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A Computer-Based, Automated, Telephonic System to Monitor Patient Progress in the Home Setting

Umesh H. Patel

Charles F. Babbs
Purdue University, babbs@purdue.edu

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Umesh H. Patel and Charles F. Babbs

Biomedical Engineering Center, Purdue University, West Lafayette, Indiana, USA.

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ABSTRACT

In this report we describe an automated, telephonic system to monitor the progress of patients convalescing at home. The system includes a computerized central station that is capable of automated voice communication over the telephone, using voice reproduction, and touch-tone recognition. Peripheral hardware in multiple monitored homes need include only a touch-tone telephone, but may also be augmented by inexpensive, rudimentary diagnostic aids, such as a scale for body weight, a thermometer, or a blood pressure cuff and manometer. Current central hardware includes a NeXT computer, a fax modem, and a specialized telecommunications modem developed specifically for voice telecommunication using the NeXT.

The central station acts like a robotic nurse in that it asks patients a series of questions and records the responses. The subjective questions to be asked are patient individualized and pre-selected by the physician from a question menu including items targeted specifically for the patient's disease or condition. In addition, clinical data such as body weight, blood pressure, and body temperature obtained from in-home diagnostic aids may be transmitted to the central station over the telephone using touch tones. The time-of-day and frequency of calling are pre-selectable, according to the patient's preference and clinical status. Data obtained by the central station can be easily accessed by the duty nurse via menu driven software. Reports depicting significant responses as a function of time are generated in graphical format to facilitate rapid identification of adverse trends. Hard copy reports can be dispersed directly by fax.

Results from a pilot study show patients with cardiac disease readily use the system without difficulty or complaints. In one patient a five pound increase in body weight was detected, which prompted the patient's cardiologist to adjust his medication. In this way automated telephone follow-up can provide early detection of complications before they become severe, making the home environment safer and more secure for convalescence and contributing to reduced health-care costs.

INTRODUCTION

Monitoring plays an important role in health care, in that professional caregivers can quickly detect adverse trends and gather useful feedback on how a therapy is progressing. Several studies have shown the advantages of in-home monitoring in the general population for a variety of disease states. Katz and co-workers [5] investigated the usefulness of in-home monitoring of uterine activity in women at high risk for preterm labor. Historically, if preterm labor is detected early enough, proper, prompt treatment can prevent a premature birth. In the group of women with uterine monitoring 88% of the women delivered at term, whereas in the control group that did not have monitoring only 59% delivered at term.

In-home monitoring has also proved useful in treating patients with heart disease. Telephone transmitters were used to periodically monitor electrocardiograms (ECG's) of patients with cardiac arrhythmias by Chadda *et al.* [2]. Drug regimens were optimized on the basis of the data collected. In a 15-month period, only 1 patient of the 19 using the telephone transmitter system died. Twelve patients of 24 patients not using the telephone transmitter system died. In another study Capone *et al.* [1] reported the advantages of a transtelephonic management system for patients after myocardial infarction. The management system consisted of manual telephone follow-up calls to the patients from hospitals. The investigators asked patients how they felt, and a transtelephonic ECG was taken. In the one year 5.6% of the patients died who were using the system, compared to 12.9% who were not using the system. These studies clearly establish the potential benefits of in-home patient monitoring, not only to evaluate the patient's condition and response to therapy, but also to abort life-threatening complications and the attendant costs of dealing with them in-hospital.

Clearly, larger groups of patients might be able to benefit from in-home monitoring, if technology were available to conduct monitoring at reasonable cost. In particular, patients with chronic disease, such as congestive heart failure, might benefit, because drug therapy could be managed more effectively. In patients with congestive heart failure (CHF) physicians are most concerned in monitoring cardiac symptoms and body weight to characterize the response to therapy. However, cardiac symptoms and body weight can fluctuate from week to week, and the interval between office visits for 90% of CHF patients is between 2 to 4 months [3]. Thus, if the patient perceives his health as satisfactory, the physician will receive no feedback about the patient's condition between office visits. A 5-1b increase in body weight might go undetected. Breathlessness or ankle swelling might be infrequent, denied by the patient, or considered too trivial to warrant disturbing the physician. These symptoms might well indicate that drug therapy is not working as efficiently as required. As a result, the patient's condition might deteriorate to the point that re-hospitalization is necessary. For geriatric patients with congestive heart failure, the frequency of hospital readmission after 3 months was reported to be 30% [6]. If re-hospitalization can be reduced by one third to 20%, the economic benefit to society would be very great indeed.

