Journey: Final Report

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1 Introduction

1.1 Motivation

There is a history of clinical research that demonstrates that the measurement of quantitative gait markers (parameters that can be objectively measured about the way a person walks) may aid in improving assessments, estimating recovery time, and directing interventions for patients. Of the many possible parameters, gait variability (the stride-to-stride fluctuations in spatial or temporal parameters of one's walking pattern) has been shown to be associated with increased risk of falling, dementia severity, and cognitive impairment.

However, gait variability is difficult to quantify. Clinics make use of complex motion capture systems (mats with embedded pressure sensors, videos, etc), but these are expensive and time consuming to collect and process data. Others utilize more qualitative approaches to gait assessment, but these can be subjective and difficult to standardize. Both cases are also limited in the number of strides used for analysis.

Gait variability is also a relatively new biomarker. There is much debate in the literature over its correlation and predictive power for clinical diagnosis. For researchers, a causal relationship between gait variability and declining cognition is best studied in a longitudinal fashion. This is an ideal opportunity for a mobile application, as it makes it much easier to accumulate data over time and outside the laboratory, compared to conventional methods.

1.2 Goal

Thus, the goal of our app, Journey, is to enable simple measurement of gait variability (specifically step-time variability, the average deviation from the mean of one's stride time), for patients undergoing rehabilitation. As we developed this through a co-design processes with physiotherapists and a physician at Bridgepoint Active Healthcare, the secondary goal was to enable patients, caregivers and their healthcare providers to track, share and visualize patient progress with meaningul feedback.

2 Application Design

We have split the software design into 2 major components. The front end which collects and analyzes accelerometer data, and the back end which stores user information and measurement data inside a database. Back end also manages user types and security permissions for access to measurement data.

2.1 Block Diagram

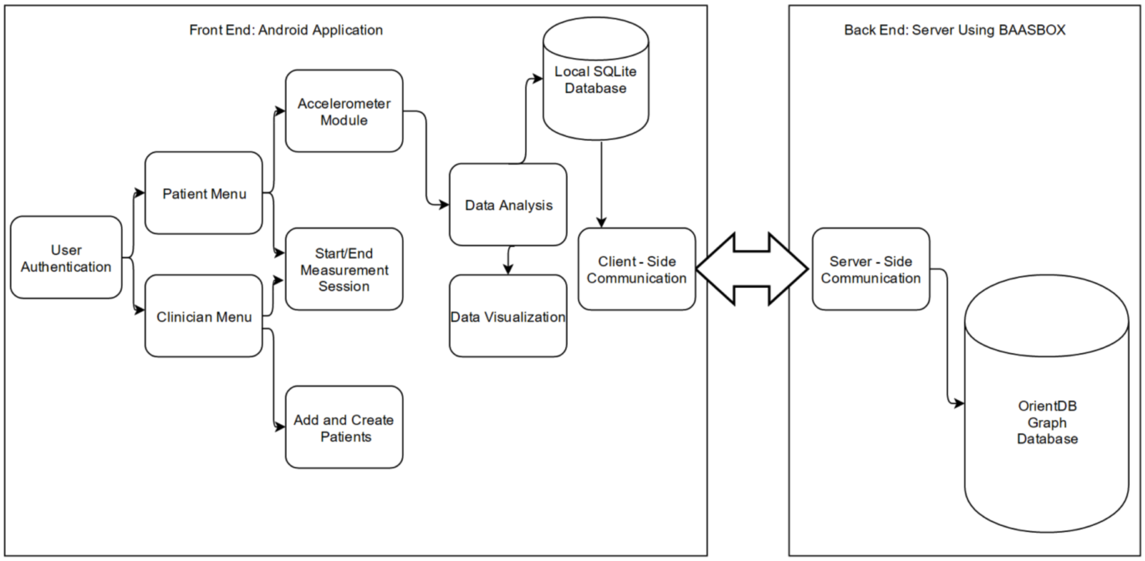


Figure 1: Software Architecture for Journey

2.2 Application Workflow

1. The user opens the app, and if using for the first time, is directed to create an account and indicate if they are a clinician or patient.

