_ID

```

## 3.3 Back-end Database

As data in the WANDA system is critical and personal, the loss of any data must be actively guarded against. If there is missing data, the system cannot evaluate the patient's status accurately and void the system's effectiveness. Therefore, a back-end server in WHI SOPHI [17] for data backup and recovery was developed. WHI SOPHI is a database integration project that it stores and displays web pages, files, and data from all projects at the UCLA WHI. Data backups are useful for restoring state following a disaster or restoring small numbers of files after they have been accidentally deleted or corrupted. Data in the third tier is used for data analysis (such as linear regression) and clinical data security projects.

### 3.3.1 Data backup and recovery

WANDA B. applies an offline backup method which performs data backup while there is no current update [21]. The data entry times are statistically analyzed and the system sets a backup and recovery schedule. When a database backup occurs, all unfinished file backups are checked for completion before the new backup procedure is executed. The DBMS communicates with the SOPHI client application to support transactional properties of data, coordinated backup and recovery. The data backup log file (see Fig. 3.12) in the SOPHI client application maintains the last modification timestamp, distributed database information, the unique ID of the last updated data, and other various components. To support coordinated backup and recovery with the DBMS, the application interfaces with the back-end server through WANDA APIs.

Database Information			The last updated data ID	Timestamp
Name	Address	Password		

**Fig 3.12. The format of WANDA B. database backup log file**

In order to perform a backup of distributed web databases, the SOPHI client application takes a central role (Fig 3.13). Using its

backup log file and PHP APIs, it controls data delivery between distributed web databases and the DBMS. The developed APIs execute SQL queries, deliver data, manage database backup, and enact recovery procedures.

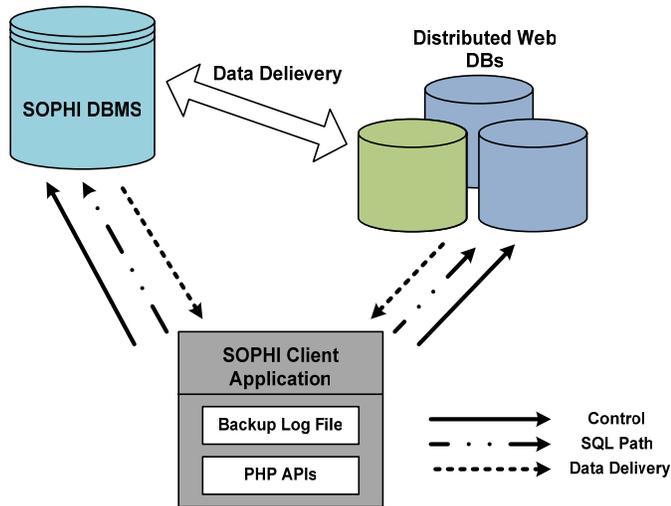


Fig 3.13. WANDA data backup system configuration

Just like DATALINK[23], the WANDA platform utilizes a backup copy of the database for restoring the database to one of four possible consistent states.

- Offline backup state (OBS) : The state when an offline backup was taken.
- Quiescent point state (QPS) : The state when no update was being allowed to the database.
- Point-in-time state (PTS) : Some arbitrary point-in-time state.
- Current time state (CTS) : The state at the time of crash.

#### 4. WEB AND MOBILE APPLICATIONS

Both WANDA B. and Mobile WANDA provide two different monitoring applications for healthcare providers, and they operate on the web server tier. One is a web application ([18]) and the other is a smartphone application. Both the web application and the smartphone application have functions to check patients' weight, blood pressure, heart rate, daily questions, and calorie consumption. The interfaces of applications are clear, consistent, and communicative, so users do not need to worry about underlying file types, software architectures, and operating systems. Data can be viewed as graphs or tables. Also, the web application shows the statistical result of SMS answers. The graph mode shows the amount of calories burned in hourly-based format and other values in daily-based format using the length of the bar, spectrum of colors, and annotation (Fig 4.2 and Fig 4.3). The structure of the website and data display modes, fonts, and graph colors were defined in the meeting with caregivers who are users of this system.

The access to the web application requires user verification in order to prohibit access by unauthorized users. The initial page asks for a user ID and a password that is provided to individuals in a private meeting. Healthcare providers can also add more

patients and synchronize data via the WANDA webpage if necessary.

