MyHeart: An Intelligent mHealth Home Monitoring System Supporting Heart Failure Self-Care

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***Abstract*— MyHeart is a telehealth system designed to bridge the current gap in the Congestive Heart Failure care continuum that occurs when the patient transitions from the hospital to the home environment. The system uses wireless health devices and a mobile application on the patient's end, a rule-based expert system, and a dashboard on the clinician's end to facilitate the exchange of information pertaining to vitals, symptoms, and health risk. The system also sends messages to patients that aim to encourage self-care as per Fogg's behavior model. An experiment to evaluate MyHeart is currently underway at Loma Linda University Medical Center and encouraging initial findings are reported.**

Keywords—heart failure; home monitoring; telemedicine; expert system; mobile health application

I. Introduction

Congestive heart failure (CHF) is a chronic condition that is common among individuals older than 65[1,2]. A report published by the American Heart Association indicated that CHF is the most frequent cause for hospital readmissions such that 21.2% of Medicare patients diagnosed with CHF were readmitted to the hospital within 30 days of discharge and the estimated cost of diagnosis and treatment was 30.7 billion dollars in 2012 [2]. CHF is not curable but evidence shows that the quality of life and life expectancy of patients could be improved if the condition is managed by adhering to medications, monitoring symptoms, and salt intake in diet [3]. Still, individuals with CHF are faced with increasing complexity in self-care management in their homes .

Prior studies have shown that providing better support for patients in the home could have a dramatic effect on cost and efficacy of healthcare [5, 6]. Using a home monitoring system is one approach that has shown promise in promoting self-care, quality of life, and improved clinical outcomes [7, 8].

Recently a few technical systems have been developed to assist CHF patients . For example, a system called WANDA was built to collect various measurements and symptoms from heart failure patients while they are at home. It aimed to help clinicians monitor patients remotely while automatically analyzing their data [9]. Another home monitoring system that only measured weight on a daily basis was found to reduce the length of patients stay at the hospital [10]. CARDIAC was also designed to provide support through a conversational assistant [11]. Other systems that incorporate artificial intelligence in their design were also reported [12].

The problem is that self-care requires behavior change and support from clinical personnel. In theory, three elements must converge at the same time for a behavior to change [13]. These elements are: 1) motivation; 2) ability; and 3) trigger. According to Fogg's Behavior Model [13], when at least one of those three elements is missing behavior doesn't change. Typically people have low motivation and a low ability to change. If one's ability is high then change can occur. Similarly if one's motivation factor is high, change can occur. What leads to higher motivation? If the activity is pleasurable instead of painful, if there is hope as opposed to fear, and if doing the activity leads to acceptance as opposed to rejection. Our ability to do something is higher when it takes less time, less effort, and less cost. However, Fogg states that an external "behavior trigger" is required to propel a person to change. We believe "just-in-time" texting can act as effective triggers and our recent work has provided support for this hypothesis [14].

Clinicians are key for providing personalized interventions, however, the growing number of cases and the limited number of clinicians drives the need to find more effective strategies to support self-care. A major problem that Loma Linda University and Medical center (LLU) is currently facing is with hospital readmission. About 30% of their CHF patients are readmitted within 30 days while nearly 50% are readmitted after 60 days. While prior studies for home monitoring systems informed this research, none of their designs were found to meet the requirements of the LLU context. Thus, we design and build a novel home telemonitoring system for LLU that combines existing technologies with a customized mobile application and rule set, MyHeart, to support CHF self-care. The paper describes the architecture, implementation, security, and evaluation of the MyHeart system.

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II. System Architecture

MyHeart is a multifaceted system designed to enhance data flow and communication between CHF patients and healthcare providers through a secure and reliable channel. It is comprised of three major components: 1) a patient facing data collection suite including a mobile app; 2) a data aggregator with rule based expert system; 3) a healthcare provider's dashboard (see Figure 1).

