An Automatic Medication Management System for Independently Living Healthcare Patients

by Corey McCall
HIM Thesis Defense
Introduction

- Introduction
- Background
- Approach
- Prototype Hardware
- Prototype Software
- Evaluation
- Conclusion
- Questions
Introduction

• Medication noncompliance is a growing issue

• Retirement age Americans are predicted to overload the current healthcare system within the next 10 years

• In-home care is more efficient, but current assistive technologies are either costly or too complicated for elderly patients to use

Image: Predicted population growth by age group

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Introduction

**Goal:** A system that implements automatic medication management and passive remote monitoring to manage complex medication schedules for outpatients

**Impact:** Prolong independent living, eliminate medication noncompliance, and reduce the burden on the healthcare system

*Image:* The position of the solution in the healthcare system
Background

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Background

EMMA

• Remotely controlled by doctors
• Dispenses individual dosages for patient
• Format restricted to pills
• Medicine must be packed by manufacturer into special hard paper board.

Image: Caregiver loading EMMA²
Background

Intel Proactive Health Lab

- Uses RFID to identify medicine containers
- Schedule information entered with special RFID cards
- Uses scale to check compliance
- Must be setup by caregiver.

Image: Medicine platform and display
Approach

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- Background
  - Approach
- Prototype Hardware
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Approach

Enhance a patient’s traditional medicine storage device

• Provide notifications
• Provide administration assistance
• Monitor compliance
• Alert caregiver

Image: Traditional Lazy Susan Medicine Shelf

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Approach

Requirements

1. Intuitive User Interface
2. Medicine Container Distinction
3. Dosage Intake Monitoring
4. Optimized Dosage Scheduling
5. Unexpected Input Handling
6. Pharmacy Integration
7. Direct Communication with Caregiver
8. Remote Care
Prototype Hardware

- Introduction
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- Approach
  - Prototype Hardware
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- Questions
Prototype Hardware

System Components

- RFID Reader
- Scale
- Microcontroller / Network Interface
- User Interface Panel
- Motorized Rotation Platform

Image: SolidWorks® prototype assembly model
Prototype Hardware

Top View

Section Divider

Image: SolidWorks® model of top of prototype

Image: SolidWorks® model of section divider

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Prototype Hardware

Scale Platform

RFID Reader

Image: SolidWorks® model of scale and scale platform with RFID reader

Image: RFID Reader
Prototype Hardware

Why RFID?

• Close proximity wireless identification
• No battery
• Inexpensive
• Onboard memory
• Easy to attach to medicine containers
• Easy to integrate into pharmacy

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Prototype Hardware

User Interface Panel

- LCD Display
- 3 Pushbuttons
- 3 LEDs

Image: SolidWorks® user interface panel assembly model
Prototype Hardware

Cost

<table>
<thead>
<tr>
<th>Category</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Components</td>
<td>$611.67</td>
</tr>
<tr>
<td>Other Electronics</td>
<td>$105.05</td>
</tr>
<tr>
<td>Materials</td>
<td>$164.30</td>
</tr>
<tr>
<td>Pharmacy Equipment</td>
<td>$130.49</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$1,011.51</strong></td>
</tr>
</tbody>
</table>

*Image:* Prototype cost organized by category
Prototype Hardware

Image: Photo of final prototype assembled
Prototype Hardware

Image: Photo of final prototype disassembled
Prototype Software

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- Prototype Hardware
  - Prototype Software
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- Questions
Prototype Software

Basic Patient Operation

• Adding New Medicine:
  • Patient places medicine on front of platform
  • No other manual input required

• Taking Medicine:
  • Audible alarm activated and text message sent
  • Medicine is automatically rotated to front of platform
  • Display shows dosage instructions

• Handling Noncompliance:
  • Display shows patient that noncompliance was detected
  • Patient’s caregiver is alerted via text message
Prototype Software

Image: Photo of prototype administering the “Naproxen” medicine
Prototype Software

Advanced Operation

• Initialization
  • Patient or caregiver enters basic information with the two buttons
  • Medicine containers can then be placed on the device one at a time

