Persuasive Sensing: A Novel In-Home Monitoring Technology to Assist Elderly Adult Diabetic Patients

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Abstract. Diabetes mellitus is a common but serious chronic disease that kills thousands of patients worldwide each year. While there are several useful regimens that can be followed to manage the disease, elderly adult patients have particular difficulties in self-managing the disease. In this paper we present a novel approach to self-management – persuasive sensing – that uses environmental and body-wearable sensors that continuously detects activities and physiological parameters. Our system sends persuasive text messages and a weekly health newsletter aimed to alter the subject's behavior. We present the findings from an in-home monitoring implementation. The results obtained are quite encouraging. We discuss the challenges and lessons learned from such a field experiment and how we can improve upon the technology.

1 Introduction

Diabetes mellitus is the most common and serious chronic disease in the United States. There are nearly 26 million Americans with diabetes of which 10.9 million (or 26.9%) are aged 65 and older [1]. California in particular has the highest incidence of new diabetes cases and nearly 4 million people estimated to be suffering from the disease [2]. The costs of caring for this disease are astronomical and are estimated to exceed more than $24 billion in California and $174 billion nationally [1, 2].

Diabetes remains a major health problem being responsible for up to 8% of national health care expenditure. Diabetes mellitus is a chronic disease characterized by a sustained elevated blood glucose level, caused by a reduction in the action of insulin secretion where related metabolic disturbances generate severe, acute and long-term complications that are responsible for premature death and disability [10]. The World Health Organization projects that diabetes deaths will increase by more than 50% in the next ten years without urgent action. Most notably, diabetes deaths are projected to increase by over 80% in low-middle income countries between 2006 and 2015 [18].

Despite the availability of effective treatment, diabetes remains poorly controlled. Fewer than 7% of diabetic patients meet treatment goals for lipids, blood pressure,

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and glycosylated hemoglobin A1c [3, 4]. Elderly patients with diabetes have higher rates of mortality, congestive heart failure, myocardial infarction and stroke as compared to age-matched controls without the disease [5]. Moreover, despite evidence that the mortality rate is decreasing over time, the rate of complications is remaining the same [6]. As a result, the average number of lifetime complications per patient is increasing as patients are living longer. With the incidence of diabetes rapidly rising, this is a fatal combination for the economic wellbeing of our health system.

Poor adherence to recommended self-management guidelines is well-recognized as a significant barrier to effective glycemic control. Improved outcomes have been associated with better adherence to medications, blood sugar self-monitoring, diet and lifestyle changes, and appointment attendance [7 - 9]. Barriers include time constraints, knowledge deficits, denial, limited social support, inadequate resources, and low self-efficacy.

Many of the elderly adults have difficulty achieving tight control because of the high degree of cognitive resources needed to manage diabetes. A major challenge in chronic disease self-management, particularly in elderly Americans, is social isolation [15]. Elderly diabetic patients with poor social support have twice the mortality rate of those with adequate support [16]. Furthermore, though families and friends want to help their loved ones better manage their conditions they often do not know how to act or when to act. Studies consistently show that patients with empowered caregivers or peers have better outcomes [16].

Mobile phones are an ideal platform for supporting chronic diseases like diabetes because they are ubiquitous, low-cost, reliable, real-time, and versatile; and unlike most technologies, actually enjoy greater usage amongst racial/ethnic minorities. In self-management, mobile phones can help individuals remember to do various health-related activities and record them, and also help others in their personal wellness ecosystem to review ongoing health patterns and respond quickly to changes in health status [11, 12]. Using wireless sensor networks within the home can help to remotely monitor activity of daily living (ADL) which can then be used to send effective reminders and feedback [13, 19].

In this paper we describe the design, implementation and evaluation of such a mobile and wireless sensor system. In particular we describe a novel approach that we call "persuasive sensing", in which elderly patients with diabetes receive customized text messages based on their sensor data to motivate them towards a healthier lifestyle. They also receive a customized health newsletter (weekly) that is aimed to inform and educate them on their various daily activities. The prototype implementation and its evaluation show tremendous positive results.