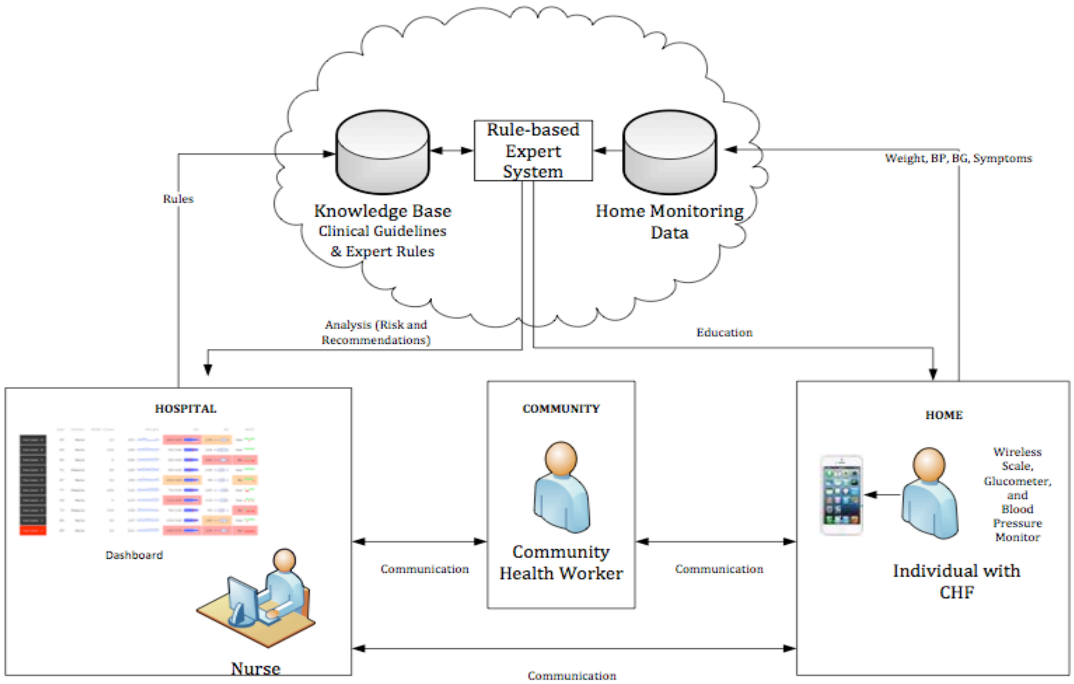


Fig. 1. MyHeart System Architecture

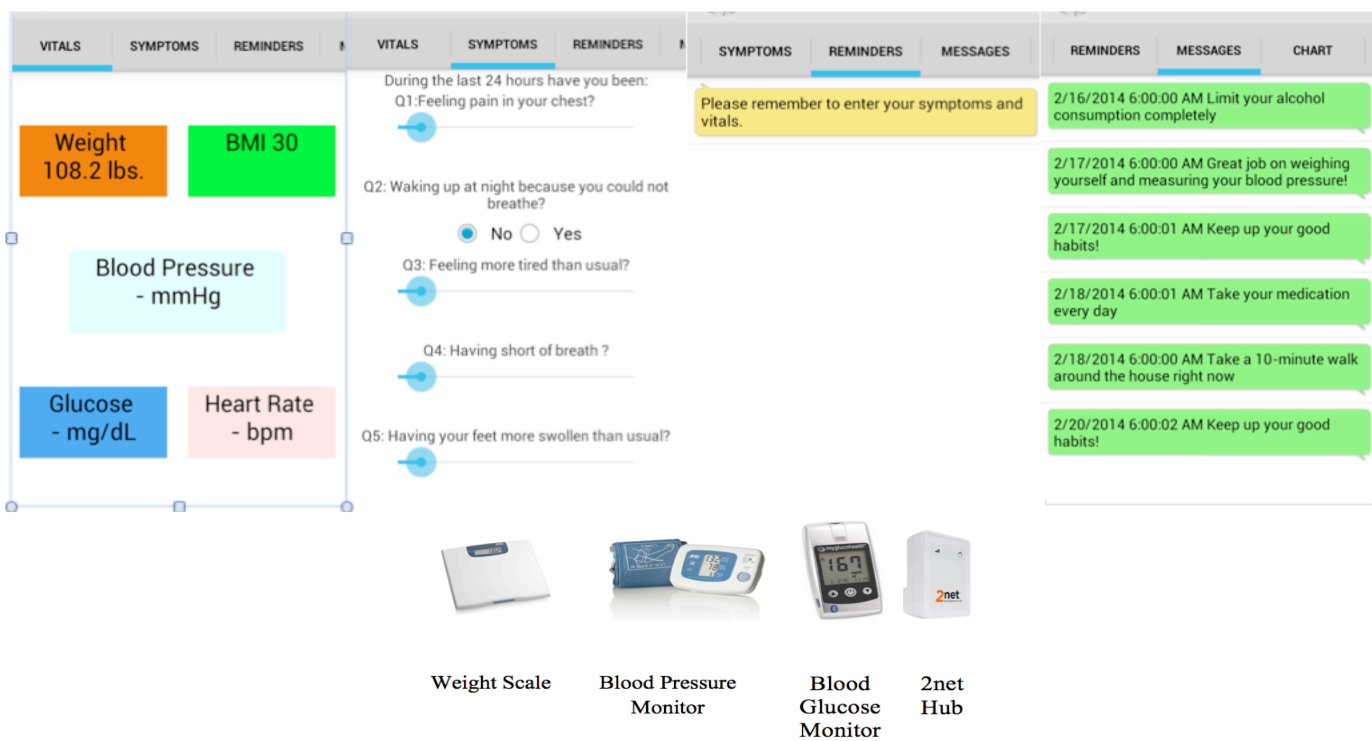


Fig. 2. MyHeart Devices and Mobile Application with Messages

III. Implementation

All patient data that flows from the homes to Cloud to the Clinician's dashboard is encrypted as per HIPAA requirements. The following sections describe each component.:

A. Data Collection Suite

The patient facing data collection suite is a set of consumer accessible electronic devices paired with a custom build mobile application to collect patient's vitals and symptoms on a daily basis. Patient's vitals such as blood pressure, weight, and blood glucose are measured using A&D and MyGlucoHealth devices which connect via bluetooth through 2Net communication hub [15]. Data transmission utilizes cellular technology and is initially collected at the MyGlucoHealth data repository. Patient's symptoms are collected via custom developed smartphone app running on Android OS. Symptom measurements, such as chest pain, shortness of breath, swollen feet etc, are collected and stored in local database at the IDEA Lab at Claremont Graduate University. Data communication is established once the mobile application authenticates itself via web services API. Additional functionalities such as measurements display, trending, messaging, and notification are also available for the patient via the mobile application.

Figure 2 shows the devices and mobile application. The application is designed to collect symptoms and display vitals and messages to encourage self-care behaviors. Example behavior change message would be "Great job for getting your weight under 215Ibs" or "God loves you".

B. Rule Based Expert System

The rule-based expert system sits in the cloud (See Fig. 1). It processes daily incoming data points (i.e., weight, blood pressure, blood glucose, and symptoms) and calculates a risk score. The risk score is a product of each parameter (i.e. measurement or symptom) multiplied by a weight. All parameters had an equal weight as per the requirements that were gathered initially. This risk score is used to help inform healthcare providers of any possible relapse of a given patient on a daily basis. In addition, the risk score also triggers urgent notifications to both healthcare providers about the patient's current health status.

To obtain the rules, we interviewed the director of cardiac health and wellness at LLU. Even though there are well-established guidelines available from AHA, the nurse suggested we incorporate the values shown in Table 1 as source for rules in the expert system. So in a way the MyHeart system is mimicking how the human nurse would process when she sees the health data.

