NORTHERN ARIZONA UNIVERSITY

Mobile Data Collection for Gait Analysis

Team MDC

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Project Mentor: Dr. Omar Badreddin

Project Sponsor

Dr. Kyle Winfree

- Department of Informatics and Computing
- The PD Shoe is designed to make simple reminders for patients with Parkinson's Disease.

PhD, Biomechanics and Movement Science

Data Collection for Gait Analysis

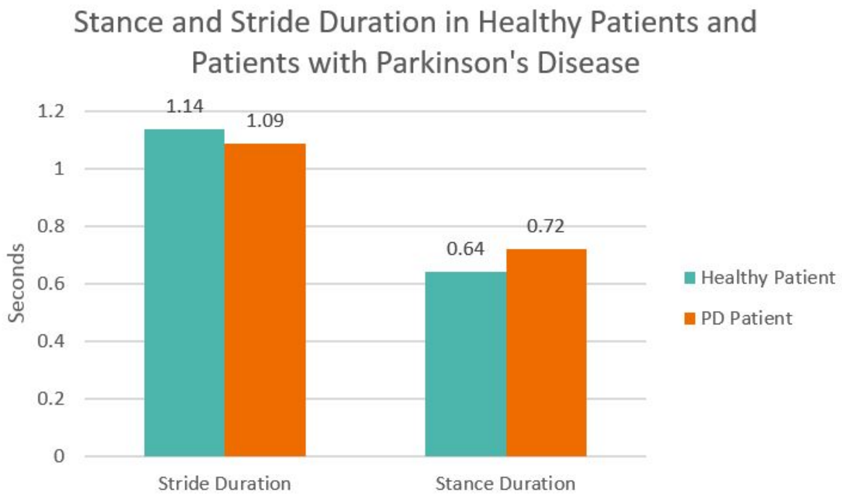
Few commercial tools for collecting data on gait. Data often limited to activity level.

Existing Wearable Devices:

- Fitbit
- Jawbone
- Nike+ Sportband
- LifeGait

Data Collection for Gait Analysis

- Raw data collection outside of clinical setting allows for analysis outputs
  - Stride Duration
  - Foot Strike Pattern
  - Weight Distribution
- 10 million patients worldwide with PD
- Supports diagnosis and testing of treatment effectiveness and other physical therapies



Challenging Requirements

Requirements elicited from regular meetings with sponsor:

- Sufficient Granularity of Data
  - Time Delta Between Readings of less than 10 milliseconds
- Near Real-time Analysis of Data
- Automated Data Centralization
- Access to Data for Statistical Packages such as Matlab and Octave
- Standardized Modules Extensible to Many Wearable Devices

Key Risks

Loss of data
Power interruptions, network congestion, weak control flow system

Poor Data Granularity
Inefficient hardware or software design

Lag in Data Availability
Poor network connectivity

Data Synchronization Errors
Unsynchronized devices and poorly calibrated sensors

Server Cannot Handle Number of Requests
Potentially 1000 rows to insert every 10 seconds

Postgresql limits
Max Table Size - 32 TB

Development Process

Evolutionary Rapid Development

WBS	Tasks	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Milestone 1 (Hardware Level)**	1/16/16	3/17/16	62	100%	44	62	0
1.1	Assemble Hardware	1/16/16	1/21/16	6	100%	4	6	0
1.2	Develop Sensor Reading Capability	1/22/16	2/5/16	15	100%	11	15	0
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1.5	Develop Advanced Command Handling	3/1/16	3/17/16	17	100%	13	17	0
2	**Milestone 2 (Mobile Application Level)**	2/17/16	4/6/16	50	100%	36	50	0
2.1	Design Application Protocol for Bluetooth	2/17/16	2/24/16	8	100%	6	8	0
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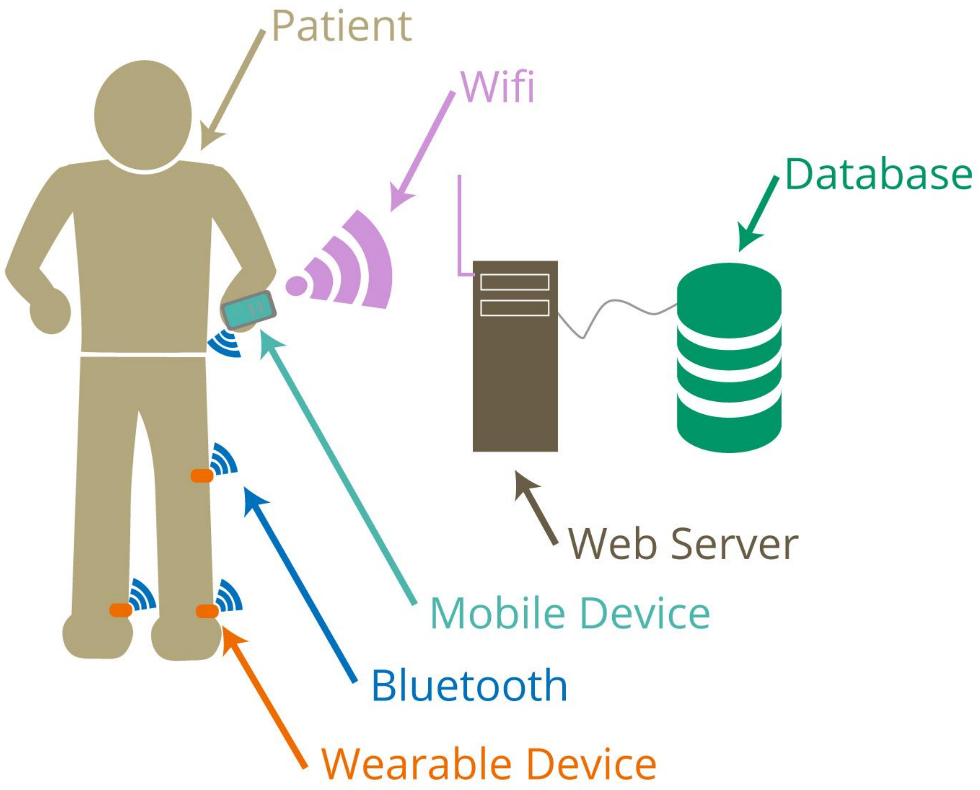
2.7	Develop Final User Interface	3/16/16	4/6/16	22	100%	16	22	0
3	**Milestone 3 (Web Server Level)**	1/30/16	4/6/16	68	100%	48	68	0
3.1	Setup Server Database	1/30/16	2/7/16	8	100%	5	8	0
3.2	Develop Server Database	3/11/16	3/17/16	7	100%	5	7	0
3.3	Develop Server API	3/18/16	4/6/16	20	100%	14	20	0
3.4	Develop HTTP Format	3/18/16	3/31/16	14	100%	10	14	0
4	**Milestone 4 (Testing & Refining)**	4/7/16	5/5/16	28	25%	21	7	21
4.1	Testing & Refining	4/7/16	5/5/16	28	25%	21	7	21