    - The patient is allowed to create, store and access trial measurement data
    - The clinician is allowed to manage multiple patients. The clinician can also create and access trial data for all of the patients it manages. The clinician is able create new patient accounts or add existing patient accounts to manage.

2. The clinician is able to create new patients and/or fetch existing accounts by using API's communicating with the server.

    - The **BAASBOX** framework allows creation of new users using an API call, once the required information is entered a new 'patient' user is created on the server.
    - The clinician also has the option to add an existing patient account that has already been created. This uses **BAASBOX** follow API call. This API call

gives clinician users access to patient data that is being followed. The 'follow' design is an intuitive design to allow access to other user's data.

3. The **Measurement** class enables start/stop/store trials

    - Trials collects data from **Accelerometer** class. The data is stored and retrieved from the local SQLite Database.

4. **Accelerometer** class handles collection of sensor data, data analysis, gait identification, and data visualization.

    - Once the accelerometer data is processed and analyzed, the processed data is sent to the **BAASBOX** server for storage as a Document. Each trial is stored with a userID so it can be queried in future instances of the application.

5. Trials are retrieved from the server using the **Client Side Communication module**.

    - To retrieve all the patient trials from the server we query the OrientDB database for all trials that contain the patients userID using a fetch API call.

3 Statement of Functionality and Screen Shots

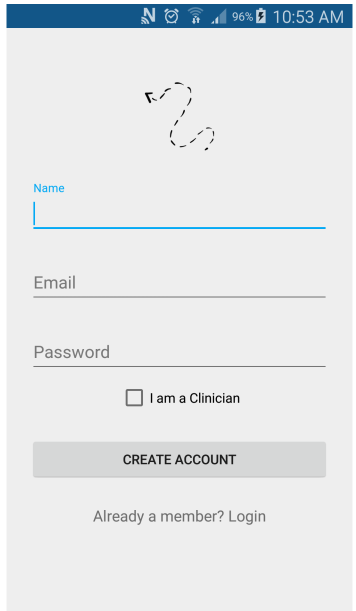
3.1 Register/Log In

The user opens the app, and if opening for the first time, is directed to create an account indicating if they are a clinician or patient. If they are a return user, they will log in to their existing account. The applications cached data maintains user authentication data required to keep the user logged-in at every instance of the application.

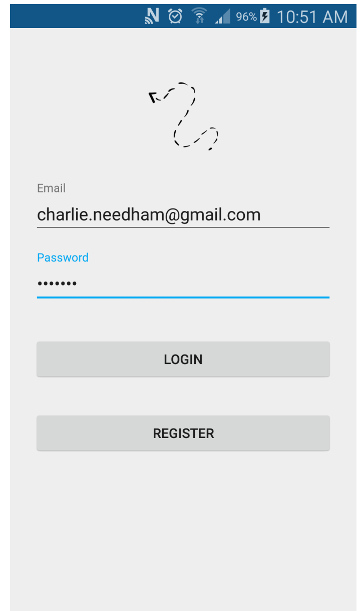
3.2 Patient list

The clinician can add a new patient to their list by creating an account, or find an existing patient account. Once a patient is created or added by the clinician, the clinician now automatically has access to the patients past and new trial data stored on the server. We

