Internet-Aware Smart Medical Refrigerator

Paul Kuwik, Thomas Largi, Matt York and Dennis Crump
Department of Electrical and Computer Engineering
Virginia Military Institute
Lexington, VA 24450 USA

Faculty Advisors: James C. Squire, P.E., Ph.D.
David Livingston, P.E., Ph.D.

Abstract

Social mobility and an aging population have resulted in a higher number of elderly living alone without nearby family than ever before, and they 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, yet home healthcare services are frequently unaffordable or unavailable.

A team of four undergraduate electrical engineering students advised by a biomedical engineer, a computer engineer, and a physician designed a medical internet-aware insulin refrigerator for such a patient living alone. The device consists of a small refrigerator monitored by an embedded microcontroller and connected to a standard telephone outlet. The microcontroller monitors patient access to the smart medical refrigerator. If the door is not opened in a 16-hour period, the microcontroller dials an internet service provider and sends an email and/or a pager alert to a physician or family member anywhere in the world. The system also has an integrated battery-backup that automatically takes over if AC power fails, automatically charges when AC power is available, fully charges in under 60 minutes, and can sustain an hour and a half power outage. The refrigerator has been through two design evaluations with a physician and has been tested during a week-long trial by a diabetic patient.

1. Introduction

During the past century the life expectancy in the United States has increased by more than 50% because of advances in medicine. In 1900, the U.S. life expectancy was 47.3 years and in 2001 the secretary of the US Department of Human Health and Service, Tommy G. Thompson, reported it had increased to a record high 77.2 years [5]. There is a direct relationship between the increase of the life expectancy and the increase in the elderly population. According to the New York State 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." [4]. The 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, stated "it isn't uncommon at all to have patients with 10-15 different drug prescriptions and some up to 40 different drug prescriptions" [1], which can be confusing to geriatric patients. Dosing can be further complicated by senile dementia and Alzheimer's syndrome, which is expected to rise 27% by 2020 [4]. The increasing number of elderly people living alone combined with increasingly complex medical dosing has increased the need for home healthcare providers. Montana Congressman Denny Rehberg reported that as the demand increases "for in-home healthcare providers and community health center nurses… Nursing degree graduation rates have plummeted during the past three years, most recently falling over 7% while demand for the life saving care they provide is projected to grow 21% in the next few years" [3]. Those healthcare providers are needed to assure patient compliance with prescription dosing and monitor their patients against temporary incapacitation caused by a fall, stroke, TIA, or serious illness that may be fatal if untreated. Families with elderly relatives who can not afford such a person to check up on their elderly loved ones 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 stroke a few hours may make the difference between life and death.

The fact that elderly patients must frequently take medications suggests a method to monitor their continued well-being is to use a "smart" medicinal dispenser that can alert a healthcare provider or family member if the patient does not access their 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, because they require being taken multiple times each day and thus the medicine dispenser can warn family members within hours of patient incapacitation.

We chose to develop a smart refrigerator for insulin. This is commonly-prescribed medication, the Centers for Disease Control and Prevention estimated that 18.2 million American adults have diabetes [2], which must be stored in a refrigerator, and elderly diabetics have elevated risk factors for a number of incapacitating diseases, making them particularly vulnerable if living alone.

2. Smart Medical Refrigerator Concept

We developed a smart medical refrigerator (Figure 1) that monitors the usage of insulin by diabetic patients and can alert a physician or family members if the patient does not access the medicine in a programmable time period. It is reliable, costs a fraction of the expense of home nursing care, can alert the family or physician quickly in case of emergency, and provides emotional security to the elderly patient living alone.

