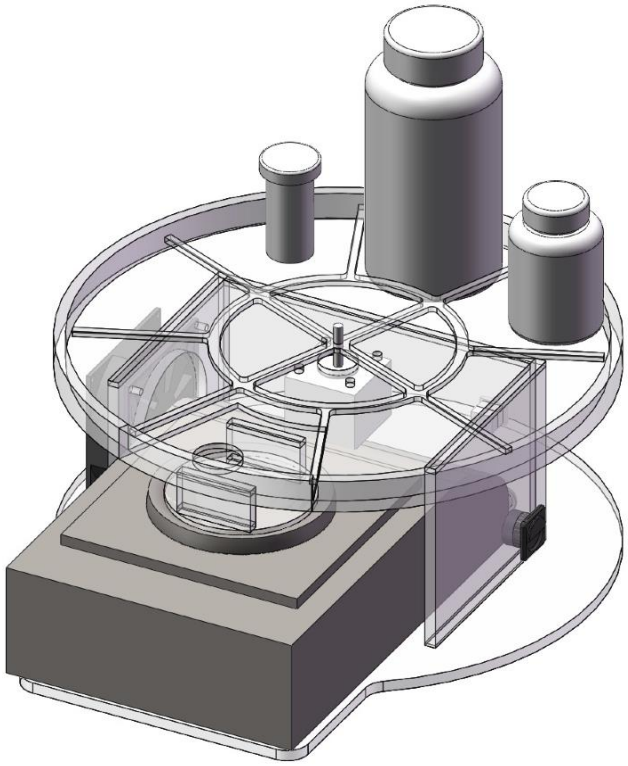

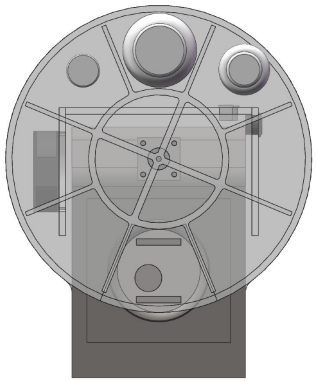

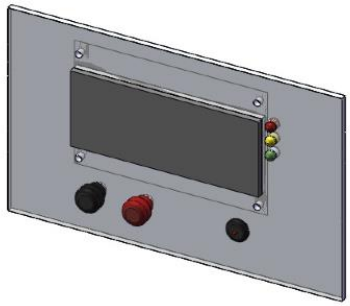

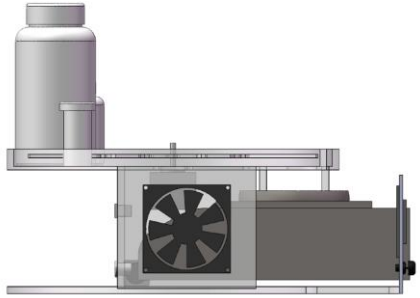

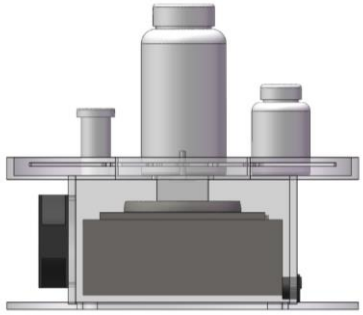

An Automatic Medication Management System for Independently Living Healthcare Patients