System Overview

Four Components

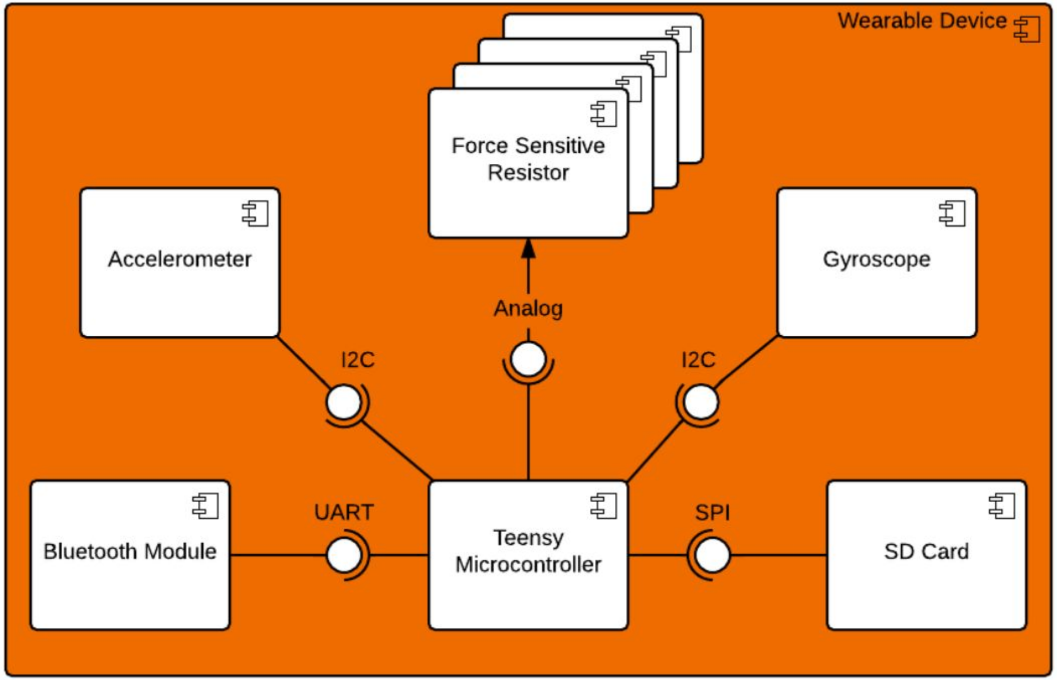
- Wearable Device
- Mobile Device
- Web Server
- Database



Wearable Device

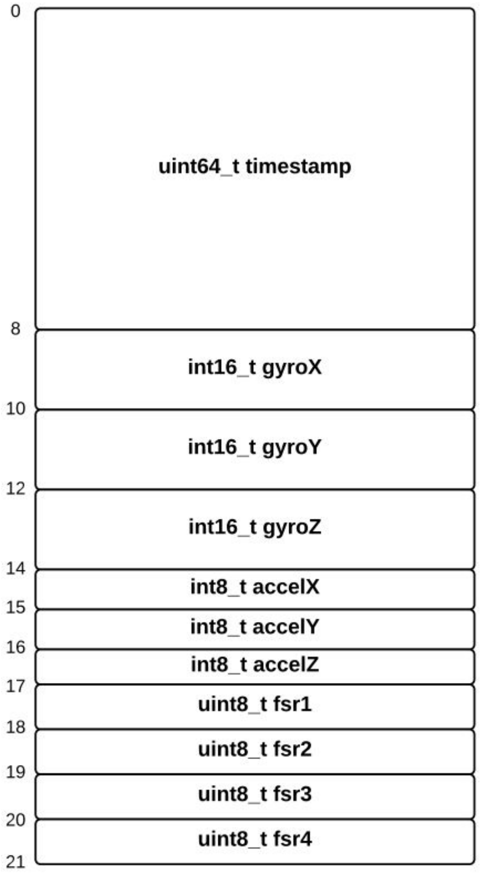
Teensy 3.2 microcontroller was selected over the Arduino and Photon

Modular design with various sensors and components



Wearable Device: Database

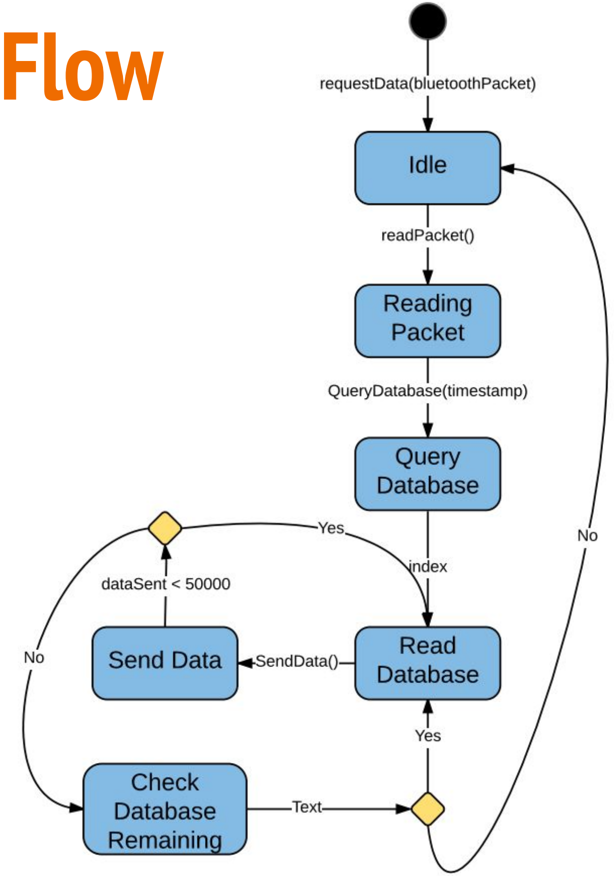
- Rows 'indexed' by timestamp
- Decoupled from specific sensors on device
- Space requirements reduced by 65% compared to CSV format