The refrigerator, connected to a standard telephone line, contains a microcontroller to monitor the door position. If the door is not opened in a programmable time period, a modem within the smart medical 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 alert a family member or doctor. The email may

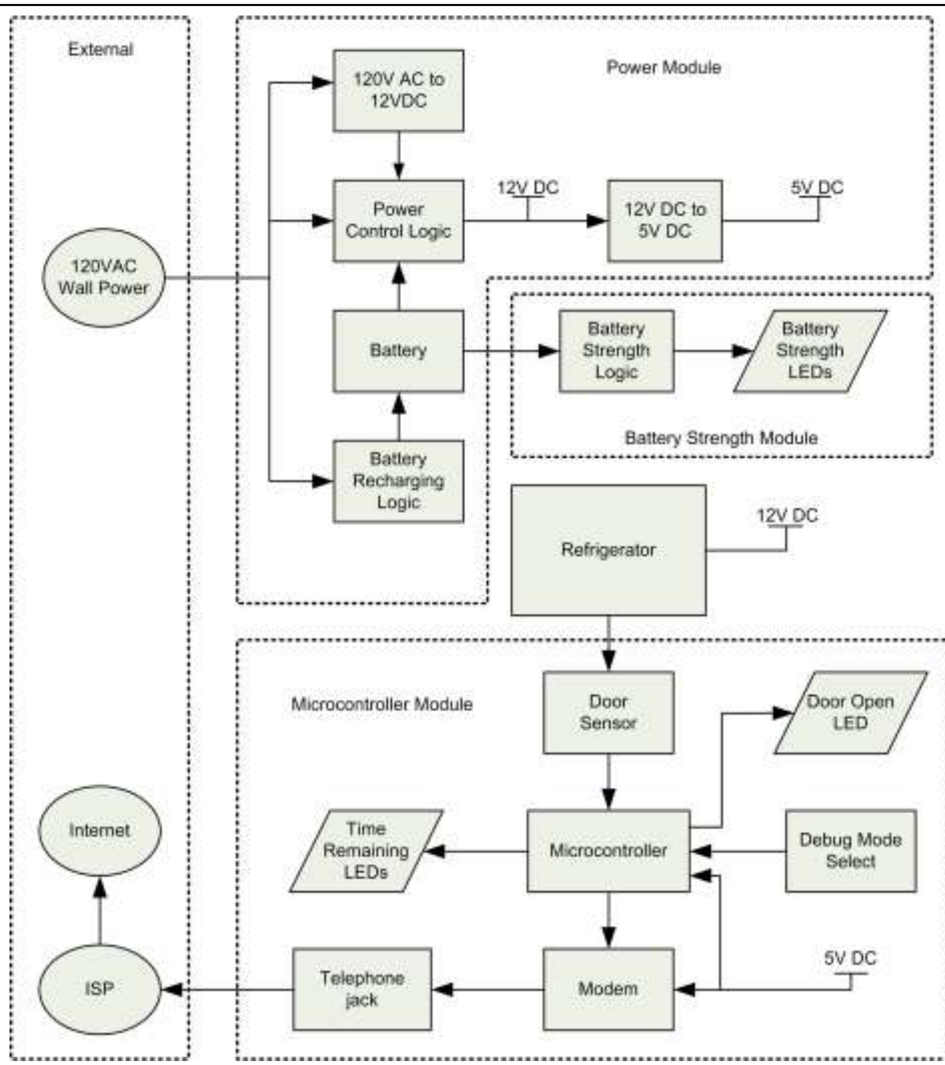

Figure 1- The Smart Medical Refrigerator is composed of four major systems: the refrigerator, the power module, the battery strength module, and the microcontroller module.

be sent directly to a person, or may be formatted to send a text message to a cell phone, or a beeper alert through a paging service.