by Corey McCall

HIM Thesis Defense

Introduction

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

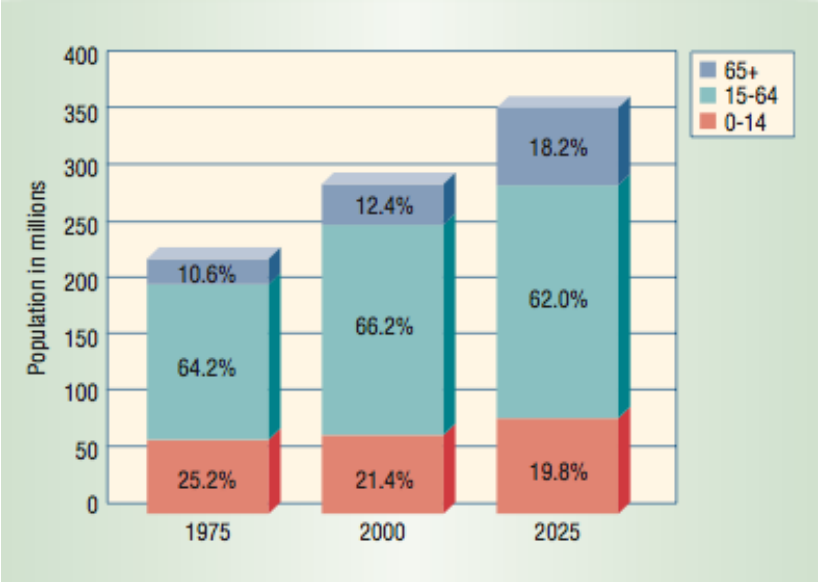

Image: Predicted population growth by age group[1]

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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

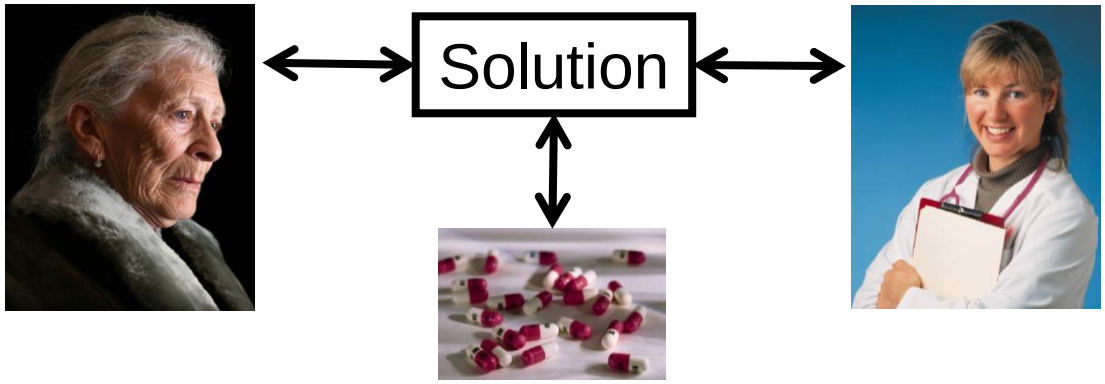

Image: The position of the solution in the healthcare system

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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 EMMA[2]

UCF

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[3]

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Approach

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UCF

Approach

Enhance a patient's traditional medicine storage device

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

Image: Traditional Lazy Susan Medicine Shelf[4]

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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