2 System Architecture and Prototype

Any at-home healthcare solution must detect and respond to the activities and/or characteristics of the older person. A network of sensors (worn, carried, or environmental) is an ideal technology platform for detecting and responding to health-relevant parameters such as movement, sleep, weight, physiological data and social activity

[14]. In designing our system, the following key principles were kept in mind throughout the process:

- This is a healthcare problem, not a technology problem. At the center is the patient, not the technology. That also means as the experiment progresses, we must adapt based on patient's feedback.
- The simpler the technology, the better. Patients must comprehend what is being sent as feedback.
- Wireless Sensor Networks (WNSs) for healthcare are mission-critical; reliability is of paramount importance.
- The daily feedback persuasive messages must be kept fresh and not boring so the patient is eager to receive them and learn how to change his/her behavior.
- It has to work in the home, not just in the lab.

A WSN device is a packaged data collecting or actuating component, which includes a sensor and/or actuator, a radio stack, an enclosure, an embedded processor, and a power delivery mechanism [14]. The sensor interacts with the environment and sends an appropriate signal (analog or digital) to the embedded processor (also called microcontroller unit). We used Iris Mote technology developed by Intel and UC Berkeley labs. The mote hardware platform consists of a microprocessor and radio chip (MPR). Sensors connect directly to the mote processor radio boards via various interfaces. This combination gives the mote the ability to sense, compute and communicate. The mote enables raw data collected by the sensors to be analyzed in various ways before sending it to an aggregator (in our case a laptop) that we placed within the home. The aggregator then uploads daily activity data to the cloud through secured channels via the Internet. The following different types of sensors were implemented in this project:

- A simple on/off switch that detects open/close of garage door (through which subject leaves homes).
- A simple on/off switch that detects the back porch door for open or close.
- A blood glucose monitor device that can connect easily to the laptop via USB and which can upload Blood Glucose values daily.
- An infra-red analog sensor that detects presence in the bedroom.
- A photo sensor connected to the TV to detect television viewing.
- A pressure pad sensor (from Colonial Medical) placed in the couch in the living room in front of TV.
- A simple on/off switch to detect opening and closing of medication cabinet.
- A simple on/off switch to detect open/close of cabinet containing insulin.
- A wireless weight machine (from Tanita Corporation) that sends value via Bluetooth.
- A commercial body-wearable sensor from BodyMedia Inc. which is an arm-band that the patient wears 24 hours. This multi-sensor senses number of steps walked, quality of sleep, and many other physiological parameters. Data is sent to the cloud via USB upload.

The subject was shown how to log into BodyMedia website where he could input diet/nutrition information. Our system would then fetch daily diet data and compute total calories consumed. We also provided the patient with bottled water and asked him to only drink that during the course of the experiment. This was a simple way for us to monitor water intake.

The overall architecture schematic is shown in Fig. 1, while actual photos taken from the implementation site are shown in Fig. 2. The on/off switches were not wireless, so we had to run wires from them to the microcontroller. We originally had plans to sense the kitchen microwave and refrigerator usage also. But as the long wires would disturb the subject's mobility and accessibility in the kitchen, we abandoned that idea.