This report is dedicated to the proposition that re-hospitalization rates might be reduced by increased monitoring of patients between office visits. If certain physiologic variables are monitored at shorter intervals than 2 to 4 months, downward trends could be identified faster and perhaps major complications requiring re-hospitalization could be prevented.

For patients who do not require major professional care at home, from a practical standpoint, obtaining clinical data by having a nurse visit each patient at home cannot be considered efficient or cost-effective. Even for a nurse to manually call patients on a daily or even weekly basis cannot be considered efficient use of expensive labor resources. Thus, an efficient method of in-home monitoring is needed that can handle a large volume of patients and provide meaningful clinical data, from which patient progress can be assessed.

Based on this analysis, we created a computerized, automated in-home monitoring system, and have begun to evaluate its performance in an initial group of patients with CHF. This report provides insight to the details of the system, and presents preliminary pilot study results obtained using the system.

SYSTEM DESIGN AND DEVELOPMENT

Design Specifications

The developed monitoring system needed to satisfy the following requirements:

- the method of monitoring should be efficient,
- relevant clinical data should be obtained,
- the system must have the flexibility to monitor several patient groups simultaneously,
- patients who use the system should feel that it is easy to respond to,
- nurses should be able to operate and learn the system easily,
- the system must be relatively inexpensive,
- clinical information should be distributed to patient's physician in an efficient manner.

Based on these specifications, the following framework for an in-home monitoring system was developed.

The system would consist of a computerized, central station from which all communication would originate (Figure 1). The central station could be located in a home health care agency, a hospital, an HMO, or a large group practice. Telephone calls would be made to patients at their homes from the central station. The calling would be automated and with minimal human involvement. A series of prerecorded questions specific to a patient's condition or disease would be asked, and the patient would respond to the questions using a number key-pad on a touch-tone telephone. There would be no special equipment in the patient's home except for rudimentary diagnostic aids such as scale, thermometer, and perhaps a blood pressure reader. Data obtained at the central station would be tabulated and graphical patient reports showing patient responses would be generated. The reports could then be printed or electronically delivered directly from the central station on a regular basis. The system would be operated by a nurse who would be required to enter general patients information into the monitoring system database, review patient reports that were generated, and if required, converse with patients.

