December 12, 2016
Kine Jax

Requirements Specification

Kine Jax

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Version:
1.1

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This document contributes to this project by outlining the specific details and requirements needed to successfully accomplished this project. It also lays the groundwork for what specific protocols and technologies that are needed to fulfil the hardware constraints. Overall the document gives breadth and depth to why the KineTrax project is important and how it will be accomplished.

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I. Introduction

Moore’s law states that the number of transistors per square inch on integrated circuits double approximately every two years. So far, this has held true and as a result, technology has continually become smaller, faster, and cheaper. Because of this, we continue to think of new ways to integrate technology into our daily lives. For example, embedding our homes with smart devices and giving our cars autonomy. We now wear devices that sense and track our health, fitness, and location, such as Apple Watches, Fitbit, Garmin, and Xiaomi wearables. These sort of wearable devices have created a new area of study. Furthermore, the wearable technology market is increasing rapidly, with millions of units being sold every year, and growing. The market is projected to be worth 31.2 Billion USD by 2020[1]. With such a high growth expectancy, there is much opportunity to be had for new technologies, ideas, and research questions.

Dr. Kyle Winfree, alumni and now professor of Northern Arizona University, has a keen interest in this growing field. With a BS in Physics, MSE in Robotics, and PhD in Biomechanics and Movement Science, Dr. Winfree believes that there is more potential to these devices than just having a phone on your wrist that counts your steps. He believes there is a huge potential for improvement, especially in the area of healthcare. He is specifically focusing on neurological diseases that impair an individual's ability to move.

Dr. Winfree is working on the development of a wearable piece of technology that will allow for a complete gait analysis throughout the day: KineTrax. This device was designed and fabricated by Micah Kurtz, a former NAU graduate student who received a master's degree in Electrical Engineering, and will ultimately be used to analyze the movement of individuals with movement impairments. This device will allow doctors to better analyze the effects of medication and treatment of patients. While there are some devices that can monitor a person’s gait, these devices tend to be expensive, non-portable, and/or limited in functionality. Dr. Winfree wishes for an adaptable logging device, which can be expanded to utilize a wide array of different external sensors. The goal of the KineTrax is to create a mesh of wearable devices that can do just that. The KineJax team will continue the work of developing the software for this device. In this document we describe the problem, our vision for the solution, the requirements, the potential risks we could face, and how we plan to accomplish these goals.

II. Problem Statement

Wearable technologies allow us to ask new and exciting questions that give insight into unseen patterns [2][3]. These technologies allow us to view our habits and behaviors through an objective lens, which if utilized properly can greatly improve our lives [2][3]. One application of these wearable technologies is in the area of monitoring and analyzing movement, more specifically the movement of limbs [4]. This application of wearable's is the future of diagnosing and treatment of individuals with neurological impairments, such as Parkinson's and Lou Gehrig's Disease. Although there exists technologies that collect this information, they are limited in their scope and applications. Table 1 shows a comparison between these technologies. The following are short descriptions of existing technologies that attempt to quantify movement.

Fitbit is a company that aims to allow users to monitor their activity throughout the day [5] and has been growing in popularity in the past few years. Their *Surge* model contains a heart-rate sensor, GPS and an accelerometer [5]. These sensors allow the user to monitor the number of steps they take in a day and the level of activity involved in those steps such as walk and stride.

The *Kinesia 360* is a wearable device created by Great Lakes NeuroTechnologies and is designed to continuously measure Parkinson's patients throughout the day [6]. It measures mobility, tremors, and involuntary movements. The parameters it records are, the total time the user is at rest, and the total time the user is active. It also detects tremors and can print out a daily report for the user. The device is a band that is worn at the ankles and wrist, and has already been used in multiple studies [7][8]. However, it does not measure full body kinematics [6].

Vicon is a motion capturing system that makes use of an array of cameras to record and capture movement [9]. The user has reflective markers placed at critical spots on their body. This allows for the cameras to see how these points move over time. The cameras are setup around a floor space, allowing them to see the markers and create a 3D model of the user. This technology is widely used in life-science and engineering studies and allows the recording of full body kinematics [9].

Records / Technology	**Activity Level**	**Tremors Detection**	**Heart Rate**	**Location**	**Full Body Kinematics**
Fitbit	yes	no	yes	yes	no
Kinesia 360	yes	yes	yes	no	no
Vicon	Not by default	no	Not by default	no	yes

Table 1: *A comparison between a few of the existing mobility capturing technologies. Shown in the rows are the three different capturing technologies while the columns are the number of parameters each technology can record.*

These technologies try to address the problem of quantifying an individual's movement. However, they all fail in different aspects and no one technology has been able to address the problem of adaptability. For example, the *FitBit* devices does not allow for the quantification of aspect of gait such as stance and swing; it only allows the user to see the amount of steps they are taking and their activity level. The same is true for the

Kinesia 360. However, it does allow for the detection of Parkinson's tremors while the other devices do not. The *Vicon* is ideal for quantifying gait because it allows for a wide range of parameters and the addition of external sensors. Unfortunately, it is limited to a single space and can be expensive [9]. *Currently, there is no wearable device that is adaptable by design that monitors movement*. Below is a list of areas that the existing technologies fall short on. These technologies:

- Don’t allow for the addition of external sensors.
- Focus on a few aspects of movement, such as number of steps and activity level.
- Are highly application specific, meaning that the designer only focuses on a specific use case and ignores all the other possibilities.