(a) Splash screen



(b) Register

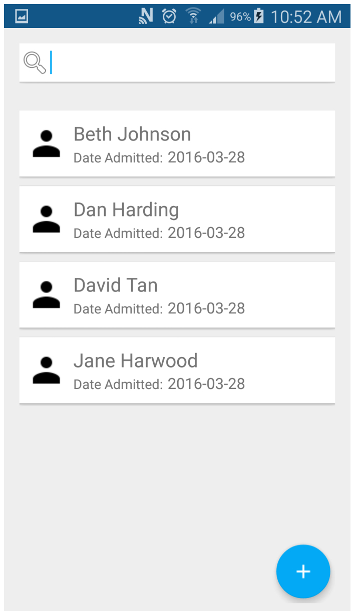


(c) Login

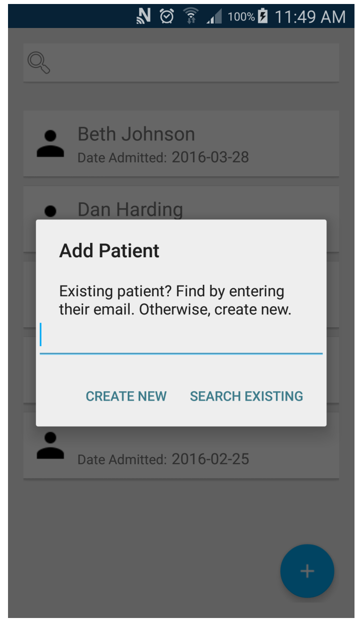
will explain the remainder of the app's functionality from the perspective of a clinician, but note that everything the clinician-user can do, the patient-user can do as well (except for adding and retrieving other patient's accounts).

3.3 Perform An Assessment

The clinician navigates to their patient's page, where they are able to review and create assessments. Once the patient is selected, a query to the server is made to retrieve all of patients past trials. Adding a new assessment directs them to a screen informing them of two options: they can choose to use the timed assessment option, and choose whether or not to use the metronome. The timed assessment turns the accelerometer sensor on and off at a predefined interval, as the phone is somewhat difficult to manipulate once it is secured on the patient's trunk. The metronome, while not a core part of our app's purpose, was added as an exploratory function as it may help patients to walk at a rhythmic pace. Once the desired options have been selected, the user presses "START" to begin the trial. The countdown timer gives the patient time to get ready, and then audio and tactile (vibration) feedback indicates that the trial has begun. If the timed assessment option was not selected,

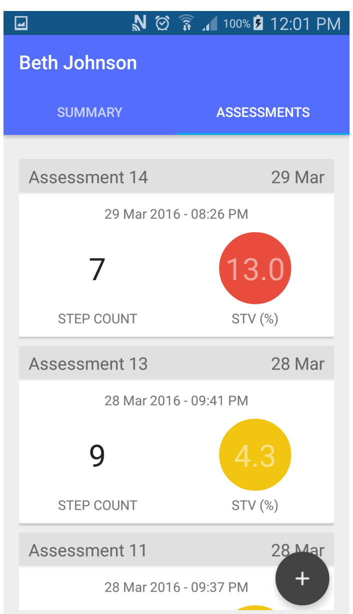


(a) Patient List

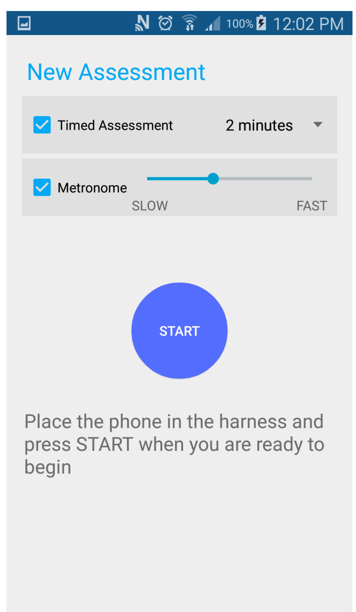


(b) Add Patient

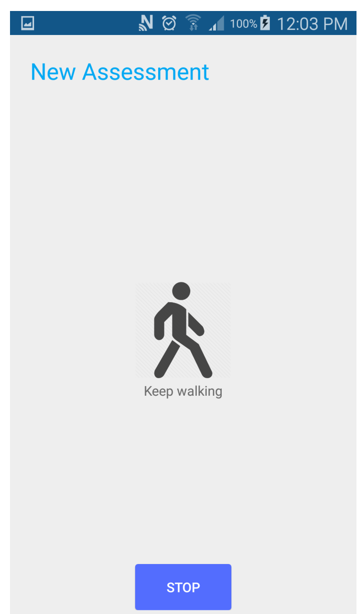
the user must press "STOP" for the trial to end. The data collected during the trial run is stored in the local SQLite database.