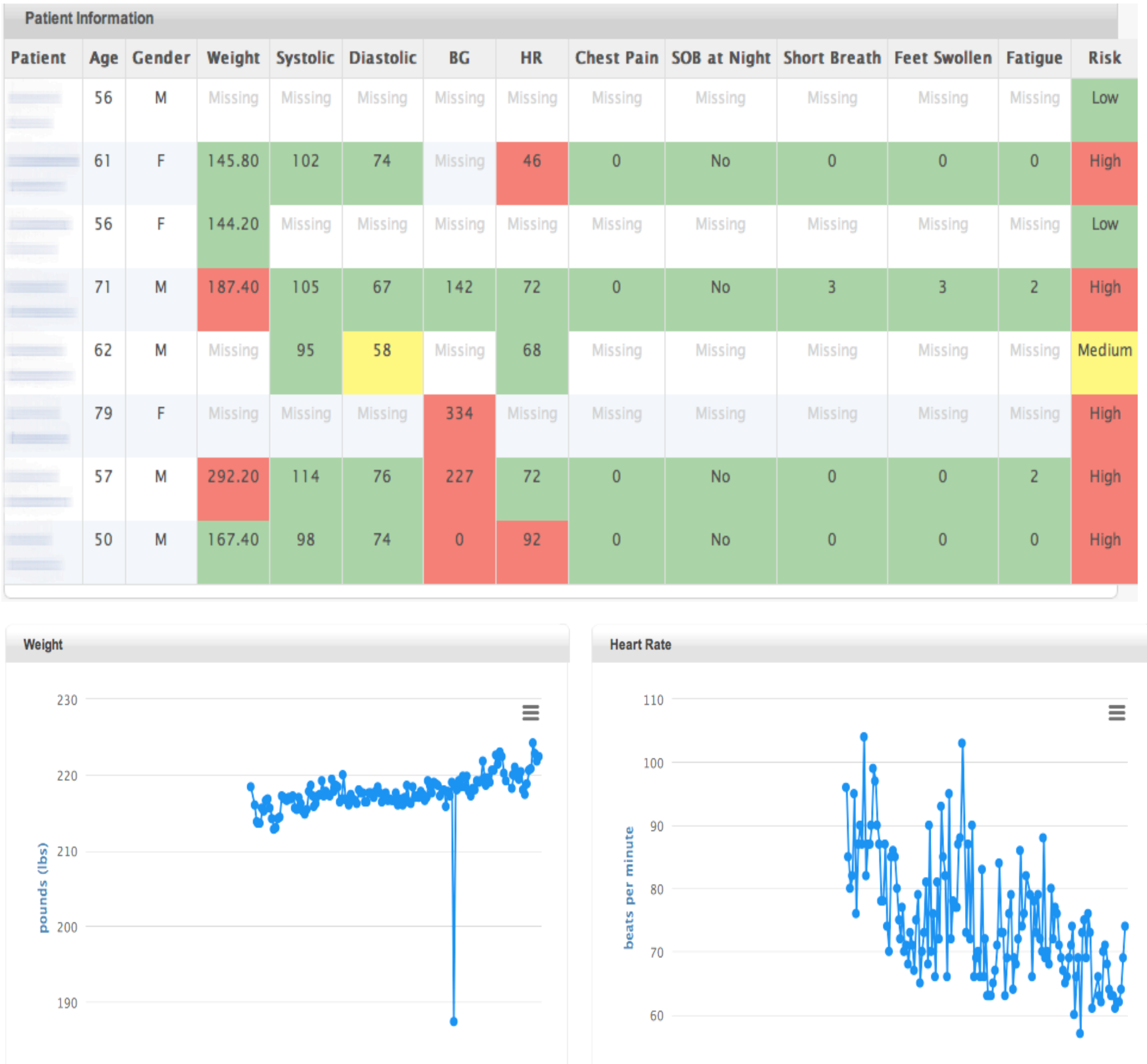
Ancillary to the expert system, is the notification system. The notification system utilizes email and SMS messages to send important messages to the heart failure nurses, and Google Cloud Messaging to communicate with patients via the mobile application.

TABLE I. Expert System Data Ranges for Rules Creation (based on input from Cardiac Nurse)

Measure-ment/ Risk	**Normal**	**Medium Risk-Below Average**	**Medium Risk-Above Average**	**High Risk-Below Average**	**High Risk-Above Average**
Heart Rate	60-79	50-59	80-99	<=49	>=100
Systolic BP	90-129	80-89	130-139	<=79	>=140
Diastolic BP	60-79	50-59	80-89	<=49	>=90
Weight	+/-1 lb	-1.5 lb	+1.5lb	-2 lb	+2 lb
Blood Glucose	60-200	<60 and >50	>200 and <240	<50	>250

C. Information Dashboard

The information dashboard is central to the daily operations for Loma Linda heart failure care-giver team. This dashboard is designed to display information that is collected daily from the patient collection suite. Each data point is analyzed by the rule engine and transformed for display. The information dashboard is presented in a tabular format with color indicators to highlight noteworthy data points. In addition, historical trending is accessible with drill down functionality (See Figure 3).



Patient Information

Patient	Age	Gender	Weight	Systolic	Diastolic	BG	HR	Chest Pain	SOB at Night	Short Breath	Feet Swollen	Fatigue	Risk
[illegible]	56	M	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Low
[illegible]	61	F	145.80	102	74	Missing	46	0	No	0	0	0	High
[illegible]	56	F	144.20	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Low
[illegible]	71	M	187.40	105	67	142	72	0	No	3	3	2	High
[illegible]	62	M	Missing	95	58	Missing	68	Missing	Missing	Missing	Missing	Missing	Medium
[illegible]	79	F	Missing	Missing	Missing	334	Missing	Missing	Missing	Missing	Missing	Missing	High
[illegible]	57	M	292.20	114	76	227	72	0	No	0	0	2	High
[illegible]	50	M	167.40	98	74	0	92	0	No	0	0	0	High

Fig. 3. MyHeart Dashboard (best viewed in color)

D. *Security and Architecture*

Because of the sensitive nature of the data, security measurements are implemented at data collection, transfer, transformation, and display. At data collection point, a unique key is generated at the patient's mobile application side. In conjunction with the patient's phone number, the unique identifier is transferred to the central database every time the patient's phone communicates with the database. Data collection between MyGlucoHealth and the database is established based on an automated scheduled method that runs daily. Security for MyGlucoHealth is developed at the vendor's location.