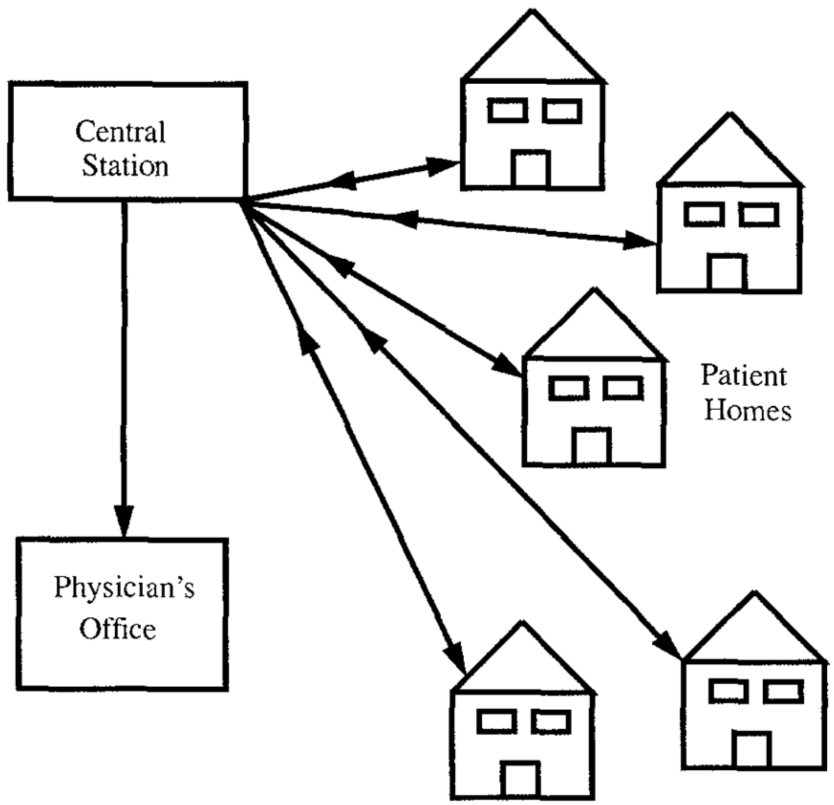

Figure 1. Sketch showing communication pathways of the monitoring system. Communication originates from the computerized central station, from which telephonic monitoring calls are placed to patients at their homes. Responses are tabulated at the central station and reports are sent to the patient's physician.

Hardware

The computer platform used to develop the system was NeXT computer (NeXT Computers, Inc., Redwood City, CA). The NeXT was chosen for several reasons. First, the computer has a built-in Motorola 56001 25MHz digital signal processor (DSP), a 8-bit, 8012.8 Hz analog-to-digital converter input from a microphone miniphone jack, and 16-bit, 44.1 kHz digital-to-analog convert output from a stereo headphone jack, or integrated speaker. This hardware made the system ideal for voice reproduction and recording over telephone lines. In addition, the computer uses a Motorola 68040 25 MHz processor which is able to process 15 million instructions per second (MIPS) and 2 million floating point operations per second (MFLOPS). This computing power allowed software to be running virtually real-time, which was needed so that patients would not perceive any communication delays when questions were asked and responses given.

A specialized telecommunications modem was developed for this system. This modem was used to dial patient phone numbers, check on the progress of the phone call and convert touch-tone responses given by the patient to numbers. The modem was connected to the NeXT in three places: serial port, microphone miniphone jack, and the headphone jack. Communication between the modem and the NeXT was through the serial port. Sound from the NeXT was played through the headphone output, and sound from the telephone line was fed into the NeXT from the microphone input. Additional hardware required was a fax modem (FaxMaster 98/24X, HSD Microcomputer U.S. Inc., Mountain View, CA) connected to the other serial port of the NeXT and a laser printer to generate the patient reports.

Software

The NeXT uses the MACH operating system which is UNIX compatible. The user interface of the NeXT is designed so that the mouse is the primary tool for user interaction. Applications or programs run on the NeXT have consistent interfaces. Thus, menus will be located in the same position for all applications, and certain commands and menu structures are the same for all applications. This transference or consistency has been shown to decrease the training time needed to learn how to use a software program [4]. In addition, the NeXT contains a library of software functions to play and record sound, and access and use the DSP. Other software included on the NeXT allows users to send and receive fax transmissions using a fax modem. All graphical user interfaces (i.e. menu, window, and other graphic displays) for the monitoring system were developed using an application called Interface Builder. This application allowed interfaces to be produced graphically thereby reducing development time significantly. All software was written in Objective-C, an object-oriented language which is an extension of C.

Three software applications were written that transformed the computer into an automated, in-home monitoring system: a patient-calling application, a patient information application, and sound-recording application. The system could handle monitoring three different disease diagnosis groups at one time and communication to patients can be either in English or Spanish. The frequency of calling can be either every 4 hr, daily, or weekly.

Figure 2 shows the flow diagram of a call using the patient-calling application. The application begins by first queuing patients to be called based on the time of calling and frequency of calling. The patient's number is automatically dialed based on the pre-selected calling time. After the modem dials the number, the modem checks the progress of the call. If the phone line is busy or there is no answer, the patient will be requeued to be called 10 min later. The detection of a person answering is done by doing a spectral analysis of the input sound from the microphone input. If someone answers, a prerecorded question is played that asks to speak with the patient. If the patient is not home or no response is given, the calling of the patient will be requeued for a later time.