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Prototype Hardware

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Prototype Hardware

System Components

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

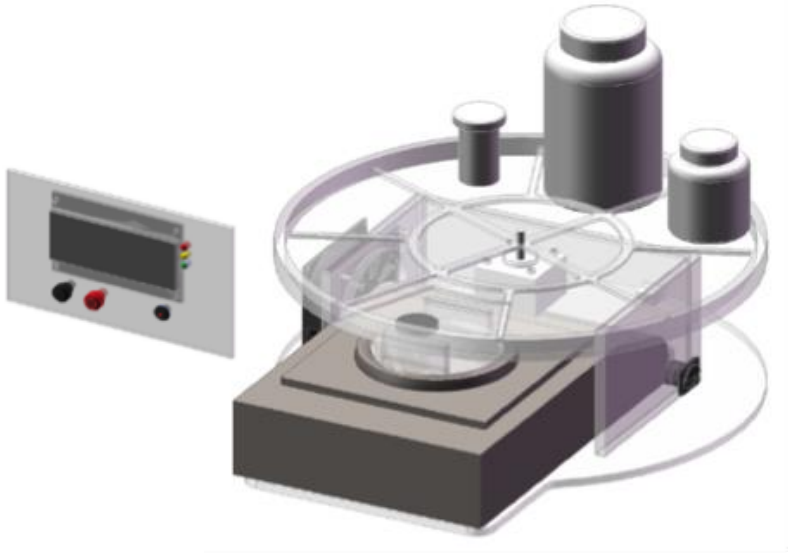

Image: SolidWorks® prototype assembly model

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Prototype Hardware

Top View

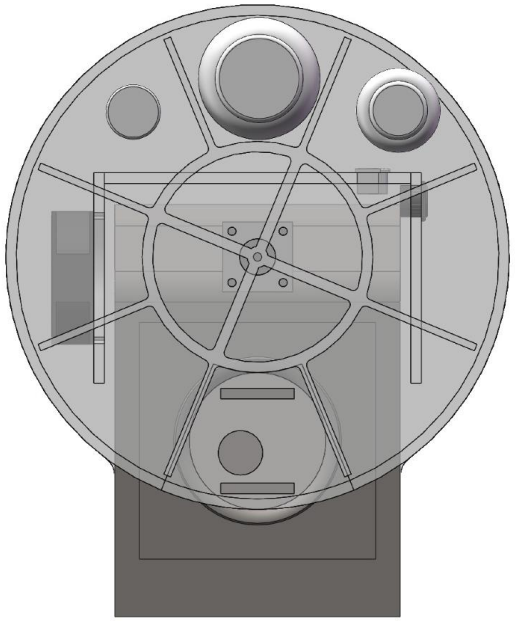

Image: SolidWorks® model of top of prototype

Section Divider

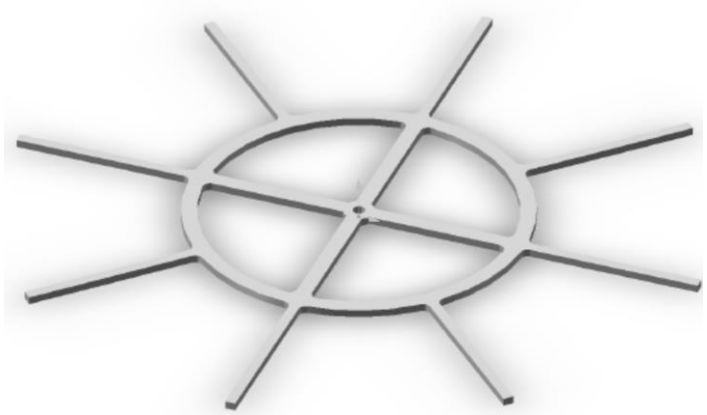

Image: SolidWorks® model of section divider

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Prototype Hardware

Scale Platform

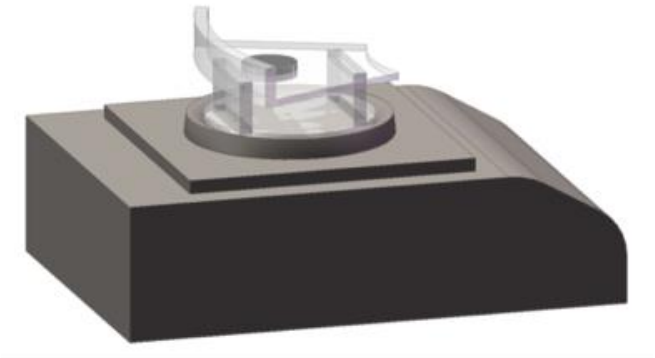

Image: SolidWorks® model of scale and scale platform with RFID reader

RFID Reader

Image: RFID Reader

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Prototype Hardware

Why RFID?

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

Image: Pharmacy RFID writer[5]

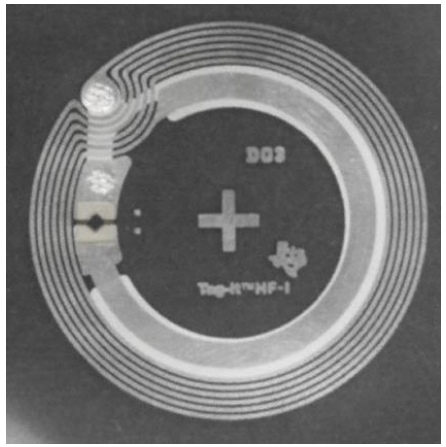

Image: RFID Tag[6]

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Prototype Hardware

User Interface Panel

- LCD Display
- 3 Pushbuttons
- 3 LEDs

Image: SolidWorks® user interface panel assembly model

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Prototype Hardware

Cost

Category	Price
System Components	$611.67
Other Electronics	$105.05
Materials	$164.30
Pharmacy Equipment	$130.49
TOTAL	**$1,011.51**