All data are collected and stored on a Microsoft SQL 2008 server with Windows based authentication. Two different design philosophies drive the database design. First, patient and rule based metadata are stored with traditional transactional normalized design for scalability. With this approach, additional patients can be quickly added without overall impact to the system. Second, all reporting and information displays, such as the information dashboard, utilize a data mart design philosophy for speed and security purposes. Although a data mart design forces data transformation between raw data and final display, the data mart design presents two additional benefits, data traceability and data security.

The main web server used Microsoft's IIS for hosting ASP.NET and VB.NET code. The dashboard is designed with open source high charts for charting needs [16]. Additional usage tracking is provided by Google Analytics [17].

IV. Evaluation

We conducted a pilot study at Loma Linda University's SACHS Medical Center to evaluate the system. Seven patients are currently enrolled and clinicians use the dashboard to view their home data daily. Current usage and perceptions about the quality of MyHeart is discussed below.

A. System Usage

Since system deployment, Google Analytics showed that the dashboard had over 250 sessions with over 800 pages viewed over a one month period. Average session usually lasts slightly over 2 and a half minutes with peak time at mid morning (10:00 AM) and early afternoon (1:00 PM).

The mobile app usage statistics show that the average session duration is around two minutes and that overall, patients viewed the symptoms screen 257 times and the messages screen 170 times over a one month period.

B. System Quality

Six dashboard users evaluated the quality of the system using an online survey. The results of the survey are shown in Table 2.

V. Conclusion

This paper described the design of a telehealth system for heart failure self-care that aims to: 1) overcome the gap that occurs when patients transition from the hospital to home environment, and 2) reduce readmissions. The system builds on the behavior model such that it sends messages to patients that potentially trigger behavior change. It also facilitates daily communication among patients and heart failure clinicians so any deterioration in health could be identified immediately. Such a system does not exist, to the best of our knowledge. Initial results show that the clinicians and patients are using the system and that some features of the system have been helpful while others need improvement. Future work will focus on incorporating feedback from the patients into the design of the system. A predictive analytics module is also underdevelopment for trend analysis and to predict blood pressure, weight, HGA1C levels in advance. A larger clinical trial is also planned to demonstrate the impact of the system on health outcomes and readmissions.

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TABLE II. MyHeart System Quality Results

Quality Statements	Strongly Disagree	Disagree	Agree	Strongly Agree
1. This dashboard has all the functions I expect to have	0.00%	33.33%	33.33%	33.33%
2. The information displayed on the dashboard was easy to understand	0.00%	0.00%	66.67%	33.33%
3. It was easy to navigate and find the information I needed	0.00%	16.67%	50.00%	33.33%
4. As a cardiac health professional, this dashboard captures all the necessary vitals and patient data	0.00%	33.33%	33.33%	33.33%
5. I trust the data presented in this dashboard	0.00%	33.33%	50.00%	16.67%
6. It was easy to learn to use this dashboard	0.00%	0.00%	66.67%	33.33%
7. I can easily pin point critical areas by using this dashboard	0.00%	0.00%	66.67%	33.33%
8. Using this dashboard would make it easier to do my job	0.00%	33.33%	33.33%	33.33%
9. Using this dashboard would enhance my effectiveness on the job	0.00%	33.33%	33.33%	33.33%
10. Using this dashboard saves me time in determining high risk patients I need to focus on	0.00%	16.67%	50.00%	33.33%
11. I utilize the patient detail page to make informed decisions about patients	0.00%	0.00%	66.67%	33.33%
12. The organization of information on this dashboard was clear	0.00%	16.67%	50.00%	33.33%
13. The dashboard allows me to make decisions about which patients to call or visit	0.00%	0.00%	66.67%	33.33%
14. The color highlight scheme is easy to understand	0.00%	0.00%	50.00%	%50.00
15. The charts in the patient detail page are clear and easy to understand	0.00%	0.00%	50.00%	50.00%
16. I find emails about patient's risk condition very helpful	0.00%	16.67%	66.67%	16.67%
17. The text alerts about patient's risk condition is extremely useful to me	16.67%	33.33%	33.33%	16.67%
18. The text message and email content notifying the patient's risk condition was easy to understand	0.00%	0.00%	66.67%	33.33%
19. Overall, I am satisfied with the dashboard	0.00%	33.33%	33.33%	33.33%

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