Wearable Device: Control Flow

Multiple Tasks

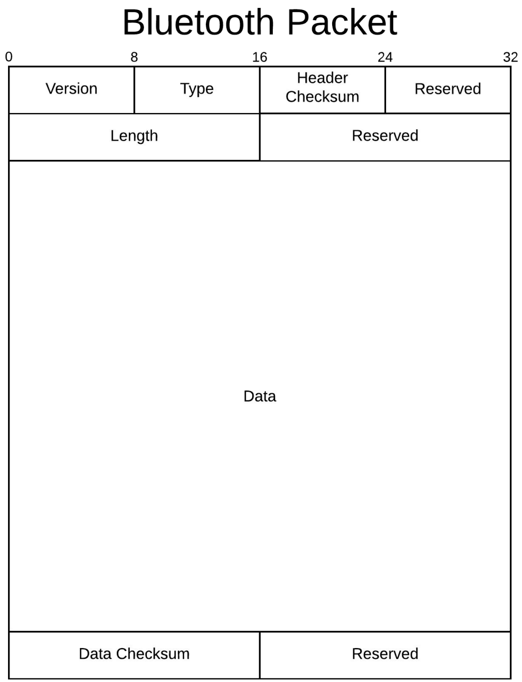
- Reading from sensors
- Send data to mobile device
- Time synchronization
- Status check
- Stop and start



Wearable Device: Communication

Bluetooth Application Protocol

- Time synchronization across numerous devices
- Data requests and responses
- Device identification with LED and/or vibration
- Sensor activation and deactivation



Mobile Device

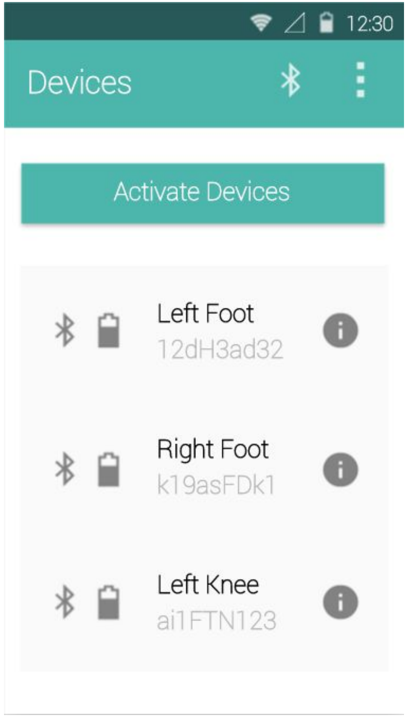
Bluetooth communication with the wearable device

WiFi connection to web server

Requests data from wearable device since last retrieved timestamp

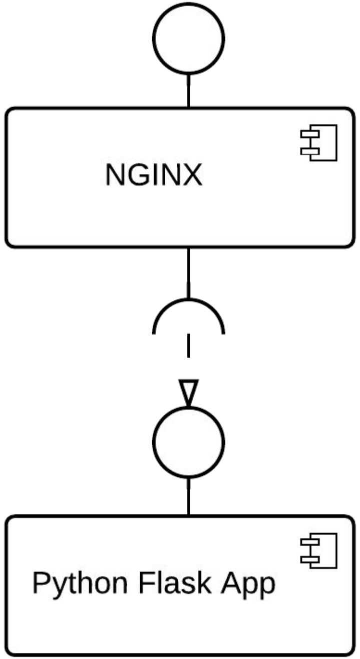
Caches data in a sqlite database until WiFi connection is available

Limited to Android platform



Web Server

- NGINX reverse proxy
- Python Flask application framework
- Handles HTTP POST requests from mobile device

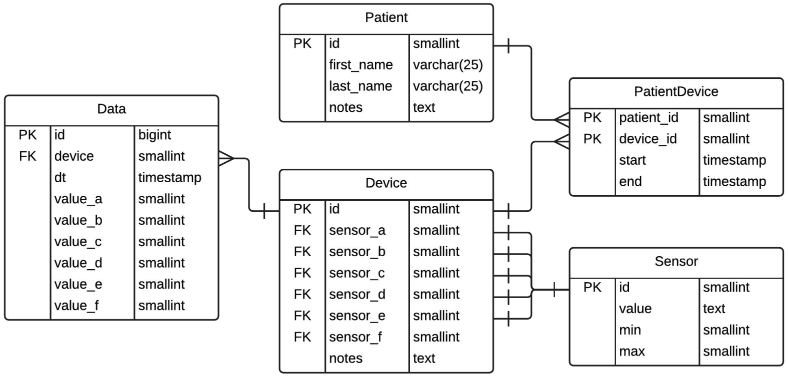


Database

Postgresql 9.3 has been selected for this system.

- Free and Open Source
- GIS Extensions
- Window functions for smoothing and cycle detection

Analysis may be completed using another layer above Postgresql depending on research needs.