Image: Prototype cost organized by category

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Prototype Hardware

Image: Photo of final prototype assembled

Prototype Hardware

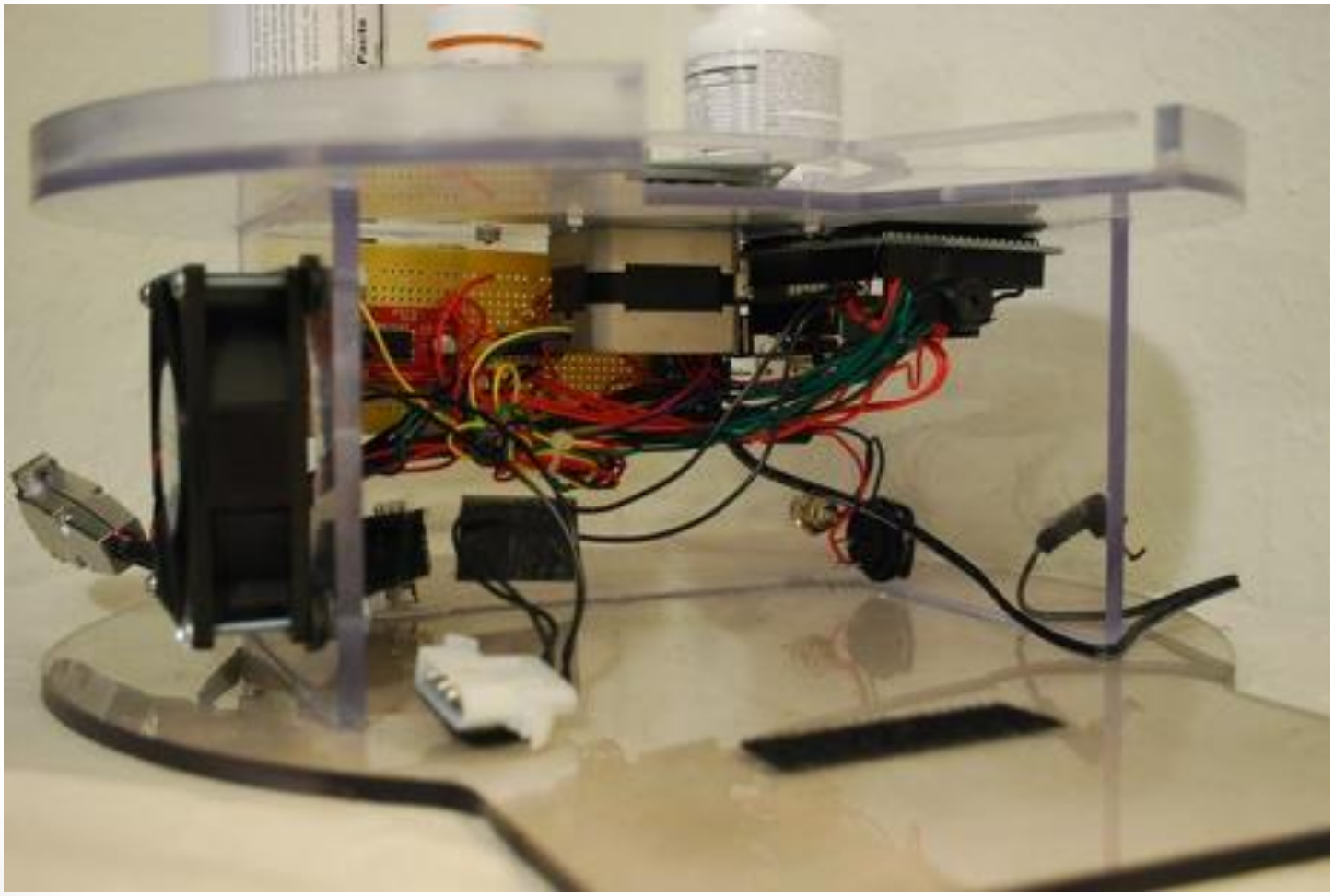

Image: Photo of final prototype disassembled

Prototype Software

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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)