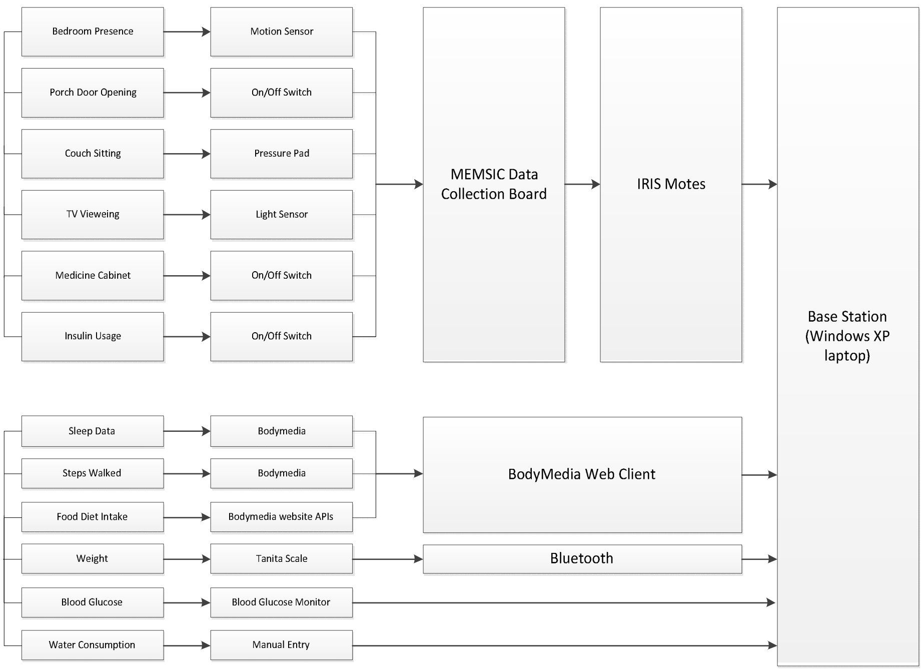

Fig. 1. Overall system architecture

3 Intervention Design and Persuasive Messaging Algorithms

Patients with type 2 diabetes can manage their chronic conditions by following certain recommended strategies. Prevention strategies for Type 2 diabetes include:

- Lose weight and keep Body Mass Index (BMI) under control
- 30 minutes or more of exercise or physical activity (brisk walking every day is fine)

- Develop a low calorie low fat diet. Nutrition guidelines include recommendations for a diet rich in whole grains, fruits and vegetables.
- Take necessary medications and measure their blood sugar regularly

Most elderly patients are challenged to adhere to these regimens due to lower cognitive abilities and lack of resources to maintain the lifestyle. Hence with technology, it is now possible to help these patients.

Our **intervention** has multiple components.

- System sends daily SMS text message on the cell phone using persuasive messages targeting behavior change.
- A tailored newsletter that summarizes healthy living parameters is presented to subject once a week and is jointly read by family member or one of our research team members.

Note our intervention (through the prototype persuasive sensing system) is aimed to engage patients in diabetes self-management through interactive SMS and newsletter approaches.

Fig. 2. Actual implementation photos from site (best viewed in color)

3.1 Primary Hypothesis

Hypothesis #1. Subject after the experimental intervention will show 5% reduction in blood glucose measurement (HbA1c measures 90-day average blood sugar).

Hypothesis #2. Subject will demonstrate more physical activity (measured by number of steps walked daily) after intervention and show trends that reach target goals set up before experiment.
Hypothesis #3. Subject will lower their daily calorie consumption and increase their intake of fruits and vegetables.

3.2 Secondary Hypothesis

Hypothesis #4. At end of intervention, subject will show improvement in BMI.
Hypothesis #5. At end of intervention subject will show weight loss.
Hypothesis #6. At end of intervention, subjects will demonstrate greater success in self-efficacy of diabetes management as measured by DES (Dissociative Experiences Scale).
Hypothesis #7. At follow up subject will show better quality of life.
It was important to ensure that daily text messages sent to the subject were fresh and relevant. Each day the subject received up to 3 text messages that were delivered to him over an LG smart phone. Below we show two examples of how messages were varied for physical activity and calorie consumption (Tables 1 and 2). The physical activity is measured by the number of steps obtained from the BodyMedia sensor.

Table 1. Messaging algorithm for physical activity

Case	Steps >= 8000	Steps < 8000
Mon	Great Job! Keep up the good work.	Don't give up on physical activity. Try walking a mile each day.
Tue	You have exceeded your goal. Congratulations.	Don't give up on physical activity. Have you taken the stairs?
Wed	You are doing very well. Keep it up!	Have you reached your goal of 8000 steps?
Thu	You are a super hero. You have exceeded your goal.	You fell short of your goal. Don't worry. Try to walk a mile after dinner.
Fri	You have exceeded your goal. Super job!	Never say never. You can do it.
Sat	Steps graph for past 5 days	
Sun	Great Job. Enjoy the Sunday with friends and family.	It is a beautiful day. Go out and do brisk walking for 30 mins.

To obtain diet/nutrition measures, the subject entered information into BodyMedia website. Using their APIs we were able to calculate total calorie consumed every day.