The Smart Insulin Refrigerator incorporates several design features, including:

- Battery backup: provides power to both the refrigerator and microcontroller during blackouts; 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: Four green LEDs display the time remaining until the battery is depleted during battery backup operation. Four lit LEDs represent an hour and half, three 45 minutes, two 30 minutes and one for 15 minutes of operation remaining.
- Simple status indicators: Bright color-coded indicators (LEDs) on the smart medical refrigerator control unit indicate if the patient has recently taken his/her insulin (green), is due for a dose (yellow), is overdue (red), or if an alert has been sent (flashing red).
- Debug mode switch: A Hall-effect sensor, which can be activated externally by placing a strong magnet in a particular orientation on the control box, can be used to put the unit in debug mode. This speeds the clock by a factor of 1,000 enabling testing without opening the enclosure. The hidden nature of the switch makes it unlikely that the patient will accidentally activate it, yet the ease of activation simplifies on-site testing and demonstration.
- Convenience: The smart medical refrigerator is easily movable, weighing only 25 pounds and the dimensions are 12x11x11 inches. It does not require a network jack for internet access, but only a standard RJ-11 telephone jack.

3. Design of Smart Medical Refrigerator

The refrigerator is composed of four major systems: the refrigerator, the power module, the battery strength module, and the microcontroller module.

3.1 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 (Figure 2). To eliminate the inconvenience of removing batteries to charge them a charger was added that automatically switches between fast and trickle-charging modes.

The relay, a double throw and double pole, is designed to deliver uninterruptible 12V DC to power the refrigerator and electronics regardless of AC power blackouts. When wall power is present the relay routes AC power to the 120V AC to 12V DC converter, whose output is then connected the refrigerator, modem, and a 12V DC to 5V DC converter that powers the electronics. If a blackout occurs eliminating the 120V AC wall power, the relay redirects 12V DC from the battery to power the system. The battery has sufficient energy to power the system for 1.5 hours.

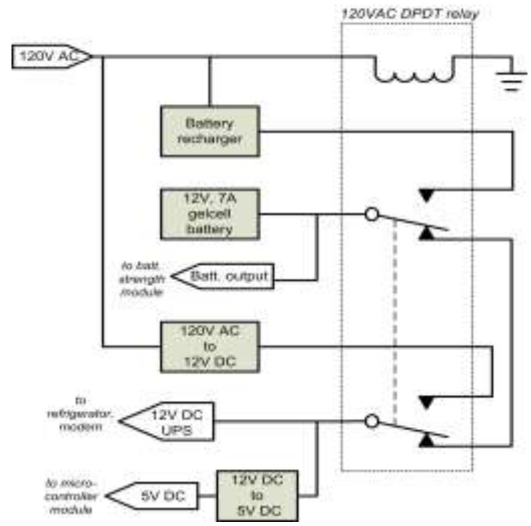

Figure 2- The power module ensures an uninterruptible 12VDC is available to power the refrigerator and electronics. The module switches between AC and battery power as needed, and automatically keeps the batteries fully-charged.

3.2 battery strength module

Battery strength is monitored using four comparators (Figure 3). The regulated 5V source powering the microcontroller is dropped using adjustable resistor 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 time remaining in the battery (Figure 4). The patient can read the time remaining by viewing four LEDs on the top of the metal electronics box.

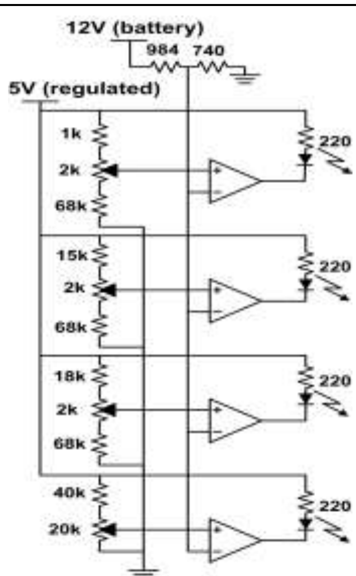

Figure 3: The battery strength module displays whether the battery can power the refrigerator and electronics for 90, 45, 30, or 15 additional minutes.