(a) Assessment History



(b) New Assessment



(c) Data collection

3.4 Signal Processing and Step Identification

Though the user does not observe this functionality, the processing of the accelerometer data and the identification of gait events is an important feature of our application. Once the accelerometer data has been collected the Y data (vertical movement) is processed to identify walking steps. This is done by:

1. Signal processing:
   (a) Apply fast fourier transform (FFT) to the data.
   (b) Apply a fourth order Butterworth low pass filter at a frequency of 60Hz to the transformed data.
2. Step identification:
   (a) Identify the peaks in the data and calculate a window equal to half the maximum gap between peaks. If the maximum gap is more than 700ms, use the half the mean gap instead. If it's less than 400ms then use 0.6 times maximum gap.
   (b) Identify steps as peaks. Each peak can't have another step identified within the size of the window, with the peak as the centre point.
   (c) A step is only identified if the distance between the peak and the minimum point to the left within the window, is within 38% of the same measurement of the previous step. The same is required for the minimum to the right of the peak.
   (d) If the gap between the most recent 2 steps is greater than 1.75 times the previous gap then look for a missed step. Look for a peak within the 40 - 60% range of the gap between steps.
3. Pause identification
   (a) Identify the median step time.
   (b) Look for any steps which are greater than 1.8 times median, and record them as a pause.

Once the accelerometer data is processed, it is propegated to the backend database server.

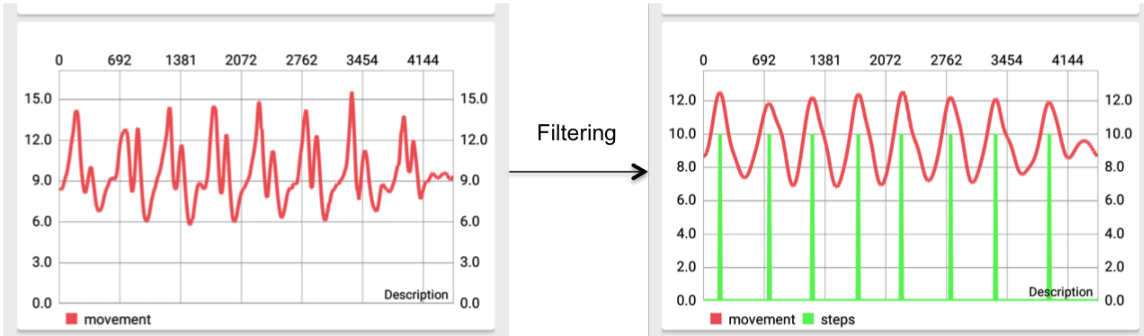


Figure 5: Signal processing and step identification

3.5 Gait Variability Analysis

Once the accelerometer successfully identifies gait events, the gait variability measure is calculated by a simple coefficient of variation.

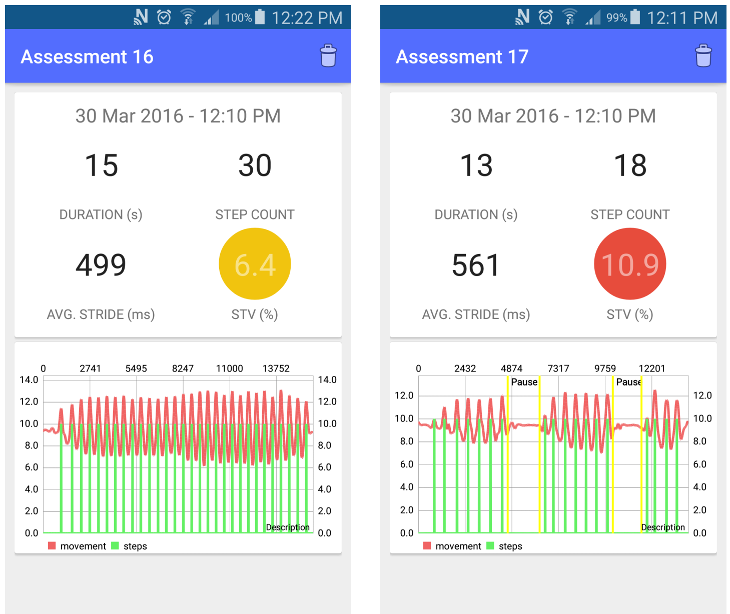
$$CV = \frac{\mu}{\sigma}$$

where μ is the mean and σ is the standard deviation of step time.

