The Smart Medical Refrigerator

Paul Kuwik, Thomas Largi, Matt York,
Dennis Crump, David Livingston and James C. Squire

During the past century, the life expectancy in the United States has increased by more than 50% due to advances in medicine. There is a direct relationship between the increase in life expectancy and the percentage increase of the elderly population. According to the Office for the Aging, “The most rapid growth nationally between 2000-2015 is expected to occur among the oldest and frailest. The 85+ cohort will grow 28.2%, from 4.3 million to 19.4 million.”

This rise in the elderly population introduces new medical and sociological challenges to society. Dr. Blakowski, director of the Palliative Care Unit at the VA in Pittsburgh, states, “It isn’t uncommon at all to have patients with 10 to 15 different drug prescriptions and some with up to 40 different drug prescriptions.” These large numbers are hard to track for any patient, however it can be further complicated by senile dementia and Alzheimer’s syndrome that is expected to rise 27% by 2020. There is also concern that a temporary incapacitation caused by a fall, stroke, Transient Ischemic Attack (a temporary blockage of an artery within the brain) or illness may turn fatal if left untreated.

Social changes and geographical mobility are also contributing to the higher and higher numbers of elderly living alone without nearby family. Rising numbers of elderly people living alone combined with increasingly complex medical dosing has increased the need for home healthcare providers.

However, supply and demand are not working with each other like economic theory would lead us to believe. Montana Congressman Denny Rehberg reports that as the demand increases “for in-home healthcare providers and community health center nurses…Nursing degree graduation rates have plummeted…most recently falling over 7% while demand for the life saving care they provide is projected to grow 21% in the next few years.”

Home healthcare services are frequently unaffordable or unavailable. Families with elderly relatives, who cannot afford such a person, must make time to assure the safety of their relative by themselves. Unfortunately, families cannot usually afford the time or expense of frequent calls each day. And, in the case of a fall or a stroke, a few hours may mean the difference between life and death. As a result, these folks are at-risk of fatal complications from minor accidents because of lack of monitoring. Elderly diabetics are particularly at risk from a host of diabetes-related health complications.

The fact that elderly patients often must take medications around the clock suggests that a method to monitor their continued usage would be beneficial. One way would be to use a “smart” medicinal dispenser. This monitor would alert a healthcare provider, or family member, if the patient does not access his or her medicine in a timely fashion.

Commonly prescribed medicines such as *benazepril* (to reduce blood pressure), *metoprolol* (to prevent cardiac attack), *gluophage* (for Type II diabetes) and *insulin* (for Type I diabetes) are all excellent candidates for such a device. Each one must be taken multiple times every day. Thus, the medicine dispenser can warn family members within hours of patient incapacitation. Unlike radio-linked health monitors (“I’ve fallen down and I can’t get up!”), monitoring patient access to medicines is passive; it does not require patients to wear radio transmitters, or be conscious to activate them.

We have developed such a monitoring device that stores insulin. This is a commonly prescribed medication. The Centers for Disease Control and Prevention estimate that 18.2 million US adults have diabetes. Insulin must be refrigerated. What’s more, elderly diabetics have elevated risk factors for a number of incapacitating diseases that makes them particularly vulnerable if living alone.

Front and back photo of the Smart Medical Refrigerator prototype

Smart medical refrigerator concept

The Smart Medical Refrigerator (Fig. 1) monitors the use of insulin by diabetic patients and can alert a physician or family members if the patient does not access the medicine in a set time frame. It is reliable, costs a fraction of the expense of home nursing care (the prototype was fabricated for less than $250), alerts the family or physician quickly in an emergency, and provides emotional security to the elderly patient living alone.

The Smart Insulin Refrigerator is connected to a standard telephone line. A microcontroller monitors the refrigerator door’s position. If the door is not opened within a programmable time period, a modem within the refrigerator dials an internet service provider (ISP), establishes a simple mail transfer protocol (SMTP) connection to the mail server, and sends an email alert to any number of designated contacts such as the doctor, a family member, and neighbor. The message may be sent directly to an email account, or may be formatted to send a text message to a cell phone, or a beeper alert through a