This shows that the existing technologies are unable to solve the problem of providing a wearable monitoring system that can be expanded. Now that we have illustrated the problem we will explain our vision for the solution.

III. Solution Vision

The solution involves an array of custom designed embedded circuit boards that will be able to gather day-to-day gait information over an extended period of time. The patient will wear seven of these devices, which will be placed at the leg joints and torso, as shown in Figure 3. The devices need to be placed in specific locations in order to properly analyze the movement of the limbs. This method is very similar to motion capturing systems such as *Vicon*. However, the KineTrax device will be different because it does not require external cameras and equipment. Furthermore, the KineTrax device will be easily setup and adaptable. This is unlike the *Vicon*, which is costly and complicated to assemble. Figure 4 shows how the KineTrax will bridge the domains of motion capturing systems and wearable technologies to create a solution to the problem of monitoring movement over an extended period of time.

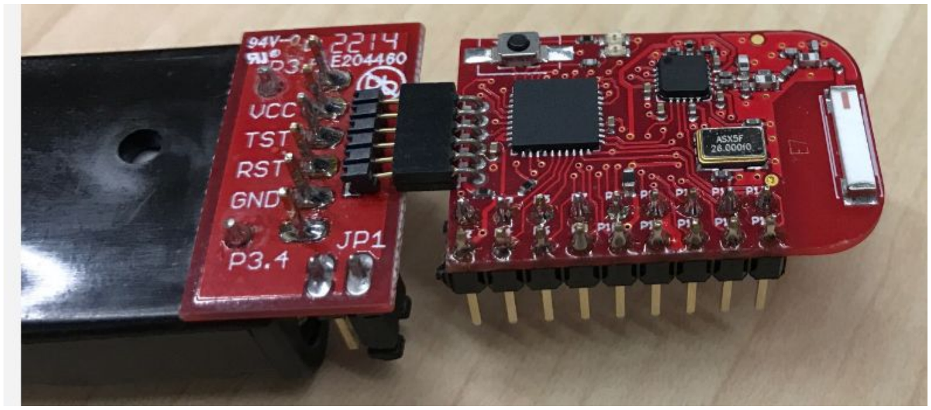

Figure 1: *The development board used in prototyping.*

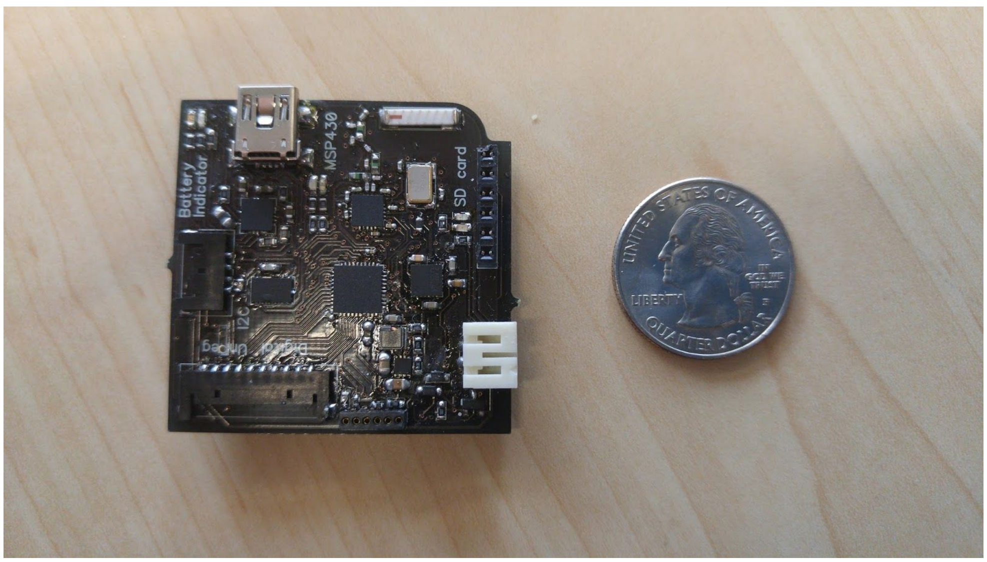

Figure 2: *An image of the custom KineTrax device next to a quarter for scale.*

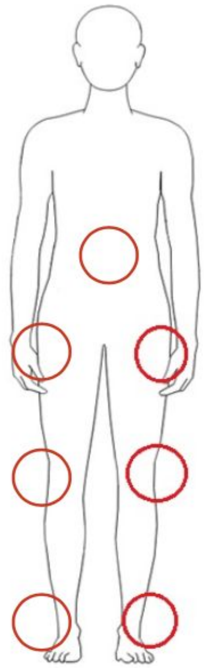

Figure 3: *This diagram marks the location where the KineTrax devices will be placed on the body. The placement of the devices at the joints of the hip, knees, and ankles.*