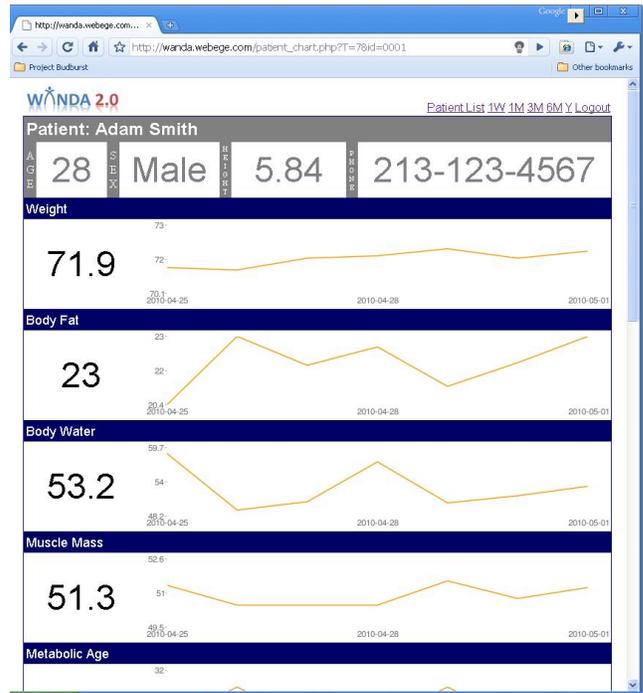


Fig 4.1. WANDA web application

The iPhone's 3.5 inch multi-touch display with 480-by-320-pixel resolution lets users navigate by touching the screen. The iPhone 3G uses a technology protocol called HSDPA (High-Speed Downlink Packet Access) to download data quickly over UMTS (Universal Mobile Telecommunications System) networks. In addition, its weight is only 135g, making it easy to carry. Therefore, the WANDA B. iPhone application helps users access the WANDA web database data. Using a WANDA application on an iPhone enables caregivers to monitor patient status whenever and wherever they want. In the table mode, healthcare providers can check patient's daily question answers, weight, blood pressure, heart rate, and calorie expenditure. The table mode also provides statistical information. The graph mode displays each value as a color bar (Fig 4.2).



Fig 4.2. WANDA B. iPhone application

We also built the Mobile WANDA system on the Nexus One, another popular smart phone platform. The Nexus One has a 3.7 inch screen with a 800-by-480-pixel resolution. It also possesses hardware specifications superior to that of the iPhone. The Nexus One has weight similar to the iPhone's weight, 130g, and it also use the same HSDPA protocol. Moreover, as the Nexus One's Google Android platform allows users to use Bluetooth API, we can directly get data from health care devices. When users start the application, they choose between 'record' and 'history' options (see Fig 4.3). If a user chooses the record option, they are brought to a screen where they choose the specific measurement they wish to take. After choosing the measurement type and following the instructions on the phone, he or she can see the numerical data on the screen. The recorded data will be uploaded to the server. For the questionnaire option, user can answer twelve questions and the answers will directly transmit to the web server. If the user presses the 'history' option, he is given the option of choosing to view a graph of weekly or monthly data. This function would assist users in monitoring their own personal health status.



Fig 4.3. Mobile WANDA Android application

## 5. RESULTS

WANDA B. was approved by the UCLA institutional review board (IRB), which approves, monitors, and reviews biomedical and behavioral research involving humans with the aim to protect the rights and welfare of the research subjects.

Since November 31st, 2009, the WANDA B. system for the health data collection on 16 different subjects older than 60. They were all provided with Bluetooth weight scales, blood pressure monitors, Pods, and PAM devices. Every day, questions (listed in Table 1.2) are delivered to each patient, and WANDA B. monitors their responses.

The small study (Fig 5.1 and Table 5.1) has enabled patients to reduce or maintain weight, and it has reduced the number of blood pressure values which are out of the acceptable range given in Table 1.1. Many initial test results show that the number of measurements which were out of the acceptable range was decreased as the patients use the WANDA B. system.

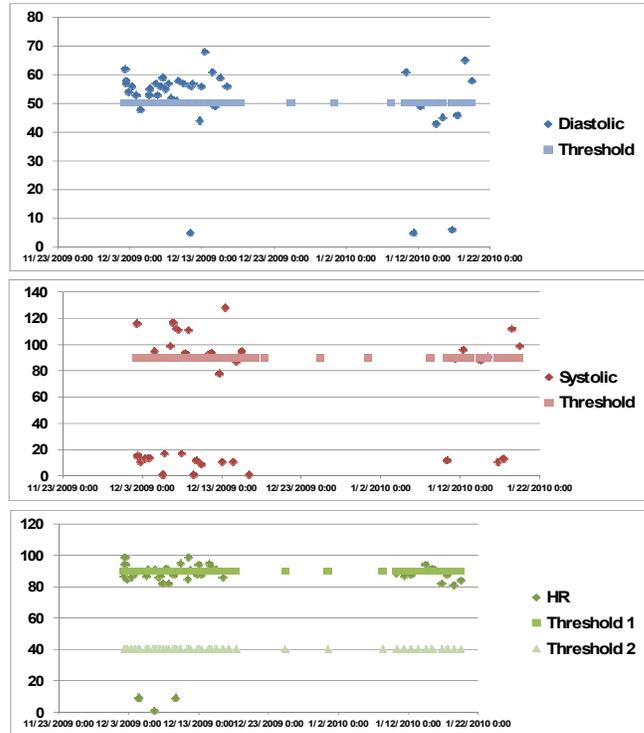


Fig 5.1. Changes in Diastolic, systolic, HR values

In order to compare two paired result values where both observations are taken from the same or matched subjects, a paired t-test was used. Among 13 patients, 5 patients who participated in the test more than 2 months were chosen to prove the result. When the null hypothesis and the alternative hypothesis are given as below and the degree of freedom is 4 with 95% confidence, the two-tailed inverse of the Student's t-distribution value is 2.78.