Entity Relationship Diagram

Project Testing

Unit Testing Components & Integration Testing

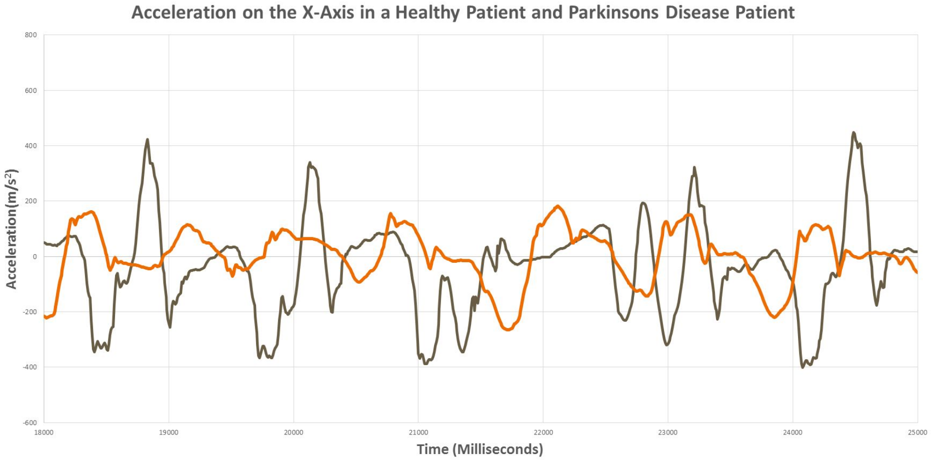
- Wearable device difficult to test due to limited emulation options
- Other components have available libraries and interface mocking

Functional Testing

- Data successfully transferred through hierarchy of system
- Performance and efficiency tests of data communication

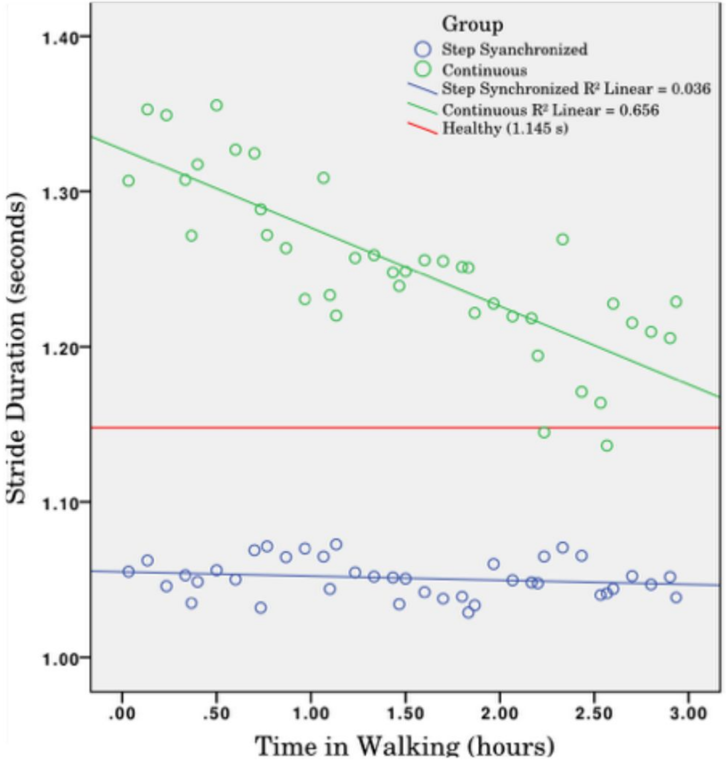
Non-Functional Testing

- Usability testing with Dr. Winfree's research students
- Evaluate hardware reliability in shoe form



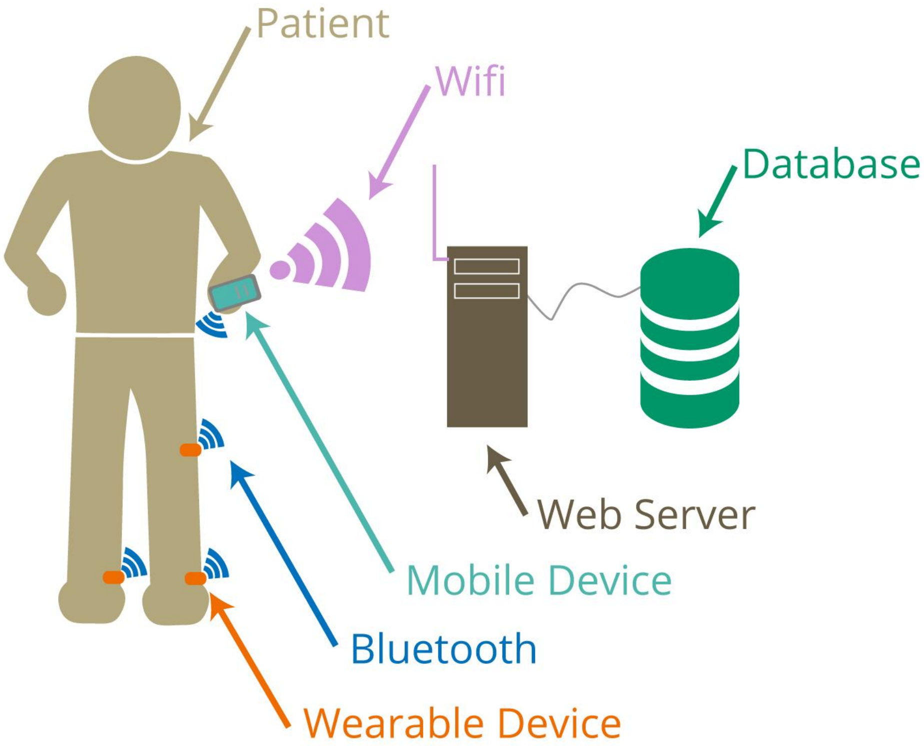
Future Work

- Statistical Analysis for Detecting Current Activity
- Optimization
  - Power efficiency
  - Bluetooth efficiency
- Data Analysis and Visualization Through Web API
- Embed Wearable Device in Shoe