Each step time is calculated by identifying the time at the index of the local maximas (green line in Figure 5). The time at the local maxima is subtracted from the time at the local maxima of the previous step. The mean is calculated from the sum of the total step times divided by the number of steps that were identified. The standard deviation is calculated as the total squared difference between each step time and the mean, divided by the number of steps identified minus 1.

3.6 Summary and Feedback

The user can assess patient status and overall progress in the summary tab. The first card indicates how well the most recent trials have gone. Colours are used as a motivational tool to give the patient feedback on whether their gait variability measure was high, medium or low. Thresholds for these categories were chosen based on a review of the literature on

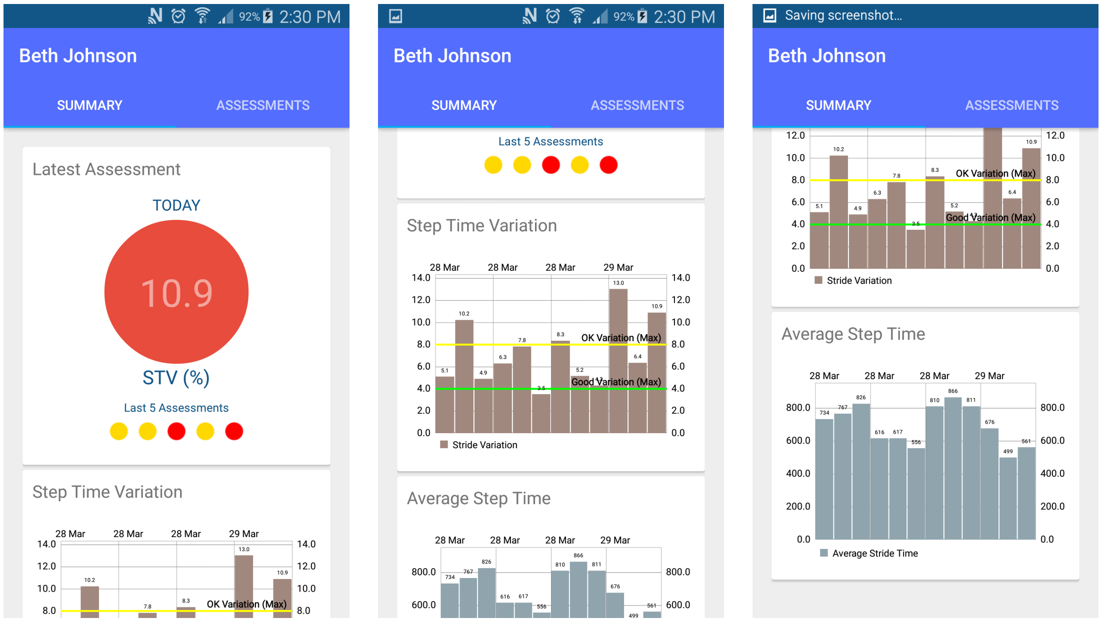


(a) Details of Assessment (b) Pauses during Assessment

gait variability, but are not yet clinically validated. Also included in the summary page are graphs to provide the clinician with a longitudinal view of changes in average step time and step time variation over the course of the assessment period.

4 What We Learned and Might Have Done Differently

During the development of this project, we did a number of things well and things we could have done better. We learned how valuable it is to get input from outside sources (including potential end users at an early stage). Another important learning was on the decision to use open-source packages versus developing things from scratch. In some cases, it was useful to adopt other's code to avoid reinventing the wheel. In other cases (such as using Baasbox) it may have been easier to build the back-end rather than using something pre-existing which lacks appropriate documentation. Along the same lines would be to ensure the functionalities of the app were well mapped out, to ensure the architecture we were developing was suitable for the organizational framework we were trying to attain.