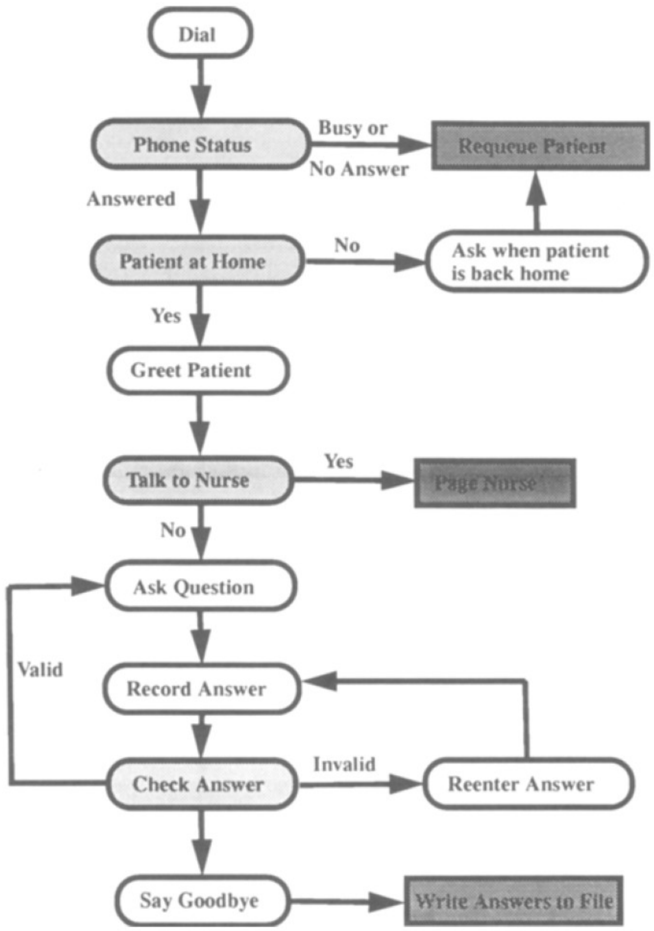

Figure 2. Flow diagram of an automated patient call using the calling application. Call begins by modem dialing patient's number. Patient call is requeued if phone line is busy, phone was not answered, or patient was not home. The nurse overseeing the system will become involved in a call only if patient requests to speak to a nurse. Answers of asked questions are checked to see if a valid answer is given. If the answer was not valid, the patient is asked to reenter the response. If three invalid answers are given for a question, the answer to the question is recorded as "no answer given."

If the patient is home, the recorded message asks to speak with the patient and when the patient acknowledges he is there (by pressing a number on the telephone keypad), a recorded message is played to greet the patient. The application has a "break out" feature that allows the patient to converse directly with the nurse in cases of confusion or in emergencies. If the patient wants to talk to the nurse, the application then pages the duty nurse to pick up the telephone. This is the only point in time when the nurse need be involved in the calling process. If the patient does not page the nurse, pre-recorded, patient individualized and diagnosis specific questions are asked of the patient. The patient answers the questions by pressing numbers on the touch-tone keypad on the telephone. Currently, a maximum of 10 subjective questions and patient body weight can be asked. The subjective questions are questions that can be answered with a response of "yes" ("press 1") or "no" ("press 0"). If responses are incorrect (i.e. a wrong number pressed), the application detects this and request the patient to reenter his response. All responses are recorded and saved to a file. The patient name and phone number is then removed from the calling queue.

The patient information application was designed for nurses to enter and view patient information. From this application, patients may be added to the monitoring database. Specific information about calling, such as phone number, calling time, calling frequency, and preferred language are entered here. Figures 3 and 4 show examples of the application screens for the patient information application. Text information is entered by positioning the mouse cursor within a text field, clicking on the mouse, and then typing in the required information. Other selections, such as calling day, can be made by pointing the mouse cursor next to the desired item and clicking. In addition patient reports could be viewed from this application. If the nurse desires to make some note about the patient, a window can be used to enter that information. The reports can be faxed or print using the print command in the application's menu. A final application was also written to record questions and commands. Figure 5 shows this interface, within which sound is shown graphically and can be edited to remove any unwanted sounds.