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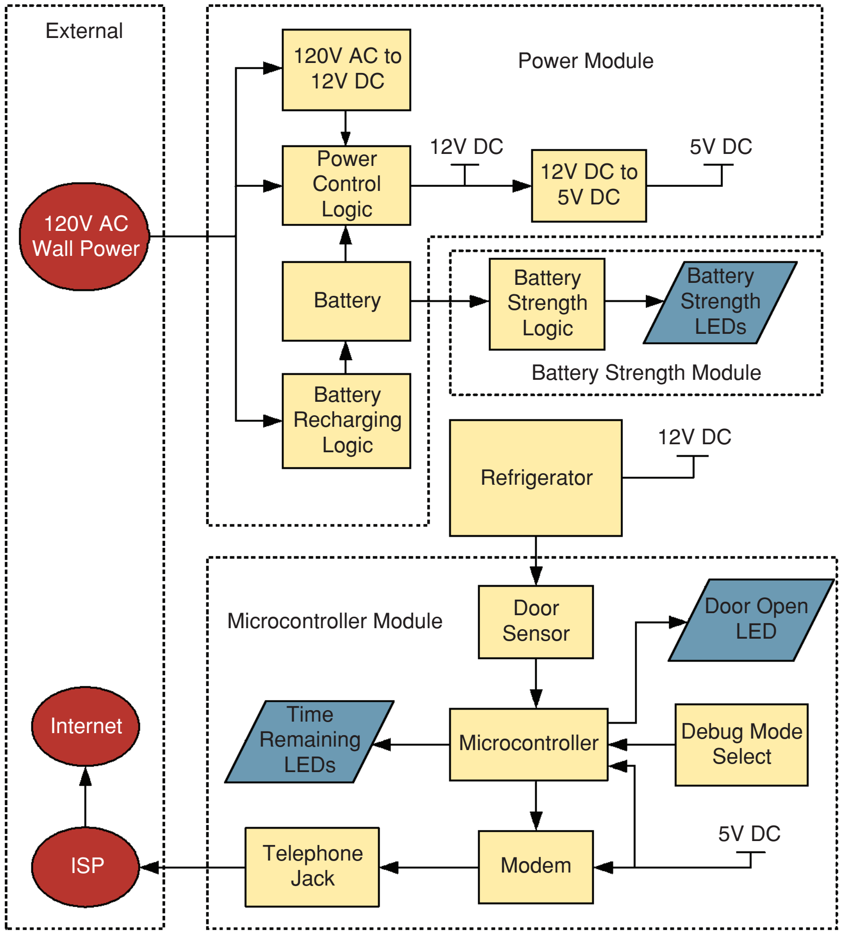

Fig. 1 The Smart Medical Refrigerator is composed of four major systems: the refrigerator, the power module, the battery strength module, and the microcontroller module.

paging service.

This refrigerator incorporates several design features including:

- *Battery backup*: It provides power to both the refrigerator and microcontroller during blackouts; it also ensures alert messages are sent even if a power glitch occurs during data transmission.
- *Automatic recharge*: While the refrigerator is connected to the house current, the battery will be automatically recharged if necessary, or trickle-charged, to maintain peak energy.
- *Battery level indicator*: Light-emitting diodes (LEDs) display the time remaining until the battery goes dead when battery backup is in operation.
- *Simple status indicators*: Color-coded LEDs on the refrigerator control unit indicate if the patient has recently taken insulin (green) (open the refrigerator door), is due for a dose (yellow), is overdue (red), or if an alert has been sent (flashing red).
- *Debug mode switch*: A small Hall-effect transducer (a common type of magnetic field sensor) can be activated externally by placing a magnet in a particular orientation on the control box which puts the unit into debug mode. This mode speeds the clock by a factor of 1,000. This enables testing without opening the enclosure. The hidden nature of the switch makes it unlikely that the patient will accidentally activate it. This feature simplifies on-site testing and demonstration.
- *Convenience*: The smart medical refrigerator is easily movable since it weighs only 25 pounds. Its dimensions are 12x11x11 inches. Also, the refrigerator only requires a standard RJ-11 telephone for internet access, not a network drop.

Design

The refrigerator has four major systems: the refrigerator, the power module, the battery strength module and the microcontroller module. The prototype refrigeration unit itself was modified from a commercially available portable, solid-state 12V picnic refrigerator by replacing its power supply with the battery-backup unit and by wiring in a door sensor.