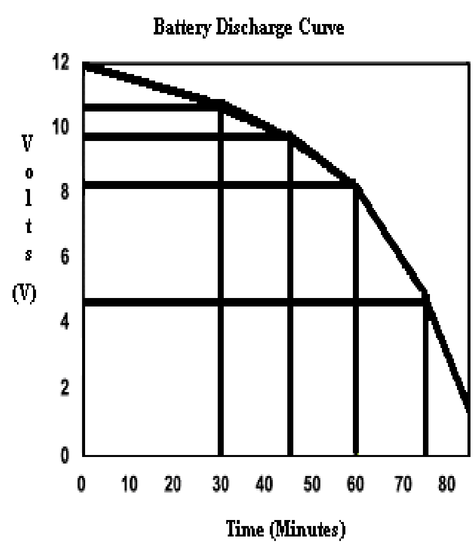

Figure 4: Experimentally-measured battery voltage discharge curve, showing the location of comparator trip points at voltages corresponding to 90, 45, 30, and 15 minutes remaining.

3.3 microcontroller module

The microcontroller portion (Figure 5) monitors the patient's usage of the refrigerator. The processor (PIC16F628) has an internal clock that monitors the time since the refrigerator was last opened. If the cascaded counters reach 16 hours the processor communicates through the modem to format and send an email to the doctor. Each time the refrigerator door opens an interrupt is generated that resets the counters. The processor controls LEDs displaying time-to-next-insulin-injection and door-open status. 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.

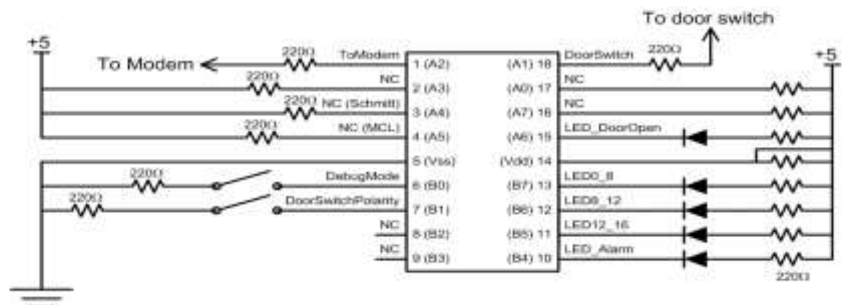

Figure 5- The microcontroller module is built around a PIC16F628, and controls the LED status indicators and modem.

3.4 patient review

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:

- There were several times that the patient would partially open the refrigerator, which the Hall-Effect sensor failed to detect. In the second design phase, a standard toggle switch will replace the Hall-Effect sensor.
- Our patient had difficulty interpreting the LED status indicators. She recommended that we change the direction of increasing time since last insulin injection from left to right.

4. Conclusion

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 employs an electronically-monitored dosing compliance to provide a mechanism to ensure not just dosing compliance but also patient safety, and so provide peace of mind to both patients and healthcare providers in our overworked healthcare system.

A slight modification allowing the unit to work on a standard household food refrigerator allows it to address the broader societal need of remote, automatic medical monitoring. Elderly patients living alone who do not take any medicine can still be expected to need at least daily access to their refrigerator; longer lapses could be sensed and family members or police alerted.

5. Acknowledgments

The authors wish to express their appreciation to Wetmore Research Grant from the Virginia Military Institute, and our advisors, VMI Electrical and Computer Engineering faculty James C. Squire, P.E., Ph.D. and David Livingston, P.E., Ph.D., and our physician Joseph M. Troise, M.D. We also wish to thank Mrs. Joyce Reid for her helpful comments during patient testing.

6. References

[1] Blakowski, Sandra. Personal interview. 28 Jan. 2004.

[2] Department of Health and Human Services. National Diabetes Fact Sheet. Centers for Disease Control and Prevention, 2003.

[3] Rehberg, Danny. “Congress Acts to Address Nursing Crisis.” 12 March 2002.

[4] Steuben Integrated Planning. (2004). Adult Services Planning.

[5] Thompson, Tommy. “Consumers & Food 2003: New Challenges, New Solutions.” National Food Policy Conference. 8 May 2003.