(a) Recent Assessments (b) Step Time Variation (c) Average Step Time

5 Contribution by Group Members

5.1 Charlie

As one of the programmers on the team, my main contribution came from writing code. I put together the basic framework of the application, splitting it into data, service, and user-interface layers. I implemented a SQLite database to store the data locally. I also wrote the code which processes the accelerometer data and identifies the steps, which was quite a time consuming task. I worked on displaying the data on the screen. This included sourcing and integrating the third party graph library, as well as displaying the values and coloured graphics on screen. I created most of the activities and fragments too, and spent a lot of time creating and modifying UI.

I did some work outside of just programming. I was actively involved in all our discussions about how the app should work and what features we should implement. The nature of the app meant a lot of testing was required, so I spent a lot of time collecting walking data to test the data processing.

5.2 Sukrit

My role as a programmer, included the deployment, maintenence and integration of the backend server deployed on a virtual machine. The server was responsible for two features, the management of users and storage of trials. To ease the workload on the backend the team used an opensource framework, BAASBOX. The BAASBOX framework includes Android API's to allow the application for communication with the server. These API calls were integrated carefully into the Android application to maintain data autonomy between user accounts. Only allowing patients to access their own data and allowing appropriate clinicians to access patient data. Unfortunately, BAASBOX documentation was not sufficient and experimentation with the API's had to be preformed to acheive proper and secure functionality.

I extracted the important components of the accelerometer data stored locally on the SQLlite databaSE, this allowed for access to important trial data regardless of the device bieng used. To store and retreive the data from the server using HTTP requests, it was necessary to convert data into JSON objects. Since acceleremoter data was large some slight modification to the BAASBOX configuration was necessary to accomodate the HTTP requests. I made UI changes to some of the existing activities that used data from the server and added UI functionality for some of the advanced clinician user features like adding existing or new patient accounts under a clinician account. Outside of programming I was involved with general discussions about the direction of the Android spplication and the maintenence of the version control repository.

5.3 Jenna

My primary role as the specialist was to provide a roadmap of the project. I gathered data by shadowing physiotherapists at Bridgepoint and translated my observations and their feedback into specific user requirements. From the user requirements, I developed the mockups directly in Android Studio to minimize the amount of conversion the programmers had to do on layout and front-end design. I did a thorough review of open-source gait analysis projects and filtered (what I perceived to be potentially) usable code. Lastly I partook in technical and user testing, which I will continue after the completion of this course.

I also took the lead in terms of communications (project proposal, presentations, final report) and project management (making sure we set and met attainable goals) to allow the programmers to focus their time on development.

6 Specialist Context

As a graduate student in Industrial Engineering with a focus on healthcare applications, this project was an opportunity to better understand how to bridge the gap between experts in medicine and technology. The development of Journey has, and will continue to support my research endeavours in two ways. Firstly, a goal of my research unit, the Interactive Media Lab, is to improve cognitive assessments using technology. The lab is currently focused on the research, development, and assessment of technologies which are clinically useful in the screening for cognitive impairment. Gait variability has been a biometric of interest for some time, but lack of access to complex equipment has made the research harder to carry out. This application will make it possible to correlate cognitive decline and gait variability, in effort to improve the way we screen for cognitive impairment. Secondly, an area of research which is of interest to me is technology acceptance among healthcare providers. With the growing use of consumer healthcare products which perform functions from tracking clinical indicators to aiding communication between patients and providers, it is important to understand the factors that drive uptake of this type of technology. The development of this app provides me with a tangible case study, as I have been working with the clinical team at Bridgepoint to define user requirements, validate features, and provide feedback on overall design.

7 Future Work

Technical Validation - A validation study will be carried out with the Dynamic Graphics Project lab of the University of Toronto using a motion capture system as the reference standard.

Correlation with Cognitive Tests - A potential addition could be the inclusion of a standard cognitive test, such as the Stroop test (where the user is asked for the colour of the text on the screen). This would enable longitudinal analysis of the relationship between gait and cognitive function over time.

Collection and Integration of User Feedback - A usability evaluation will be preformed with the team at Bridgepoint to identify functionality improvements.

Analysis of Metronome Effect - A feature which can analyze the user's step time as compared to the period of the metronome. This would enable researchers to better understand the effect of audio feedback on gait rhythmicity.

Word count: 2496

Link to source code: https://github.com/jennaleeb/journey_wireframes