Prototype Software

Static Scheduling Algorithm

Frequency	8:00am	8:00pm	2:00pm	2:00am
1x daily	X			
2x daily	X	X		
3x daily	X	X	X	
4x daily	X	X	X	X

Image: Optimal schedule based on static time slot assignment

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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

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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

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Evaluation

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Evaluation

Scale Test: Typical Pill Displacement

Condition	1 Pill	2 Pills	3 Pills	4 Pills	5 Pills
150mg, 5 pills	Pass	Pass	Pass	Pass	Pass
150mg, 250 pills	Pass	Pass	Pass	Pass	Pass
1500mg, 5 pills	Pass	Pass	Pass	Pass	Pass
1500mg, 50 pills	Pass	Pass	Pass	Pass	Pass

Image: Results of pill displacement test

Evaluation

Pill Counting Algorithm

```
counter := 0

X := Weight Displacement

while (X ≥ Pill Weight / 2)
        counter := counter + 1
        X := X – Pill Weight

return counter
```

Evaluation

Theoretical Limit Estimation

- The weight of the smallest unit that can be reliably counted is: *R**2+1, where *R* is the range of imprecision.
- *R* Tested in controlled (no air conditioning or fan) and typical environment
  - $R_{controlled}$ = 11mg
  - $R_{typical}$ = 68mg
- Minimum pill weight of prototype: 68*2+1 = **137mg**