Power management system. 120V AC from a standard wall socket powers the management system and is connected directly to the 120V AC to 12 VDC converter, 16A regulated power supply, the battery charger and a relay that forms the battery-backup logic (Fig. 2). To eliminate the inconvenience of having to remove batteries to charge them, a charger was added that automatically switches between fast and trickle-charging modes. A relay automatically routes power from the wall socket or the battery backup. The battery has sufficient energy to power the system for 1.5 hours.

Battery strength module. Battery strength is monitored using four comparators (Fig. 3). The regulated 5V source powering the microcontroller is dropped using adjustable resistor

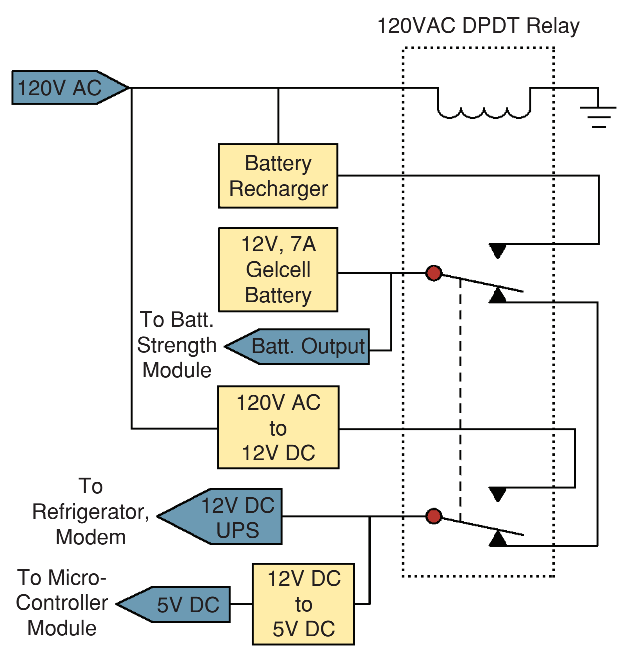

Fig. 2 The power module ensures an uninterruptible 12VDC is available to power the refrigerator and electronics. The module switches between AC and battery power as needed, and automatically keeps the batteries fully-charged.

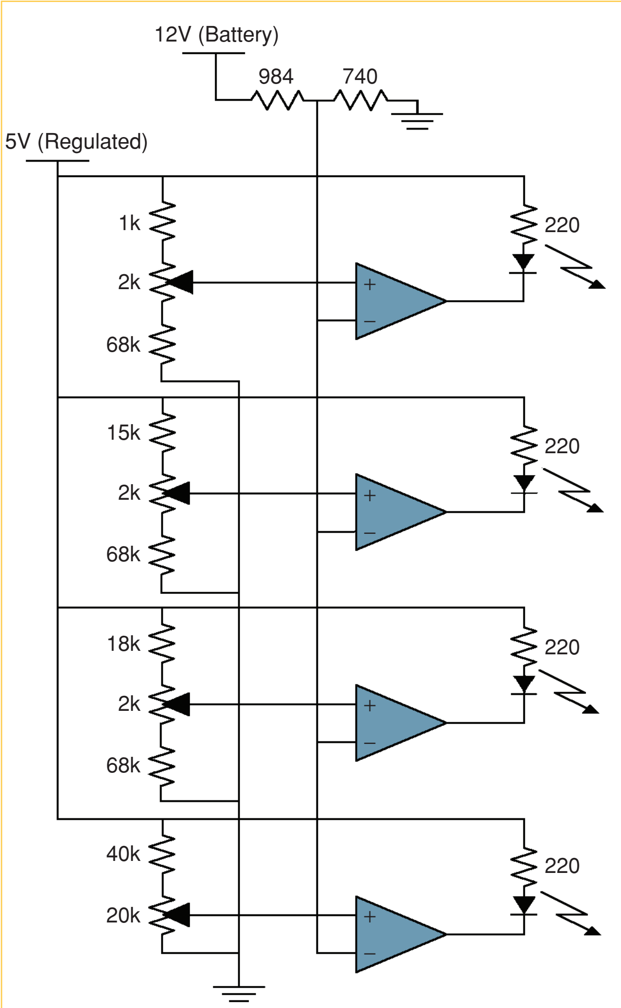

Fig. 3 The battery strength module displays whether the battery can power the refrigerator and electronics for 90, 45, 30, or 15 additional minutes.

dividers to measure four specific battery voltages. These voltage trip points are not selected at evenly-divided voltage increments, but rather correspond to 90, 45, 30 and 15 minutes of remaining battery power determined experimentally (Fig. 4). The patient can graphically read the time remaining by viewing LEDs on the top of the control box.