4 Subject Recruitment and Experiment Design

We obtained approval from our university Institutional Review Board (IRB). After IRB approved us to proceed, we distributed announcements to recruit subjects via hospitals, diabetes clinics and through personal contacts. The basic eligibility criteria that we included in our recruitment efforts were:

- Subject must have Type 2 diabetes
- Age can be between 45-85
- Gender and race – no preference
- Have familiarity with cell phone and texting
- Have a broadband internet connection at home

Table 2. Messaging algorithm for food and nutrition

Case	cal <= 2500	cal > 2500
Mon	Your careful diet is going to help you reduce weight.	Try to eat reduced portions today!
Tue	Great job. You are watching your diet and will results soon.	Avoid takeaways and snack foods that are high in fat.
Wed	Enjoy green vegetables and salads and you are on your way to lose weight.	Try 10 baby carrots and a tablespoon of fat-free dressing for a 100-calorie snack.
Thu	Your diet calorie intake is under control. Congratulations!	Did you know that obesity is one of the leading causes of death in this country?
Fri	Very well done. If you can walk 5000 extra steps, then treat yourself a Starbucks Frappuccino.	Have you tried low calorie drinks such as diet sprite?
Sat	Your diet trend is looking very good. Keep it up.	Add variety of colorful vegetables to your meal today.
Sun	Show calorie graph for past 6 days.	Choose low-fat dairy foods and lean meat.

We met with and interviewed prospective candidates who expressed interest. From the pool we selected our first subject. This subject is an 82 year old white male who is retired and lives in the Vista community near San Diego. He has type 2 diabetes, and a combination of other health problems. He agreed to the consent form and we started our project implementation.

We specifically designed a pre-post type of intervention.

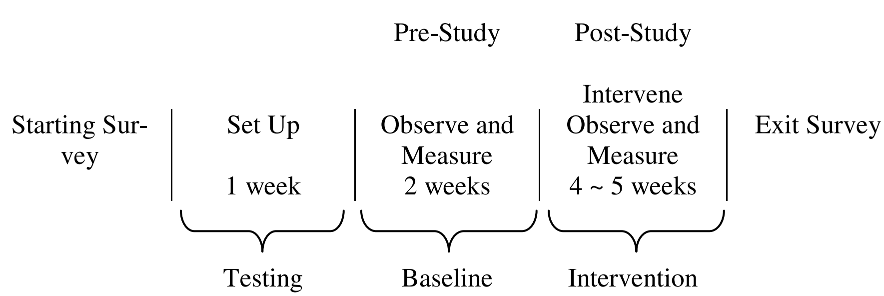

Fig. 3. Experiment design for intervention

We started our installation on October 18, 2011. Actual intervention through daily text messaging and weekly newsletter started from October 28, 2011. The experiment ended on November 25, 2011. All sensors and other equipment's were removed from the subjects' home after that. We thanked the subject and gave him a token honorarium for participation.

5 Results and Evaluation

As shown in Fig. 4A and Fig. 4B, the subject's blood glucose levels and weight is on decline trend. If subject can continue to reduce these physiological parameters, he will be in control of his chronic condition. Hypothesis #1 and #5 are supported. Both Fig. 4C and 4D demonstrate that subject has steadily increased physical activity and reduced his idle time throughout the intervention period. Hypothesis #2 is supported.

Fig. 4E shows that the subject's quality of sleep is improving in course of the intervention. Fig. 4F also shows that the sleep efficiency is getting better over time.