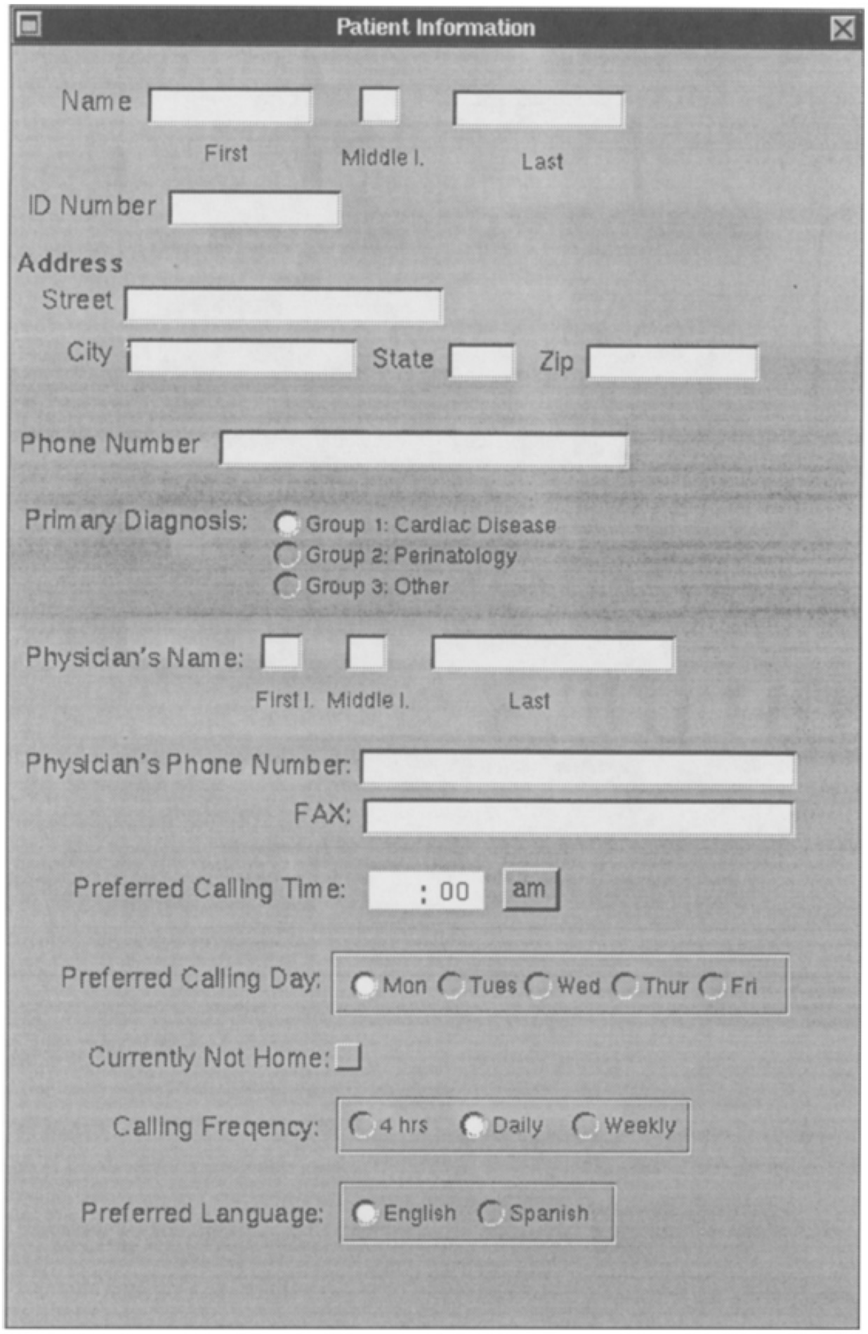

Figure 3. Patient information window for the patient information application. General information is entered in upper fields, and specific information needed for patient calling is entered in the lower fields. Fields can be accessed using a mouse.