Microcontroller module. The microcontroller (Fig. 5) monitors the patient's usage of the refrigerator. The processor (PIC16F628) has an internal timer that monitors the time since the refrigerator was last opened. If the cascaded counters reach a preset time (for testing it was set to 16 hours), the processor communicates to the modem to format and send an email to the designated contact(s). Each time the refrigerator door opens, an interrupt is generated that resets the counters. The processor controls the LEDs displaying the time-to-next-insulin-injection with color coded LEDs, door-open status, and whether or not an alarm message was sent with a blinking LED. Although programmed for insulin timing, it can be reprogrammed using an externally accessible serial adapter for any medicine's dosing schedule and to send alerts to any email address or pager number in any number of different formats.

Field testing

After reviewing a prototype refrigerator, our coordinating doctor located a diabetic patient to field test and provide critical feedback on our prototype. After testing the Smart Medical Refrigerator for a week, the patient noted two problems with the prototype:

1) Several times the patient partially opened the refrigerator that the Hall-Effect sensor failed to detect. In the second design phase, the sensor was repositioned for greater sensitivity.

2) Our patient had difficulty interpreting the LED time indicators. In accordance with her recommendations, we changed the direction of the increasing time from the last insulin injection from left to right and changed the LED type to high-output white units.

Overall the patient found the device useful and asked to keep the unit after the trial ended, noting that she found the feedback that the refrigerator's timing lights provided especially helpful. The advising doctor, whose undergraduate degree is in electrical engineering, suggested we add a date and time code to the information transmitted. He noted that the unit could be fooled if the patient did not shut the door, so the microcontroller code was modified to begin timing from the door open event, rather than the door close.

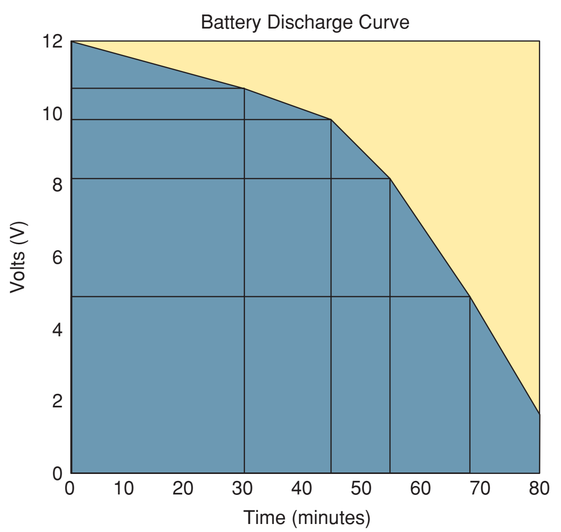

Fig. 4 Experimentally-measured battery voltage discharge curve, showing the location of comparator trip points at voltages corresponding to 90, 45, 30, and 15 minutes remaining.

Conclusions

As both the percentage and absolute numbers of elderly living alone climb to record levels, novel approaches to geriatric healthcare must be taken. The Smart Medical Refrigerator is one such approach. Perhaps it's greatest significance is that although there are a number of active-sensor units on the market that require patient interaction to send out an alarm (for instance the pop-icon "I've fallen and I can't get up" device by Home Alert), the concept of using a passive sensors to automatically sense patient incapacitation can be easily generalized. At-risk patients who do not take medication could be monitored using the same device attached to a standard household refrigerator, a pressure sensor on a carpet, a motion sensor in the kitchen, or even a tilt sensor on a toilet seat. In this way the unit could help address the broader societal need of remote, automatic well being monitoring.

Acknowledgments

The authors wish to express their appreciation to Wetmore Research Grant from the Virginia Military Institute and our advising physician Joseph M. Troise, M.D. We also wish to thank Mrs. Joyce Reid for her helpful comments during patient testing.

Read more about it

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About the authors

Paul Kuwik is in his fourth year at the Virginia Military Institute and has interests in bioengineering, sensor design, and foreign travel. He is an active member of the IEEE and is currently the student section secretary, and is a member of ΠΗΣ. He plans to enter flight school upon graduation and become an F16 pilot in the US Air Force after graduation.