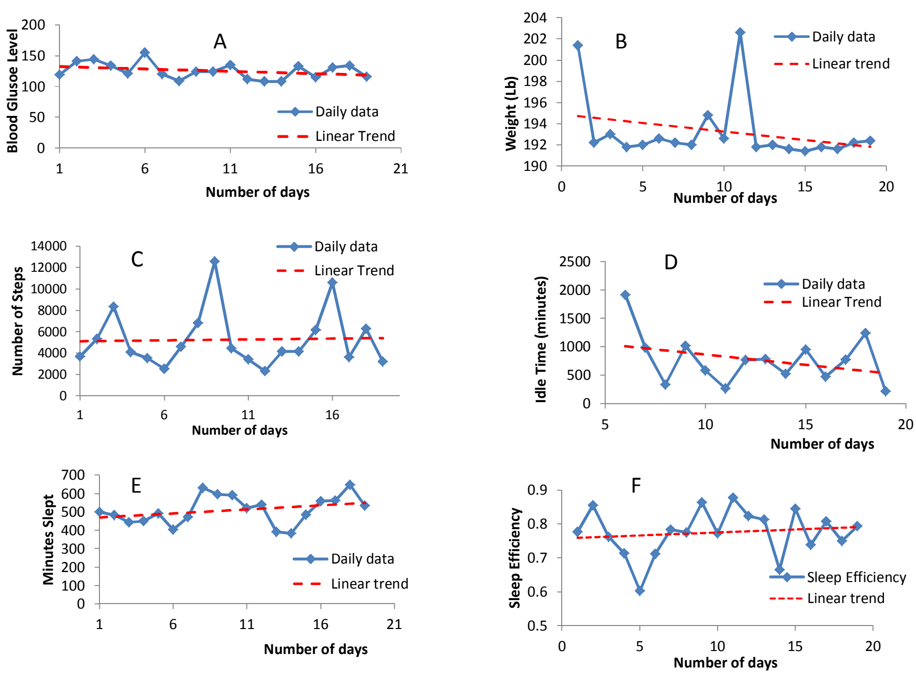

Fig. 4. Experiment results from the subject's home. (A) Blood glucose levels; (B) Weight trends; (C) Physical activity; (D) Idle time; (E) Minutes of good sleep; (F) Sleep efficiency

HbA1c is a lab test that shows the average amount of sugar in your blood over 3 months. It shows how well you are controlling your diabetes. An HbA1c of 6% or less is normal. Pre-experiment our subject's HbA1c was 12.9%. Post experiment HbA1c came to 6.6%. This is a significant improvement and validates hypothesis #1.

We also conducted a post-experiment exit survey in which we used the Diabetes DES scale to inquire about the subject's ability to manage the disease. Table 3. shows that subjects' ability to manage diabetes is improving (validates hypothesis #6) thereby improving his quality of life (hypothesis #7).

Table 3. Diabetes DES exit survey results

	Pre-Persuasive-sensing care	Post Persuasive-sensing care
I feel confident in my ability to manage my diabetes	agree	agree
I feel capable of handling my diabetes	agree	agree
I am able to do my own routine diabetes care.	agree	Strongly agree
I am able to meet the challenge of controlling my diabetes.	neutral	neutral

6 Analysis and Lessons Learned

The weekly health newsletter was customized for the subject. A snapshot of one page from the newsletter delivered on 11/24/2011 is shown below:

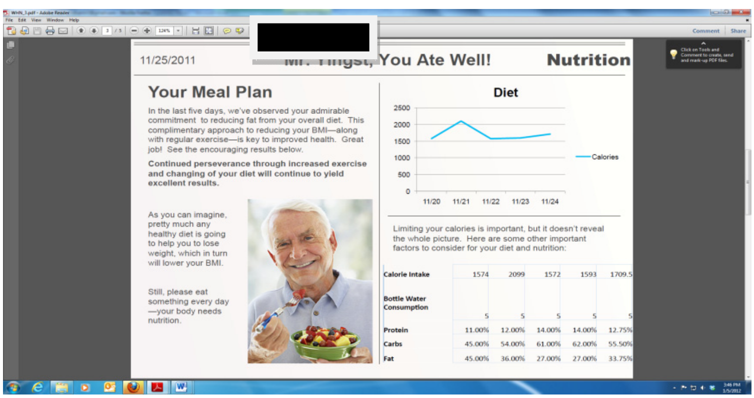

Fig. 5. Nutrition section of the newsletter

After each briefing of the newsletter with the subject, we received several useful feedbacks which helped us to customize the next version. During the implementation, we faced the following challenges:

- The Iris mote sensor system wasn't functioning sometimes and had reliability problems. A member of the team had to fix the errors several times before it became stable.