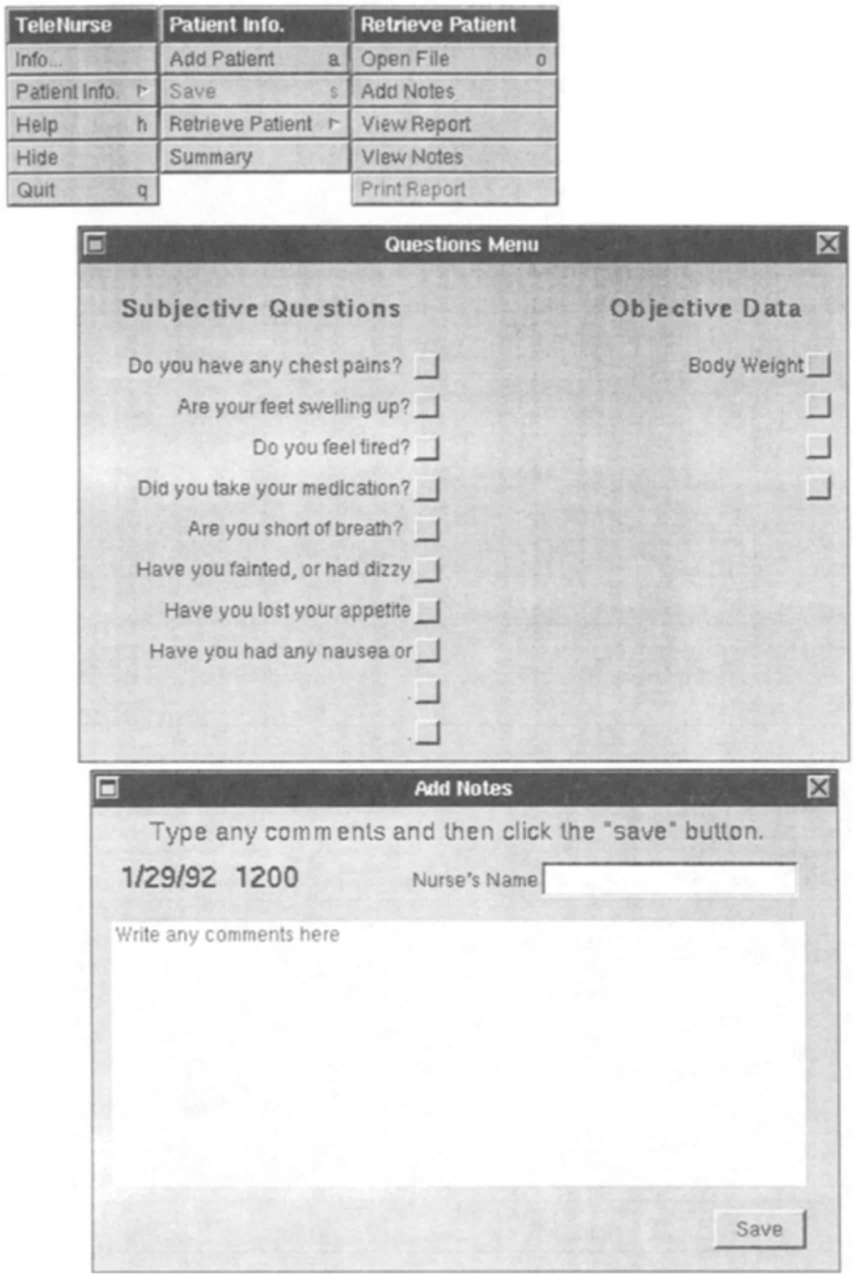

Figure 4. Menu display and other window displays for the patient information application. Using the Questions Menu window, questions to be asked of the patient can be selected. The Add Notes window allows the nurse to enter any notes or comments she might have about the patient record.

PILOT STUDY

A pilot study was conducted with the help of patients with clinical diagnosis of congestive heart failure to make a preliminary evaluation of the system. The study protocol was approved by Purdue University's Use of Human Subjects in Research Committee. The cardiologist participating in the pilot study referred three patients (2 male, 1 female) to participate in the pilot study. All patients had cardiomyopathy and coronary artery disease. One patient had prior episodes of ventricular tachycardia, and another had frank congestive heart failure. Their ages ranged from 50 to 61 years.