• Taking Medicine Early:
  • “Ready” light indicates medicines can be taken early
  • Patient manually places medicine on scale platform
  • Press the red button when prompted

• Checking Out Medicine:
  • Identical to taking medicine early if not ready
Prototype Software

Advanced Operation

• Taking Checked Out Medicine:
  • Text message sent with dosage instructions
  • When patient returns, place medicine on scale platform for compliance check

• Removing Medicine
  • Patient manually places medicine on scale platform
  • Press the black button when prompted
Prototype Software

Handling of Unexpected Input

• Abrupt Power Loss
  • An updated backup of the medicine information database is kept in persistent memory
  • At initialization, previous data is loaded and synthesized with medicines currently on the platform

• Medicine Container Tampering
  • “Most recent weight” is kept between all administered dosages
  • Entire platform is checked periodically for discrepancies

• Patient Unresponsiveness
  • All patient-dependent processes periodically alert the patient if unresponsive
  • If input is not critical, the process is dropped (e.g. remove the medicine)
## Static Scheduling Algorithm

<table>
<thead>
<tr>
<th>Frequency</th>
<th>8:00am</th>
<th>8:00pm</th>
<th>2:00pm</th>
<th>2:00am</th>
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</thead>
<tbody>
<tr>
<td>1x daily</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x daily</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3x daily</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4x daily</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**Image:** Optimal schedule based on static time slot assignment
Prototype Software

Patient / Caregiver Notification

• At initialization, user and patient telephone numbers are stored

• To alert, email is sent to ###-###-####@txt.att.net to instantiate SMS message

• Yahoo Mobile SMTP server used for outgoing alerts in prototype

Image: Text message received by caregiver
Prototype Software

Medicine Data Protocol

- **UID**: Unique identifier for the medicine container
- **Medicine Name**: Up to a 20 character name of the medicine
- **Medicine Schedule**: A frequency of 1 – 4 daily dosages
- **Special Instructions**: Special instruction indicators
- **Entry Method**: Dosage entry method
- **Most Recent Dosage Information**: Most recent dosage information to check for tampering.
- **Presence**: Whether or not the medicine has been checked out

* Not stored on RFID Tag
Evaluation

- Introduction
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- Prototype Software
  - Evaluation
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# Evaluation

## Scale Test: Typical Pill Displacement

<table>
<thead>
<tr>
<th>Condition</th>
<th>1 Pill</th>
<th>2 Pills</th>
<th>3 Pills</th>
<th>4 Pills</th>
<th>5 Pills</th>
</tr>
</thead>
<tbody>
<tr>
<td>150mg, 5 pills</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>150mg, 250 pills</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>1500mg, 5 pills</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>1500mg, 50 pills</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

*Image: Results of pill displacement test*
Evaluation

Pill Counting Algorithm

\[ counter := 0 \]

\[ X := \text{Weight Displacement} \]

while \((X \geq \text{Pill Weight} / 2)\) 
  \[ counter := counter + 1 \]
  \[ X := X - \text{Pill Weight} \]

return counter
Evaluation

Theoretical Limit Estimation

• The weight of the smallest unit that can be reliably counted is: $R \times 2 + 1$, where $R$ is the range of imprecision.

• $R$ Tested in controlled (no air conditioning or fan) and typical environment
  - $R_{\text{controlled}} = 11\text{mg}$
  - $R_{\text{typical}} = 68\text{mg}$

• Minimum pill weight of prototype: $68 \times 2 + 1 = 137\text{mg}$
Evaluation

**Image:** Results of imprecision test in a controlled environment

**Image:** Results of imprecision test in a typical environment
Evaluation

RFID Reader Range Test

Image: A visual approximation of the unreadable area on the scale platform
Evaluation

Functionality Gaps

• Pharmacy Software Integration
  • Pharmacy software has not been developed
  • Testing relied on simulated pharmacy information

• RFID Antenna Sensitivity
  • RFID read range should cover entire scale platform

• Section Divider Initialization
  • The section divider’s angular position must be manually set on power up
Conclusion

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Conclusion

Results

• Advances
  • System design
  • Scale hardware interface
  • Section divider mechanism
  • Software data protocols