- Since on/off switches were not wireless, running wires from different parts of the home to the base station area was problematic. This can only be solved with wireless sensors and switches which we are deploying in the next implementation.
- The BodyMedia arm-band needs to be tight around the skin. However as our subject was elderly, it would not connect properly sometimes. Also at times it would give some skin rashes to the subject. A solution was to place the Body Media on his leg, and under his sock, which anchors the device against his leg, delivers a better measurement than placing the device on his arm.
- The base station being a Windows XP machine rebooted itself probably due to a security update and that killed many of the processes that we were using. A manual intervention was required in-between deployment to bring everything back to normal state.

The main feedback we received from each iteration of the newsletter was the following:

- Subject clearly understands the metrics associated with Physical Activity; but, does not have a clue as to what the “other key factors” mean. Suggestion: we should have a legend on this page to define the results, and better explain what they mean and how they correlate with Subject test objectives.
- Subject felt it did not capture the true amount of water consumed, and, he reiterated that he drinks voluminous amounts of water per day. Subject raised a question: is there something else you want me to take from this page in terms of this experiment?
- The Subject felt the Newsletter is a good tool for gathering relevant information important during physician visits/follow-ups; and, could be the basis for more meaningful dialog between Subjects and physicians.
- The ‘persuasive’ text messages are not bad; but, if a Subject like him sees the same ones time-and- time again, he gets numb and bored; so, the Subject recommends that messages should be specific – more personalized, catchy, and engaging in a narrative way to motivate the Subject to continue to modify behaviors and activities.
- The Subject observes that the food groups used in our study may be based on prepared food charts; and, does not account for naturally prepared food cooked fresh every day. With the exception of rice and pasta, the subject very rarely eats restaurant prepared food, or packaged meals.

As shown in Fig 6, we noticed that the subject’s calorie intake increased steadily. For the demographic profile of the subject the goal calorie value should be around 2500 per day. So even though our hypothesis #3 was not supported, we felt that the subject was eating quite well and within the acceptable calorie levels.

A limitation of our project so far is that we are presenting results from one home and one subject. But we argue that there is a lot to be learned from this *case study*. The feedback we have received is invaluable. While the positive behavior change that has resulted isn't statistically significant, we feel that our "persuasive sensing" idea has merit for further investigation. We have just completed a second home implementation (new subject is a 60 year old woman) whose HbA1c lowered from 8.9% to 8.5%. She has an iPhone and instead of a newsletter we used the smart phone capabilities and displayed the newsletter in a PDF format.

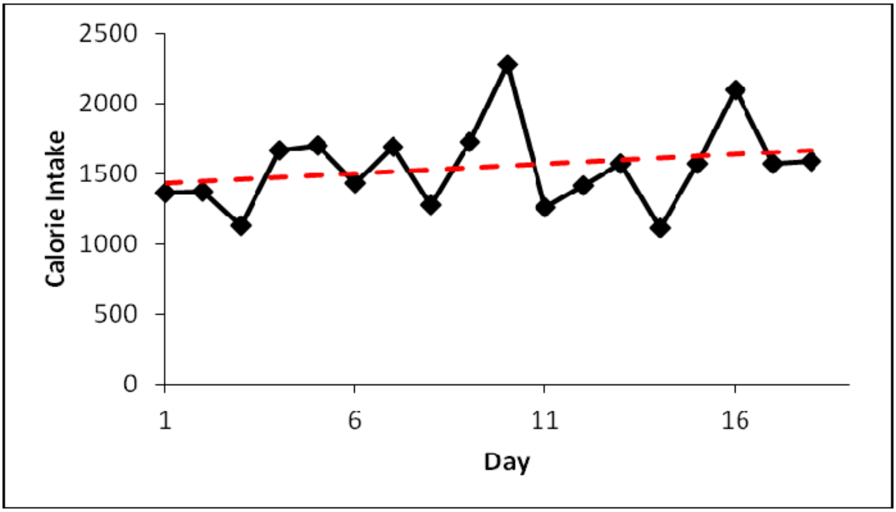

Fig. 6. Food/nutrition calorie trend

A concurrent activity of this project is to design artificial neural networks and machine learning algorithms that can mine the activity data and detect abnormal health conditions. Preliminary results were recently presented in [17] but we will report detailed results of that endeavor in a separate paper.