Upon entry into the pilot study, the patients were interviewed at home. They were told how the system worked, and what we thought were the advantages of in-home monitoring. In addition, a demonstration call from the system was given to the patients while the clinical investigator was present. None of the patients had any difficulty responding to the system during the demonstration call. Questions to be asked were determined by the patient's referring cardiologist. Calling was done on a weekly basis. Information gathered from the patient included body weight, determined by an in-home scale placed next to the telephone, and an interim history of any chest discomfort, edema, fatigue, skipped medication, nausea, appetite loss, shortness of breath, or dizzy spells.

The central station was located at Purdue University and was under control of the clinical investigator. The "break out" feature was not implemented for this pilot study. Monitoring lasted between 8 and 10 weeks. Reports were faxed to the cardiologist's office on a weekly basis where they were reviewed and the patient's condition assessed. One of the goals to the pilot study was to evaluate how "patient friendly" the system was. An anonymous questionnaire was given to the patients, in which they were asked how they felt about the system. Results from the questionnaire, showed that two of three patients felt that their cardiologist was more aware of the status of their condition. All patients said they answered the questions honestly. All patients thought the system was easy-to-use, and had no major problems using the system. One technical problem that was encountered at the beginning of the study was that the patient's voice was not detected when the patient first answered the phone. This problem was remedied by increasing the sensitivity of the "hello" detection algorithm. After this adjustment no other technical problems occurred.

During the period of monitoring, none of patients had visited the cardiologist's office. One patient, however, was hospitalized for a weekend due to dizziness. The patient's last monitoring call prior to hospitalization reported positive responses to questions on fatigue, skipped medication, shortness of breath, appetite loss and nausea. Two weeks prior to hospitalization, the patient report showed no positive responses to any questions asked. For patient number 1, a 5-1b increase in patient body weight was detected. (Figure 6 shows the report.) Based on this feedback, the patient's medication was adjusted. After the adjustment of medication, the patient's weight did not increase.

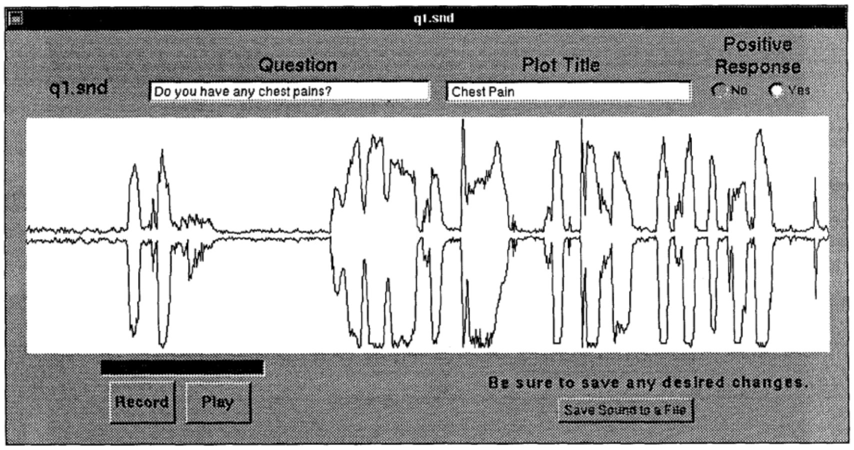

Figure 5. Sound editing window from the sound recording application. Using this application questions and comments can be recorded and saved for use in the patient calling application.