Thomas Largi is in his fourth year at the Virginia Military Institute. He is a member of the IEEE and has served as an officer for the student branch. He plans to enter the U.S. Air Force as a developmental engineer in their advanced weapons program.

Matthew York is a 2004 graduate of the Virginia Military Institute and is currently employed as an Engineering Leadership Development Program Associate at Lockheed-Martin in Northern Virginia. His interests include hands-on engineering in industry. Matt served as the chair of the IEEE student section in his senior year at the Institute. He is also a member of TBΠ and OΔK.

Dennis Crump is in his third year at the Virginia Military Institute and has interests in radio frequency communications. He is a member of the IEEE and is also a member of the TBΠ and ΠΗΣ honor societies. Upon graduation he plans to enter the U.S. Navy under the Nuclear Propulsion Officer Candidate Program and become a naval officer on a nuclear-powered submarine.

Dave Livingston and Jim Squire are professors in the Department of Electrical and Computer Engineering at the Virginia Military Institute. More information on them can be found at <www.vmi.edu/ece>.

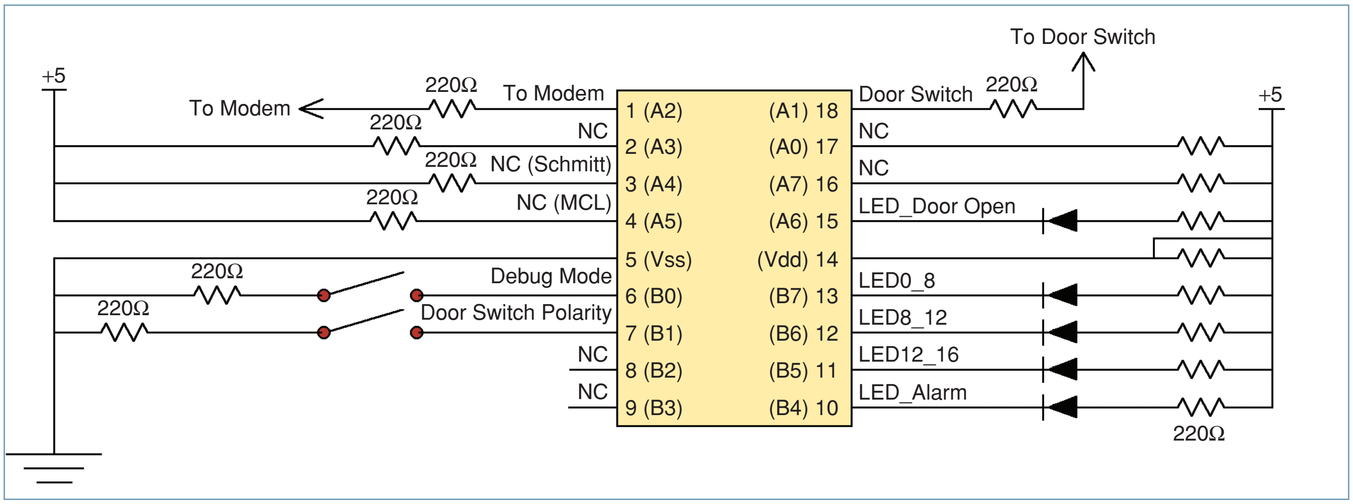

Fig. 5 The microcontroller module is built around a PIC16F628, and controls the LED status indicators and modem.

Working on the project

A team of four undergraduate electrical engineering students advised by a biomedical engineer, a computer engineer, and a physician designed the medical Internet-aware insulin refrigerator for an independent study project. The idea for the device came from one of the team members who had a concern about his elderly mother’s health. The project ran over two semesters.

During the first semester, the students formulated design criteria and decomposed the problem into four subsystems: mechanical design, power supply, analog interfacing and microcontroller interfacing. Each student was responsible for a subsystem. After review, a prototype was constructed, debug and field-tests were conducted, and modifications were made.

During the second semester, the students devoted their efforts to enhancing the prototype, documenting intellectual property, and publicizing the device. They submitted a patent application, received a patent pending and are currently marketing the licensing rights for the device. *—PK, TL, MY, DC, DL & JCS*