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References

1. Centers for Disease Control and Prevention. National diabetes fact sheet: national estimates and general information on diabetes and prediabetes in the United States. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Atlanta, GA (2011)
2. California Diabetes Program, Diabetes Information Resource Center (DIRC). California Diabetes Fact Sheet. California Department of Public Health, University of California San Francisco (2011)
3. Saydah, S.H., Fradkin, J., Cowie, C.C.: Poor control of risk factors for vascular disease among adults with previously diagnosed diabetes. JAMA 291, 335–342 (2004)
4. Saaddine, J.B., Cadwell, B., Gregg, E.W., et al.: Improvements in diabetes processes of care and intermediate outcomes: United States, 1988-2002. Ann. Intern. Med. 144, 465–474 (2006)

5. Bethel, M.A., Sloan, F.A., Belsky, D., Feinglos, M.N.: Longitudinal incidence and prevalence of adverse outcomes of diabetes mellitus in elderly patients. Arch. Intern. Med. 167(9), 921–927 (2007)
6. Sloan, F.A., Bethel, M.A., Ruiz Jr., D., Shea, A.M., Feinglos, M.N.: The growing burden of diabetes mellitus in the US elderly population. Arch. Intern. Med. 168(2), 192–199 (2008); discussion 199
7. Schectman, J.M., Nadkarni, M.M., Voss, J.D.: Diabetes metabolic control and medication adherence in an indigent population. Diab. Care 25, 1015–1021 (2002)
8. Heisler, M., Faul, J.D., Hayward, R.A., Langa, K.M., Blaum, C., Weir, D.: Mechanisms for racial and ethnic disparities in glycemic control in middle-aged and older Americans in the health and retirement study. Arch. Intern. Med. 167, 1853–1860 (2007)
9. Blonde, L., Karter, A.J.: Current evidence regarding the value of self-monitored blood glucose testing. Am. J. Med. 118(9a), 20s–26s (2005)
10. Xiao, Y., Chen, H. (eds.): Mobile Telemedicine: A Computing and Networking Perspective, ch. 8. CRC Press, Taylor & Francis Group (2008)
11. Fogg, B.J., Adler, R. (eds.): Texting for Health: A simple powerful way to improve lives. Stanford Persuasive Lab. (2009)
12. Årsand, E., Tatara, N., Østengen, G., Hartvigsen, G.: Mobile Phone-Based Self-Management Tools for Type 2 Diabetes: The Few Touch Application. Journal of Diabetes Science and Technology 4(2) (March 2010)
13. Atallah, L., Lo, B., Ali, R., King, R., Yang, G.-Z.: Real-time Activity Classification Using Ambient and Wearable Sensors. IEEE Trans. Info Tech in Biomed. 13(6) (2009)
14. Dishongh, T.J., McGrath, M.: Wireless Sensor Networks for Healthcare Applications. Artech House (2010)
15. Liu, L.: Social connections, diabetes mellitus, and risk of mortality among white and African-American adults aged 70 and older: an eight-year follow-up study. Ann. Epidemiol. 21(1), 26–33 (2011)
16. Chesla, C.A.: Do family interventions improve health? Journal of Family Nursing 16, 355 (2010)
17. Chatterjee, S., Dutta, K., Xie, H., Byun, J., Pottathil, A., Moore, M.: Mining Behavior Profiles and Health Patterns from In-Home Monitoring of Sensor Data. In: Proc. of 21st Workshop on Information Technologies and Systems (WITS 2011), Shanghai, China, December 3-4 (2011)
18. World Health Organization. 10 facts about diabetes (2011), `http://www.who.int/features/factfiles/diabetes/en/index.html`
19. Virone, G., Alwan, M., Dalal, S., Kell, S.W., Turner, B., Stankovic, J.A., Felder, R.: Behavioral Patterns of Older Adults in Assisted Living. IEEE Transactions on Information Technology in Biomedicine 12(3) (May 2008)