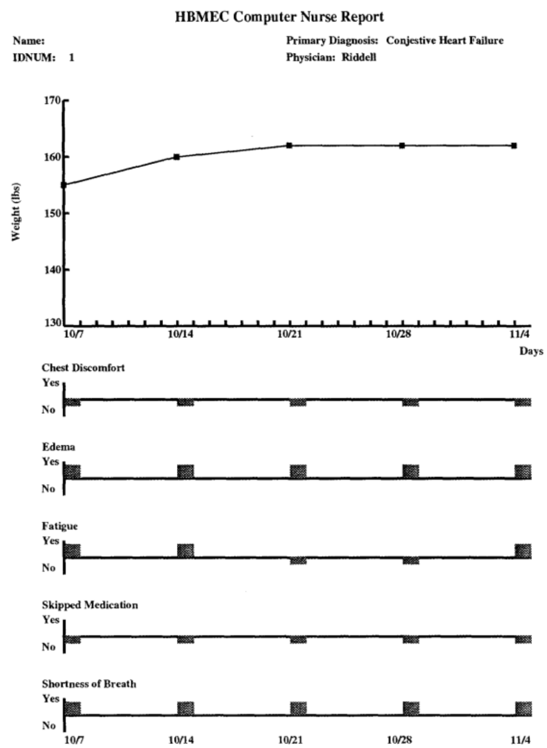

Figure 6. Patient report for patient number 1 having congestive heart failure. Top plot shows an initial 5 pound increase in body weight over a two week period. After medication was adjusted, patient weight did not increase. Bottom five bar graphs show answers to subjective questions asked of the patient.

DISCUSSION

The developed system has the cost-effectiveness, efficiency, and flexibility required for widespread, automated, telephonic in-home monitoring--not only for patients with congestive heart failure but also for patients with a wide variety of chronic diseases such as pulmonary emphysema, asthma, diabetes mellitus, ulcerative colitis, psychiatric disorders, and other conditions in which clinical status and the need to adjust therapy can vary widely on a week-to-week time scale. Results from the pilot study show that the patients were able to communicate readily with the system and that relevant clinical data were obtained. In one case, the patient's condition was managed more effectively, based upon the clinical data obtained via in-home monitoring. In the other case where the patient was hospitalized, the pilot findings suggest the sensitivity of the system for detecting the onset of complications.

The major limiting factor with the current system is that the number of patients which can be called is hardware limited. The number of patients that can be called is dependent on the number of questions asked. If a call lasts 10 min, the number of patients that can be called in a 12-hr day is 72. If calling is on a weekly basis, then 504 patients could be monitored at one time. If calls last only 5 min, then the number of patients that could be monitored increases to 1008. The pilot study thus demonstrated the feasibility and potential benefits of using an automated, telephonic, in-home monitoring system.

Patient groups that would benefit from in-home monitoring include any patients requiring some type of long-term, drug therapy. Such monitoring has the potential to provide early feedback of impending complications, which can be treated more effectively upon early detection--perhaps without expensive hospitalization, and at substantially reduced health care costs.

ACKNOWLEDGMENT

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REFERENCES

1. Capone, R.J., Stablein, D., Visco, J., Wagner, G., Gorkin, L., and Follick, M.J., The effects of a transtelephonic surveillance and prehospital emergency intervention system on the 1-year course following acute myocardial infarction. *Am. Heart J.* 116(6):1606-1615, 1988.

2. Chadda, K.D., Harrington, B.A., Kushnik, H., and Bodenheimer, M.M., The impact of transtelephonic documentation of arrhythmia on morbidity and mortality rate in sudden death survivors. *Am. Heart J.* 112:1159-1165, 1986.

3. Fleg, J.L., Hinton, P.C., Lakatta, E.G., Marcus, F.I., Smith, T.W., Strauss, H.C., Hlatky, M.A., Physician utilization of laboratory procedures to monitor outpatients with congestive heart failure. *Arch. Intern. Med.* 149:393-396, 1989.

4. Karat, C.M., Cost-justifying human factors support on development projects. *Hum. Fact. Soc. Bull.* 35:1111, 1-4, 11/1992.

5. Katz, M., Gill, P.J., and Newman, R.B., Detection of preterm labor by ambulatory monitoring of uterine activity: a preliminary report. *Obstet. Gynecol.* 68(6):773-778, 1986.

6. Rich, M.W., and Freedland, K.E., Effect of DRG's on three-month readmission rate of geriatric patients with congestive heart failure. *Am. J. Publ. Health* 78(6):680-682, 1988.