Evaluation

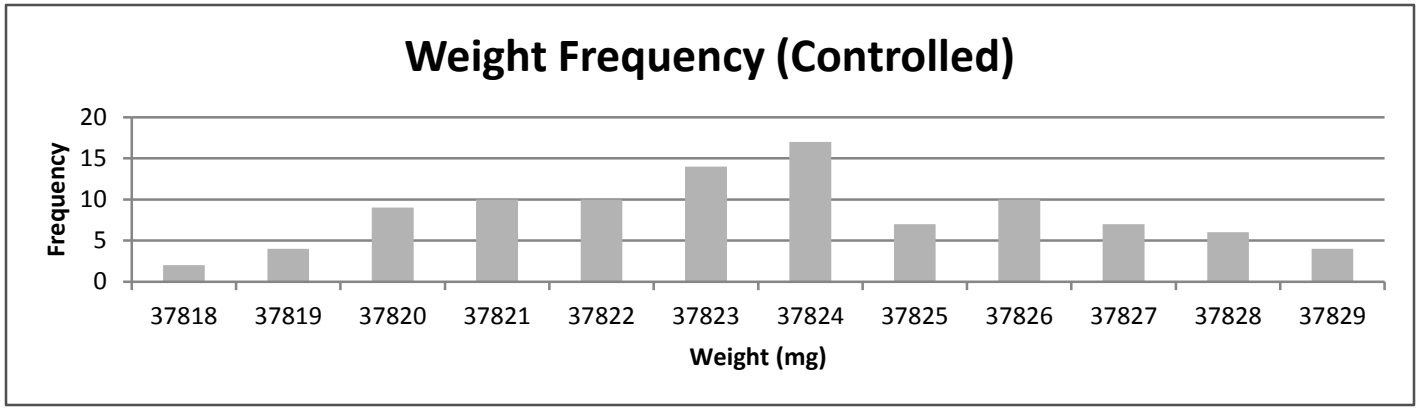

Image: Results of imprecision test in a controlled environment

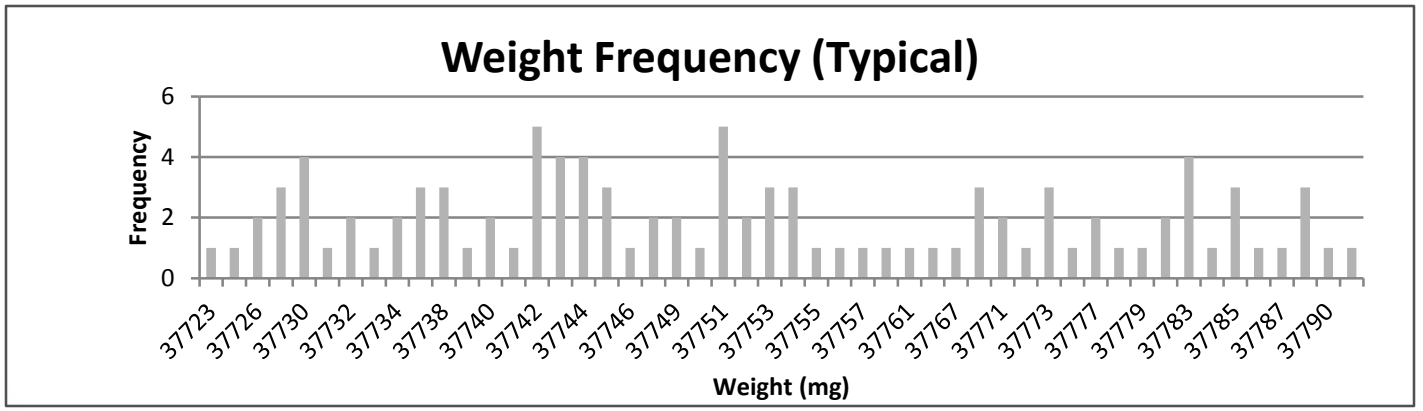

Image: Results of imprecision test in a typical environment

Evaluation

RFID Reader Range Test

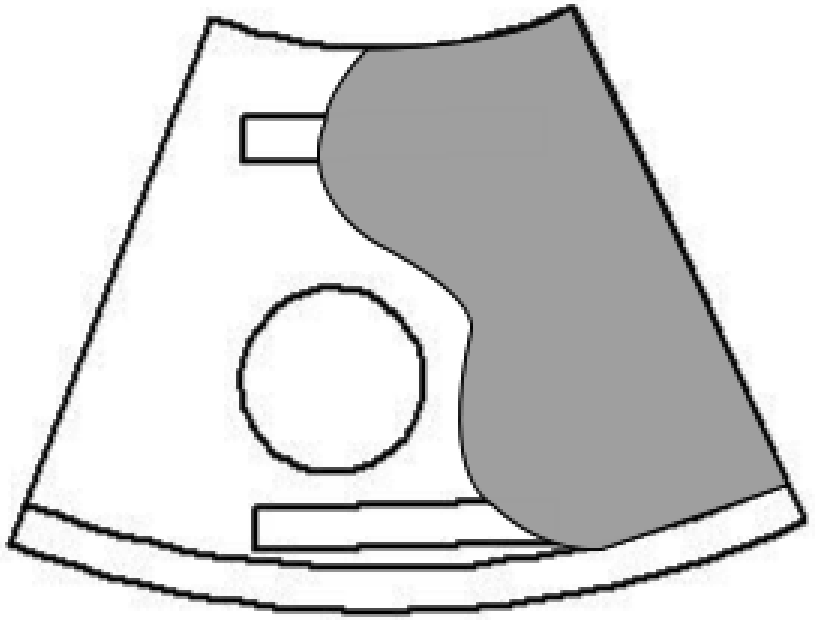

Image: A visual approximation of the unreadable area on the scale platform

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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

- C. McCall, B. Maynes, C.C. Zou, and N.J. Zhang, “RMAIS: RFID-based Medication Adherence Intelligence System,” in *Proceedings of 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 2010, pp. 3768-3771.
- C. McCall, B. Maynes, C.C. Zou, and N.J. Zhang, “A Prototype Device That Implements RFID and Remote Monitoring Technology to Track Medications for Elderly Healthcare Patients,” Poster presented as part of Showcase of Undergraduate Research Excellence, Orlando, FL, 1 April 2010. **Winner: Honorable Mention.**
- C. McCall, B. Maynes, “Personal Medication Monitor,” Project presented as part of Inventing Entrepreneurs, Orlando, FL, 26 March 2010. **Winner: First Place.**

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Questions

- Introduction
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Image Sources