• Problems
  • RFID sensitivity
Conclusion

Results

• Assumptions
  • User interface is limited to patients who are able
  • Dependence on power, the Internet, and SMS
  • This prototype is not meant for production
  • The system is limited by the number and weight of medicine containers
Conclusion

Future Work

• More abstract user interface
• Individual medicine monitoring
• Cellular-based networking
• Aperiodic dosage schedules
• Remote dosage adjustment
• Network multiple machines together
• Comprehensive system test and clinical trial
Conclusion

Publications and Presentations


Questions

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- Background
- Approach
- Prototype Hardware
- Prototype Software
- Evaluation
- Conclusion
- Questions
Image Sources


## Detailed Budget Table

<table>
<thead>
<tr>
<th>System Components</th>
<th></th>
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<tbody>
<tr>
<td>Digital Scale w/ Computer Interface</td>
<td>$354.95</td>
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<tr>
<td>RFID Reader Circuit</td>
<td>$86.25</td>
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<tr>
<td>Microcontroller Board</td>
<td>$65.00</td>
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<tr>
<td>Network Interface Card</td>
<td>$32.99</td>
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<tr>
<td>x25 RFID Tag</td>
<td>$19.73</td>
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<tr>
<td>Power Adapter</td>
<td>$18.30</td>
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<tr>
<td>LCD Screen</td>
<td>$18.00</td>
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<tr>
<td>Stepper Motor</td>
<td>$14.95</td>
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<tr>
<td>Electronic Buzzer</td>
<td>$1.50</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$611.67</strong></td>
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<table>
<thead>
<tr>
<th>Materials</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Polycarbonate Plastic</td>
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<td>Picture Frame</td>
<td>$9.99</td>
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<tr>
<td>Lazy Suzan Bearing</td>
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<tr>
<td>x4 M3 screw</td>
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<tr>
<td>x12 4-40 Screw w/ Nut</td>
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<tr>
<td>x8 6-32 Screw w/ Nut</td>
<td>$0.68</td>
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<td><strong>TOTAL</strong></td>
<td><strong>$164.30</strong></td>
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# Detailed Budget Table

<table>
<thead>
<tr>
<th>Other Electronics</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Fan</td>
<td>$17.99</td>
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<tr>
<td>Power Supply Circuit</td>
<td>$15.00</td>
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<tr>
<td>Stepper Motor Controller Board</td>
<td>$14.95</td>
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<tr>
<td>Hookup Wire</td>
<td>$6.99</td>
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<tr>
<td>x2 Large Button</td>
<td>$6.78</td>
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<tr>
<td>x2 Prototyping board</td>
<td>$5.98</td>
</tr>
<tr>
<td>x3 Connector Shield</td>
<td>$5.97</td>
</tr>
<tr>
<td>Power Switch</td>
<td>$2.99</td>
</tr>
<tr>
<td>Power Plug</td>
<td>$2.99</td>
</tr>
<tr>
<td>Pin Headers</td>
<td>$2.50</td>
</tr>
<tr>
<td>4-pin Connector Male</td>
<td>$2.39</td>
</tr>
<tr>
<td>4-pin Connector Female</td>
<td>$2.39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connector Types</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-pin Connector Male</td>
<td>$1.99</td>
</tr>
<tr>
<td>15-pin Connector Male</td>
<td>$1.99</td>
</tr>
<tr>
<td>15-pin Connector Female</td>
<td>$1.99</td>
</tr>
<tr>
<td>Solder</td>
<td>$1.95</td>
</tr>
<tr>
<td>Serial Interface Chip</td>
<td>$1.95</td>
</tr>
<tr>
<td>x7 0.1µF Capacitors</td>
<td>$1.75</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>$1.59</td>
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<tr>
<td>Power Connector</td>
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<td>x3 LED</td>
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<tr>
<td>Reset Button</td>
<td>$0.87</td>
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<tr>
<td>x3 10KΩ Resistor</td>
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<tr>
<td>x3 330Ω Resistor</td>
<td>$0.75</td>
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</tbody>
</table>

**TOTAL**                                  **$105.05**
Detailed System Architecture

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Detailed System Architecture