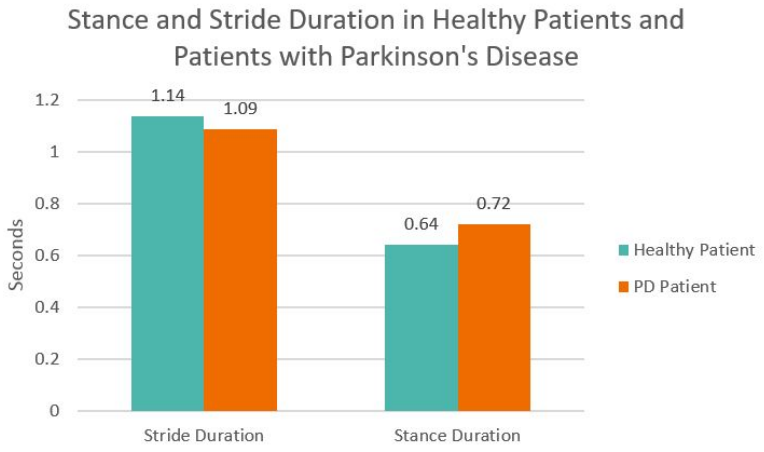
Conclusion

Centralized and near real-time collection of data for gait analysis to assess treatment impact and improve early diagnosis of Parkinson's Disease

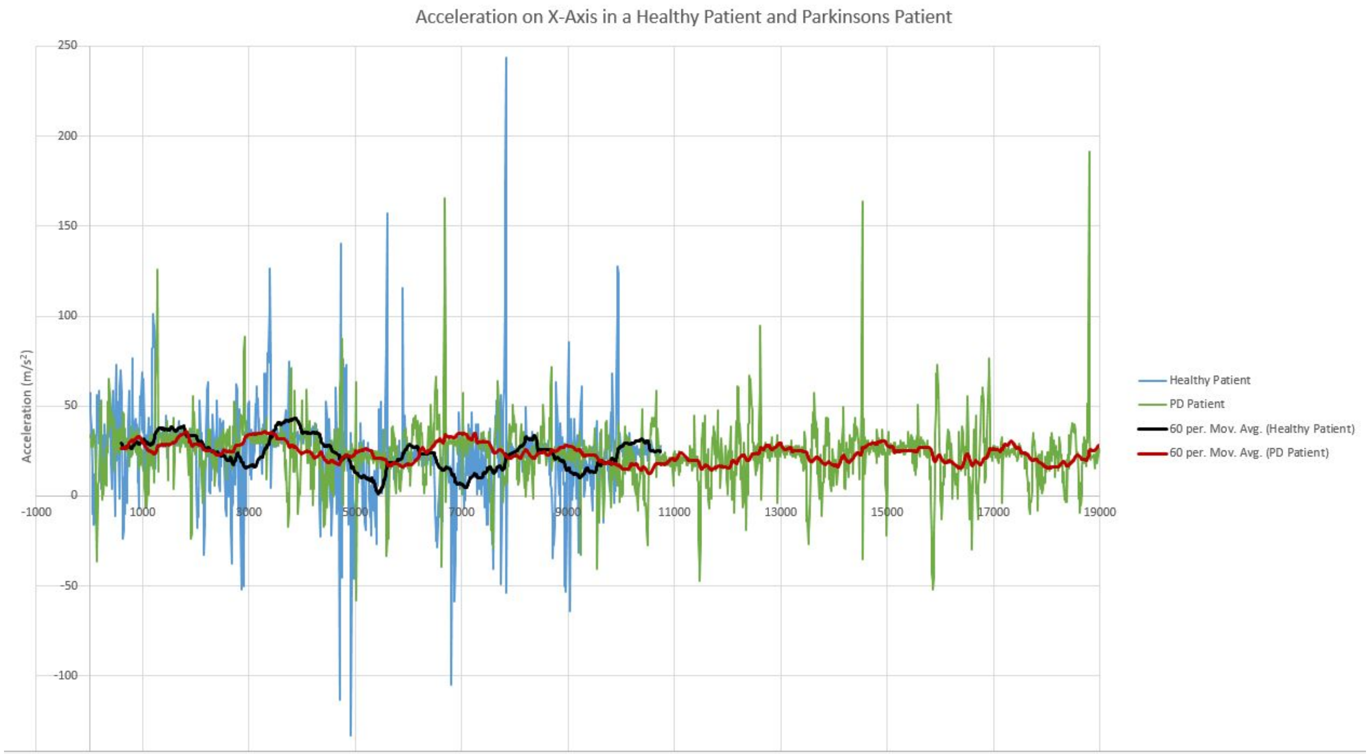


Analysis Outputs

	Healthy	PD
μ Stride Duration (s)	1.14 (0.11)	1.09 (0.19)
σ Stride Duration (s)	0.05 (0.02)	0.07 (0.03)
μ Stance Duration (s)	0.64 (0.12)	0.72 (0.14)
σ Stance Duration (s)	0.08 (0.06)	0.10 (0.06)
μ Stance Duration (%GC)	56.00 (7.51)	66.22 (6.11)
σ Stance Duration (%GC)	5.54 (5.00)	8.16 (6.64)
μ Heel Max (%GC)	10.19 (4.73)	16.72 (7.00)
σ Heel Max (%GC)	3.65 (1.48)	8.37 (6.61)
μ Ball Max (%GC)	42.15 (8.60)	44.17 (6.38)
σ Ball Max (%GC)	6.45 (5.81)	7.38 (6.97)
μ Toe Max (%GC)	53.12 (2.30)	52.44 (6.44)
σ Toe Max (%GC)	3.06 (1.99)	6.60 (6.79)