1. Ishman, E. "Inventing Wellness Systems for Aging in Place." *IEEE Computer* 37.5 (2004): 34-41
2. http://www.inrangesystems.com/
3. Fishkin, K. and M. Wang, *A Flexible, Low-Overhead Ubiquitous System for Medication Monitoring*. Rep. no. IRS-TR-03-011. Seattle, WA: Intel Corporation, 2003
4. http://www.digi-key.com/
5. http://www.ftdichip.com/
6. http://www.digi-key.com/

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Detailed Budget Table

System Components	
Digital Scale w/ Computer Interface	$354.95
RFID Reader Circuit	$86.25
Microcontroller Board	$65.00
Network Interface Card	$32.99
x25 RFID Tag	$19.73
Power Adapter	$18.30
LCD Screen	$18.00
Stepper Motor	$14.95
Electronic Buzzer	$1.50
TOTAL	**$611.67**

Materials	
Polycarbonate Plastic	$150.00
Picture Frame	$9.99
Lazy Suzan Bearing	$1.49
x4 M3 screw	$1.12
x12 4-40 Screw w/ Nut	$1.02
x8 6-32 Screw w/ Nut	$0.68
TOTAL	**$164.30**

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Detailed Budget Table

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

9-pin Connector Male	$1.99
15-pin Connector Male	$1.99
15-pin Connector Female	$1.99
Solder	$1.95
Serial Interface Chip	$1.95
x7 0.1µF Capacitors	$1.75
Voltage Regulator	$1.59
Power Connector	$1.50
x3 LED	$1.05
Reset Button	$0.87
x3 10KΩ Resistor	$0.75
x3 330Ω Resistor	$0.75
TOTAL	**$105.05**