Null Hypothesis ( $H_0$ ): The number of warnings during the first 14 days = The number of warnings during the last 14 days.

Alternative Hypothesis ( $H_1$ ): The number of warnings during the first 14 days < The number of warnings during the last 14 days.

When applying the t-test method for weight, diastolic, systolic, and heart rate data (see table 5.1), the test result obtained from the below equation gives the t-values as 1.63, 1.00, 2.45, 1.20 respectively. Therefore, the alternative hypothesis should be rejected.

$$t = \frac{\text{mean difference}}{\text{standard deviation}} \times \sqrt{n}$$

The t-test assesses whether the means of two groups are statistically different from each other. This analysis is appropriate whenever you want to compare the means of two groups, and especially appropriate as the analysis for our two-group randomized experimental design. For weight, diastolic, systolic, and heart rate values, the t-test results show that the WANDA B. study is effective for patients with CHF.

**Table 5.1. Improvements in weight, diastolic, systolic, and heart rate**

ID	Weight		Diastolic		Systolic		Heart rate	
	First	Last	First	Last	First	Last	First	Last
p1	1	0	1	0	8	2	1	1
p2	1	0	4	5	16	5	15	2
p3	1	1	6	4	7	2	4	3
p4	4	0	1	2	0	1	2	2
p5	1	1	3	0	3	0	1	0

## 6. CONCLUSION

Heart failure is a leading cause of death in USA, and there are about 4,600,000 Americans currently suffering from heart failure. Wireless health technology that uses sensors and wireless communication methods can help those heart failure patients by monitoring them and providing guidance and feedback. Patients who have cardiovascular system disorders can measure their weight, blood pressure, activity, and other vital signs by using wireless health applications whenever and wherever they need to. A wireless health system will give a real-time and computer-based analysis, reducing the need for specialist visits. This helps prevent emergency situations and alerts caregivers when they must help patients.

In this paper, we presented the Weight and Activity with Blood Pressure Monitoring System (WANDA). The WANDA is built on a three-tier architecture. The first tier is a sensor tier that measures patients' vital signals and transmits data to the web server tier. Two different versions of WANDA use Bluetooth devices and other wearable sensors in the first tier. The WANDA B. platform uses a Bluetooth weight scale, a blood pressure monitor, WHI PAM (Personal Activity Monitor), and WHI's SMS system. In order to use Ideal Life weight scales and blood pressure monitors, the user is only required to connect an Ideal Life Pod™ system to a standard phone line. Then, the main database server and a system communication unit send and receive data via a long-distance phone service plan. The WHI PAM (Personal Activity Monitor) is a 3-axis accelerometer-based activity analyzer that calculates METs and calories burned during the user's day. Based on a schedule set by doctors, the WANDA B.'s daily SMS survey system sends SMS messages (listed in Table 1.2) in order to check for heart failure symptoms. The SMS system sends a text message to the users which they can reply to like an ordinary SMS from a friend. The Mobile WANDA utilizes a Bluetooth weight scale which measures body weight, body fat, body water, bone mass, and muscle mass. With more body component information, doctors can perform a more thorough analysis and the application can be used applied to a variety of different contexts. The software application is implemented on a Nexus One smartphone, which supports Bluetooth connection, meaning that the smartphone can communicate with the weight scale and the blood pressure monitor. The Nexus One smartphone also embeds an accelerometer, which renders the usage of the PAM unnecessary for monitoring patient activity. Additionally, the users' activity data can be uploaded to the server automatically via WiFi or 3G instead of having to upload data with a USB connection. Moreover, the Mobile WANDA implements the patient questionnaire feature that is previously done by the WHI SMS questionnaire system.