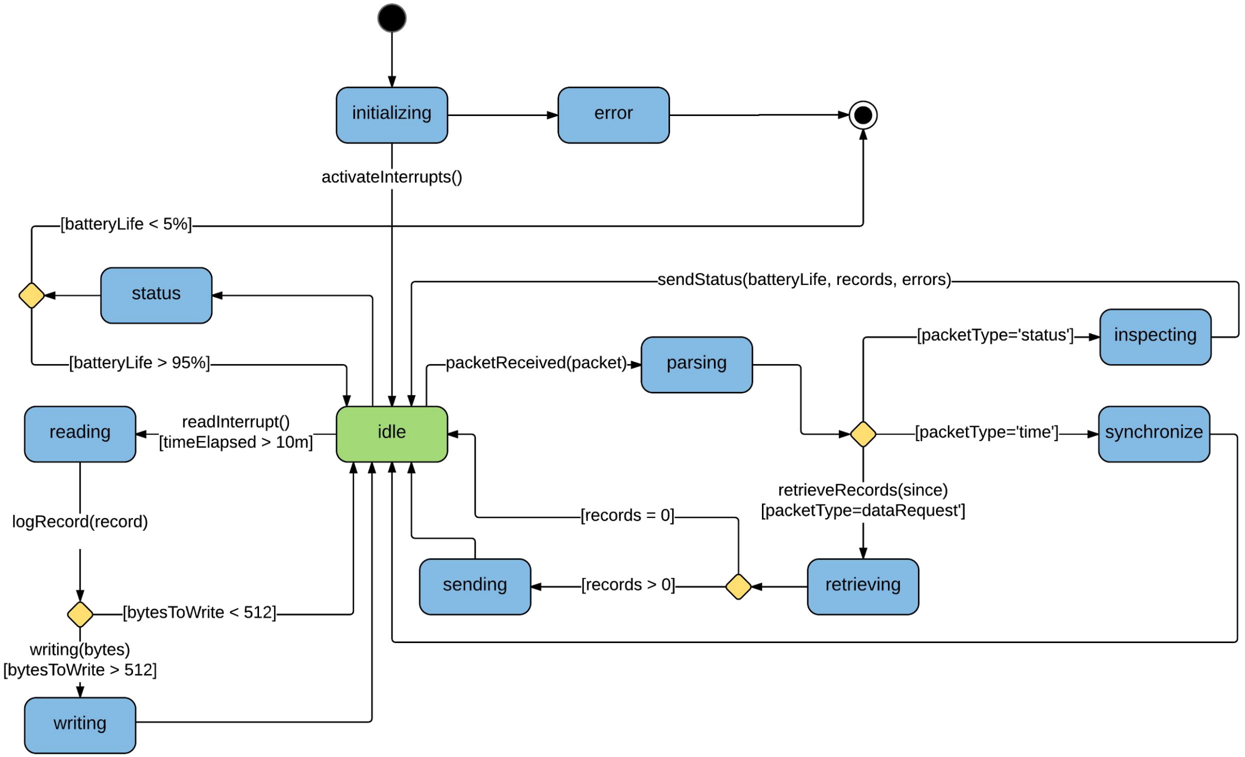
Sample Data

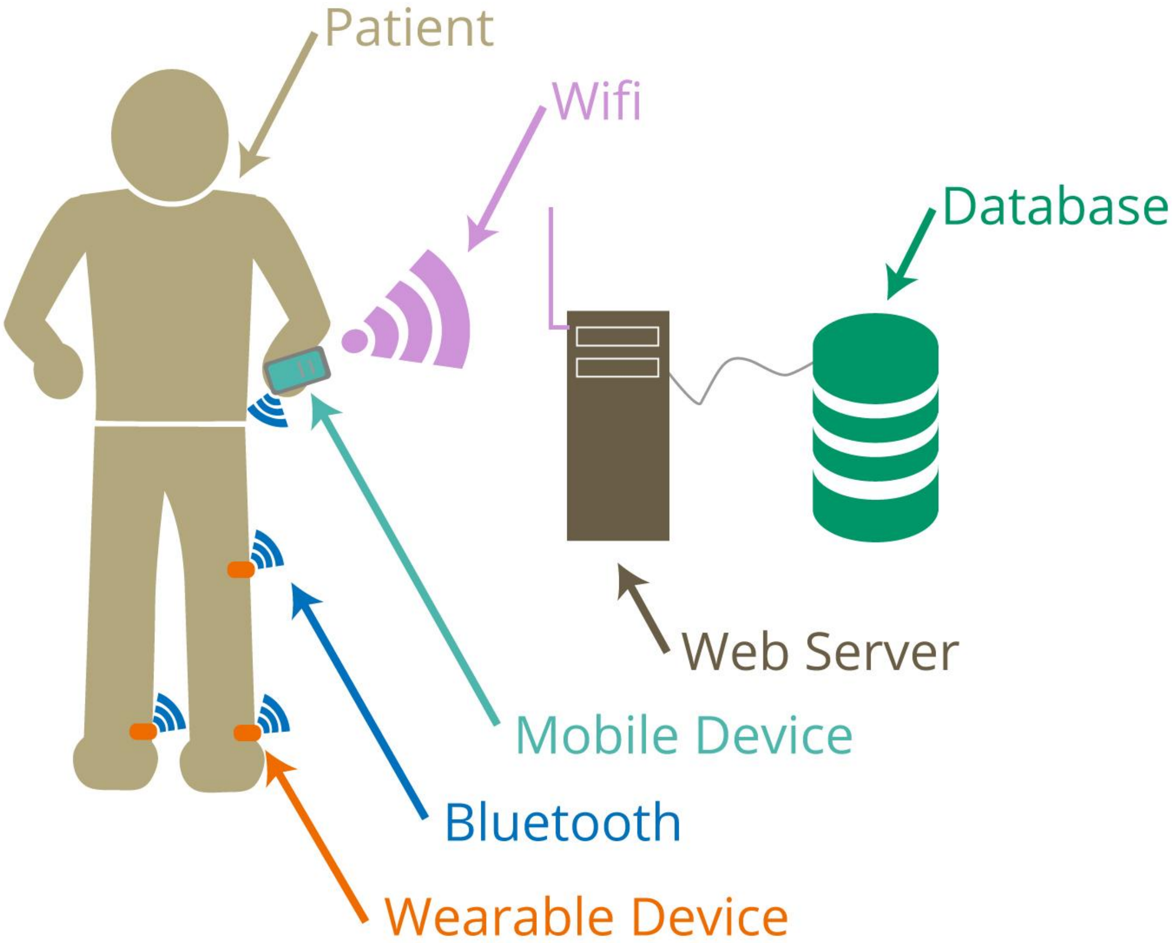

Acceleration on X-Axis in a Healthy Patient and Parkinsons Patient
Acceleration (m/s²)
250
200
150
100
50
0
-50
-100
-1000
1000
3000
5000
7000
9000
11000
13000
15000
17000
19000
Healthy Patient
PD Patient
60 per. Mov. Avg. (Healthy Patient)
60 per. Mov. Avg. (PD Patient)