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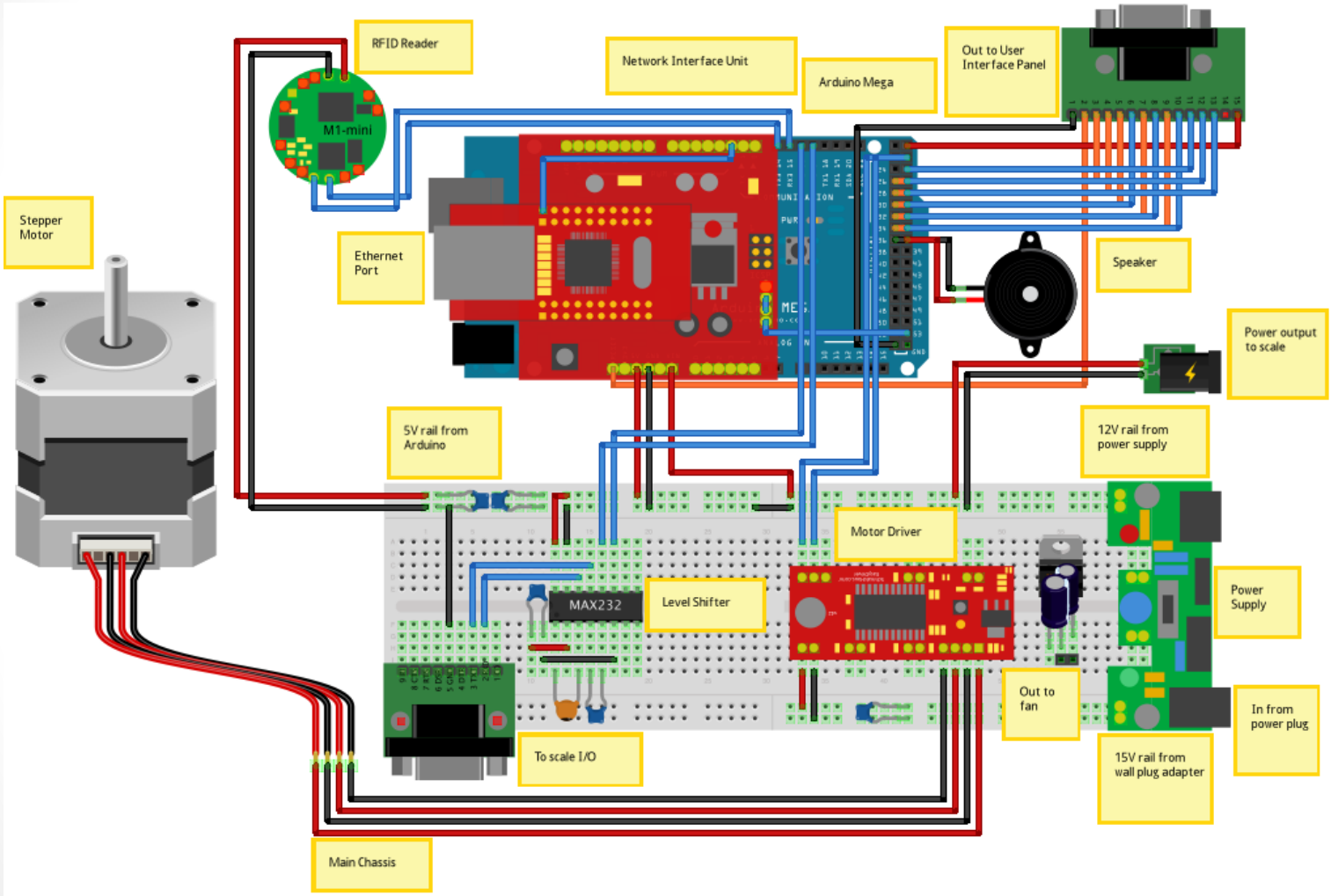
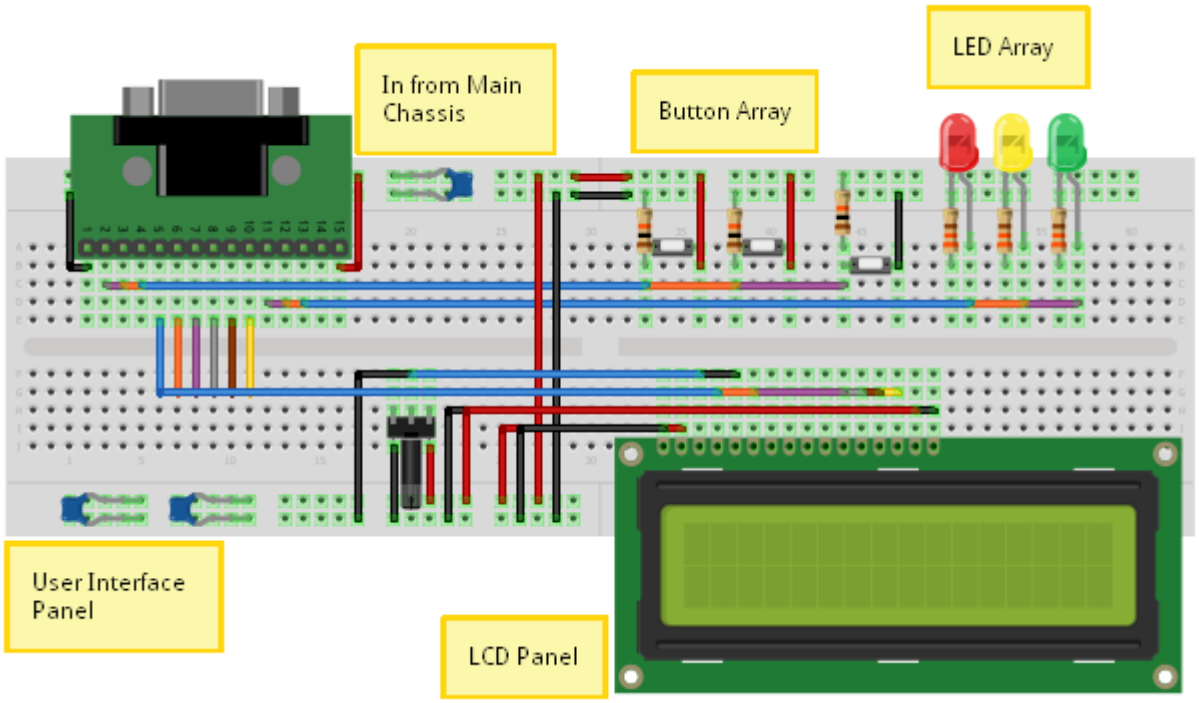
Detailed System Architecture



Detailed System Architecture



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