The second tier consists of web servers that receive data from the first tier and maintains data integrity. Since analyses of WANDA B. data involve drawing data from different databases, an abstraction of file formats and a shared ID table is required for incompatible data types. In addition, when the obtained values are out of the acceptable range, the second tier sends alert messages to health care providers via text message or e-mail. The third tier is a back-end database server in WHI SOPHI that performs backup and recovery jobs by applying an offline backup. Using its backup log file and PHP APIs, the WHI SOPHI client application controls data delivery between distributed web databases and the DBMS.

WANDA B. was approved by the UCLA institutional review board (IRB), which approves, monitors, and reviews biomedical and behavioral research involving humans, with the aim to protect the rights and welfare of the research subjects. The small study has enabled patients to reduce or maintain weight, and appears to have been correlated with reducing the number of blood pressure values which are out of the acceptable range. For weight, diastolic, systolic, and heart rate values, the paired t-test results show that the WANDA B. study is a potentially effective platform for aiding heart failure patients.

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## 8. REFERENCES

- [1] He, J. , 2001, Risk factors for congestive heart failure in US men and women: NHANES I epidemiologic follow-up study. Archives of internal medicine, 161(7), 996-. Psychometric Testing of the Heart Failure somatic awareness scale
- [2] Jurgens, C Y. ,2006, Psychometric testing of the heart failure somatic awareness scale. Journal of cardiovascular nursing, 21(2), 95-.
- [3] Haider, A W. , 2003, Systolic blood pressure, diastolic blood pressure, and pulse pressure as predictors of risk for congestive heart failure in the Framingham Heart Study. Annals of Internal Medicine, 138(1), 10-.
- [4] Redfield, M M., 2003, Burden of systolic and diastolic ventricular dysfunction in the community: appreciating the scope of the heart failure epidemic. JAMA, 289(2), 194-.
- [5] Kenchaiah, S, 2002, Obesity and the risk of heart failure. The New England Journal of Medicine, 347(5), 305-.

- [6] Hambrecht, R., 1998, Regular physical exercise corrects endothelial dysfunction and improves exercise capacity in patients with chronic heart failure. *Circulation*, 98(24), 2709-.
- [7] Liskov, B., 1988, Keynote address-data abstraction and hierarchy. *SIGPLAN notices*, 23(5), 17-.
- [8] Baker, C R., 2007, Wireless sensor networks for home health care , 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07)
- [9] Sherrill, D M., 2004, Accelerometer-based measurement of exercise and mobility for pulmonary rehabilitation, IEEE 30th Annual Northeast Bioengineering Conference 2004.
- [10] Obermayer JL., 2004, College smoking-cessation using cell phone text messaging. *J Am Coll Health*, 53(2):71-78.
- [11] Rodgers A., C 2005, Do u smoke after txt? Results of a randomised trial of smoking cessation using mobile phone text messaging. *Tob Control*; 14(4):255-261
- [12] Franklin VL. , 2006, A randomized controlled trial of Sweet Talk, a text-messaging system to support young people with diabetes. *Diabet Med*; 23(12):1332-1338.
- [13] <http://www.wirelesshealth.ucla.edu/>
- [14] <http://www.ideallifeonline.com/public/>
- [15] Jones NL, 1982, *Clinical exercise testing : 2nd edition*, Philadelphia : W. B Saunders
- [16] Bell GB., 2001, Matching records in a national medical patient index, *Comm ACM*, 44(9):83-88.
- [17] <http://cs.ucla.edu/~ani/SOPHI/>
- [18] <http://www.wanda.net>
- [19] Pettifer, S., 2009, Visualising biological data: a semantic approach to tool and database integration. *BMC bioinformatics*, 10(suppl 6), S19-.
- [20] Noy, N F., 2004, Semantic integration: a survey of ontology-based approaches. *SIGMOD record*, 33(4), 65-.
- [21] Mohan, C., 1993, An efficient and flexible method for archiving a data base. *SIGMOD record*, 22(2), 139-.
- [22] Suh, M K, 2010, WANDA B.: Weight and Activity with Blood Pressure Monitoring System for Heart Failure Patients, The Second International IEEE WoWMoM Workshop on Interdisciplinary Research on E-Health Services and Systems (IREHSS)
- [23] Bhattacharya, S., 2002, Coordinating backup/recovery and data consistency between database and file systems. In *Proceedings of the 2002 ACM SIGMOD international conference on Management of data - SIGMOD 02 SIGMOD 02.* (pp. 500-).
- [24] Yamada Y., 2009, Light-intensity activities are important for estimating physical activity energy expenditure using uniaxial and triaxial accelerometers, *European journal of applied physiology*
- [25] Hara T, 2006, The relationship between body weight reduction and intensity of daily physical activities assessed with 3-dimension accelerometer, *Japanese Journal of Physical Fitness and Sports Medicine*