Example Data

Time	FSR1	FSR2	FSR3	FSR4	AccelX	AccelY	AccelZ	GyroX	GyroY	GyroZ
8502	13	1	1	13	0.00	0.11	1.16	-0.51	-0.69	-0.71
9107	14	1	1	13	-0.00	0.11	1.17	-0.51	-0.69	-0.71
9711	9	2	2	17	0.01	0.11	1.14	-0.51	-0.69	-0.71
10315	14	1	1	2	0.00	0.12	1.16	-0.51	-0.69	-0.71
10919	1	1	1	3	0.00	0.11	1.15	-0.51	-0.69	-0.71
11523	5	1	1	11	0.01	0.12	1.15	-0.51	-0.69	-0.71
12128	16	1	1	2	0.00	0.11	1.16	-0.51	-0.69	-0.71
12732	2	1	1	2	0.00	0.11	1.15	-0.51	-0.69	-0.71

Wearable Device: Control Flow




Patient
Wifi
Database
Web Server
Mobile Device
Bluetooth
Wearable Device

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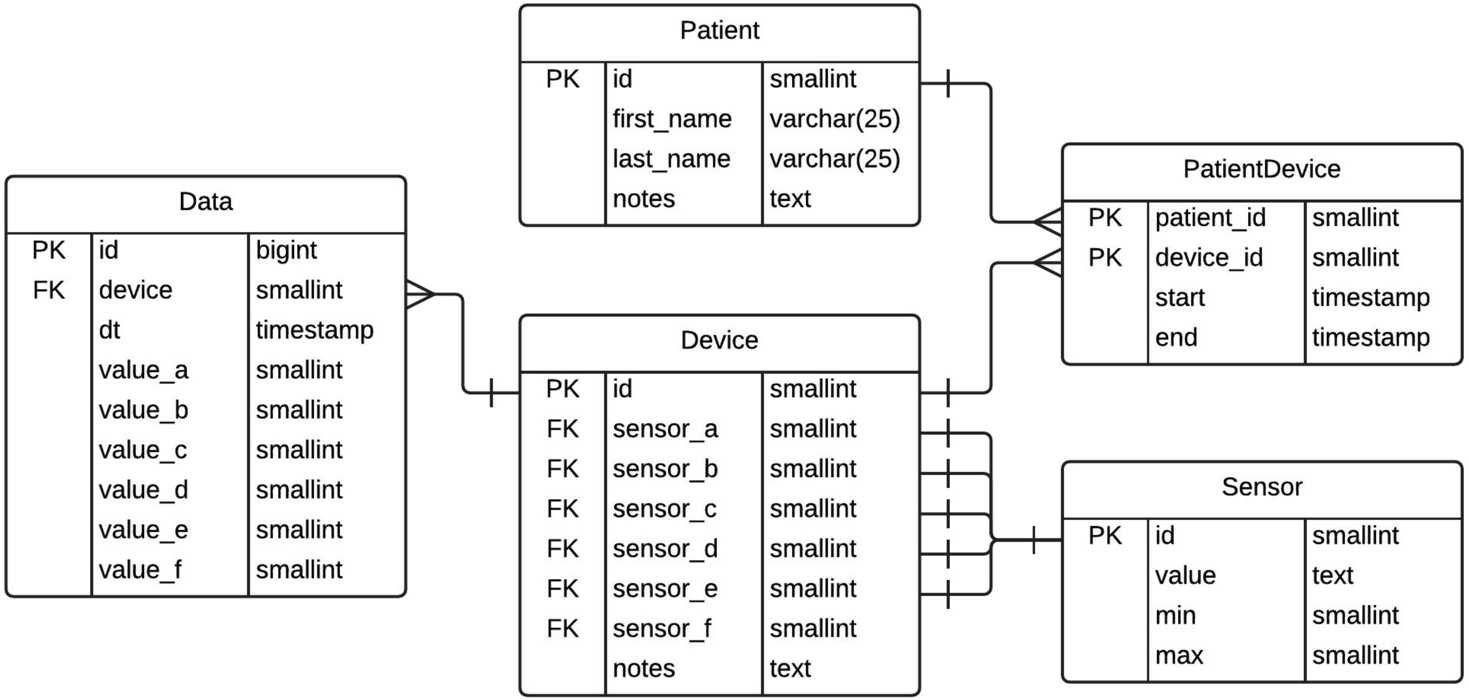
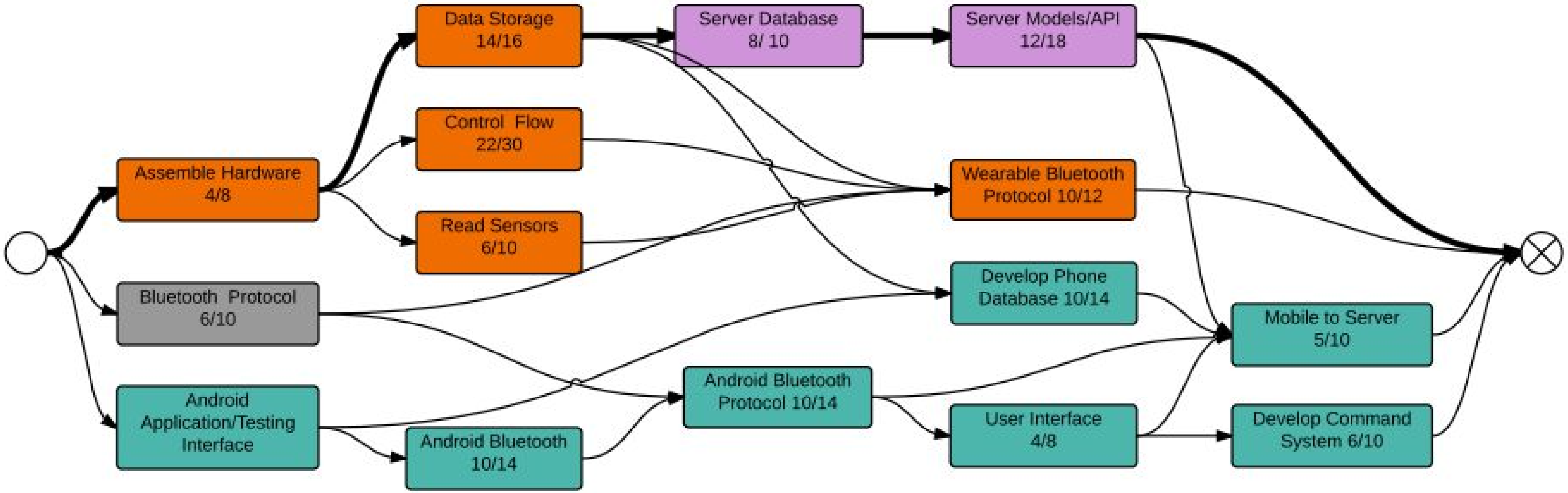


Schedule

PERT Chart used to determine three major milestones

1. Wearable device assembled, collecting data, and communicating (In testing)
2. Mobile application receiving and storing data (In testing)
   a. Performance issues over bluetooth
   b. GUI finalized
   c. Automation
3. Web server receiving and storing data (In testing)
4. Unit Testing

Pert Chart



Data Storage 14/16
Server Database 8/ 10
Server Models/API 12/18
Control Flow 22/30
Assemble Hardware 4/8
Wearable Bluetooth Protocol 10/12
Read Sensors 6/10
Develop Phone Database 10/14
Bluetooth Protocol 6/10
Mobile to Server 5/10
Android Bluetooth Protocol 10/14
Android Application/Testing Interface
User Interface 4/8
Develop Command System 6/10
Android Bluetooth 10/14

Schedule and Effort Estimation

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Slack Time

Critical Path

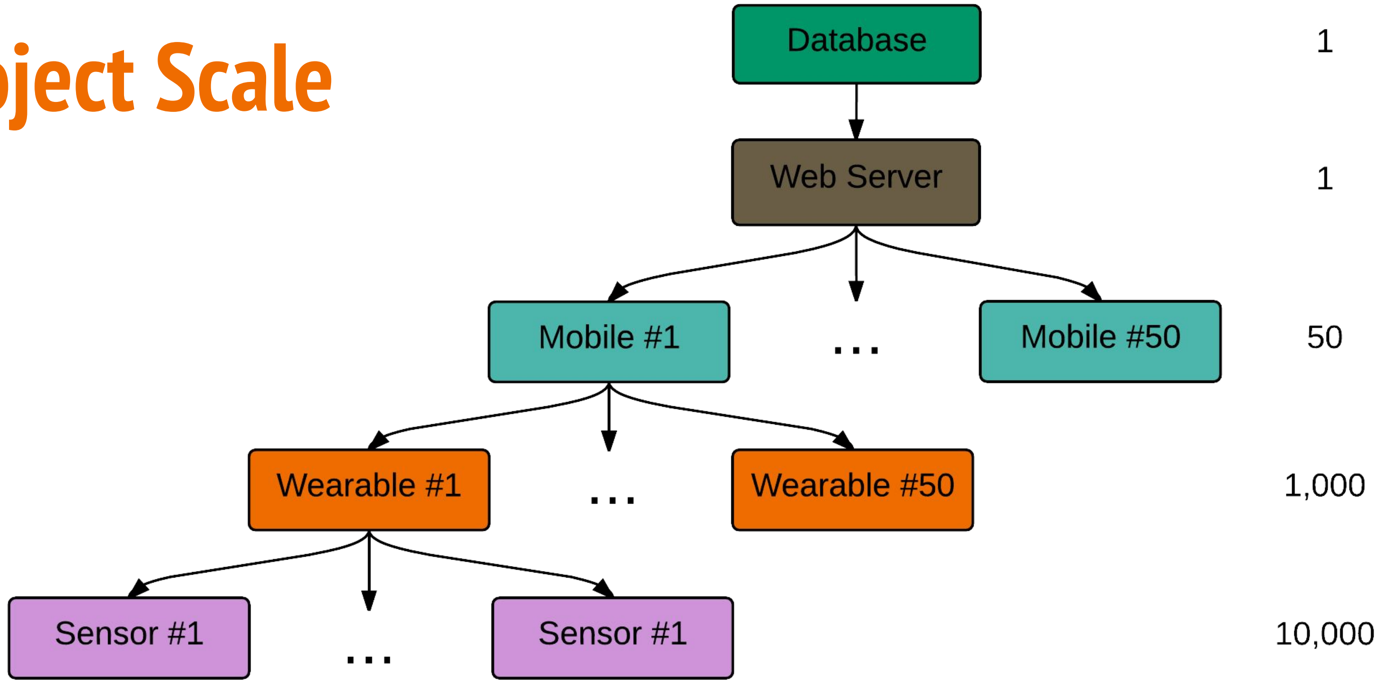
1. Assemble Hardware
2. Data Storage
3. Server Database
4. Server API
5. Web Application

Estimated Days: 58

Assumes days for task is average of best and worst case estimates. Some tasks may require multiple team members.

		Start Day		
	Days	Earliest	Latest	Slack
Wearable Device				
Assemble Hardware	6	0	0	0
Data Storage	15	6	6	0
Control Flow	26	6	21	15
Read Sensors	8	6	39	33
Bluetooth Protocol	11	32	47	15
Design				
Bluetooth Protocol	7	0	23	23
Mobile Device				
Android Application	4	0	14	14
Android Bluetooth	12	4	18	14
Android Bluetooth Protocol	12	16	30	14
Mobile Database	12	21	38	17
Mobile to Server	8	45	50	5
User Interface	6	28	42	14
Data Analysis on Mobile	10	34	48	14
Command System on Mobile	8	34	50	16
Server and Database				
Server Database	9	21	21	0
Analysis Queries	8	30	37	7
Server Models/API	15	30	30	0
Web Application	13	45	45	0

Project Scale



100 readings a second for 30 days on 1,000 Wearable Devices = 172 Billion Rows/month

30 bytes captured 100 times a second on 1,0000 Wearable Devices = 3 MB/second

Schedule Estimation and Effort Estimation

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