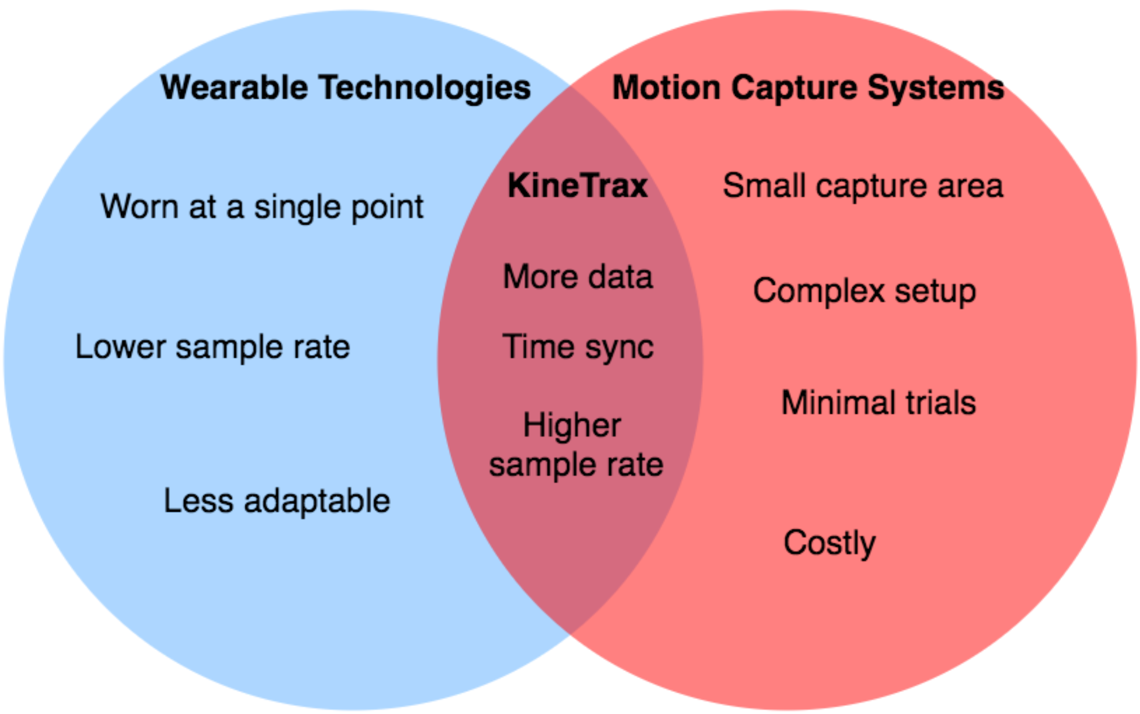

Figure 4: *A venn diagram that shows both the wearable technology and motion capturing domains. The weaknesses of each domain is shown in the exclusive areas.*

The KineTrax device falls in the intersection of these two domains. It will incorporate the mobility of wearables and the high sample rates of the motion capture systems.

The first part of the solution, which has already been completed by Micah Kurtz, is the design and fabrication of the KineTrax shown in Figure 2. The contribution this team will make to the project is to develop the software that will run on the KineTrax. Currently, the individual components have only been tested independently, but not as a whole system. *The KineJax team aims to bridge this divide and create the software framework that will allow for these different components to interact with one another.* We will expand on Micah's work by integrating and abstracting pre-existing code as well as adding new features to accomplish the goal of creating an adaptable wearable device. The implemented solution will allow each device to:

- Synchronize with other KineTrax devices.
- Calculate relative distance between itself and other devices.
- Capture and record data to the onboard SD card.
- Communicate with external peripherals and sensors.
- Be configurable by an external GUI.

These are the key features that need to be implemented to make this solution a success. The overall solution will integrate all of these features to create a system that is modular and adaptable by design.

IV. Project Requirements

Now that we have outlined our vision for the solution we will describe the requirements. These requirements will solve the problem of tracking movement in the clinical and research settings by creating an adaptable framework for further development. These requirements can be separated into three categories: functional, performance, and environmental. In the section below the details of each of these categories and sub-requirements are outlined.

Functional Requirements

Functional requirements are actions that the device and overall system will need to perform. The minimum that a KineTrax device needs to be able to do is connect and communicate with other KineTrax devices, measure and record its own movement, and be able to communicate with a GUI.

1) Seven or more KineTrax devices shall be able to connect wirelessly to one another.

    a) Each KineTrax device shall be able to act as a server, client, and router. This will be accomplished by extending the SimpliciTI protocol stack to include router like behavior (e.g. one or more devices communicating through one another).

    b) Upon startup, each KineTrax device shall be able to either connect to a pre-existing network or start a new one. This network consists of active devices and will be established by the first activated node.

2) Clocks shall synchronize time between devices.

    a) We will implement a time synchronization algorithm that will be deployed to the KineTrax device.

    b) Devices shall pull the current time from their clock and append it to a message to be sent over the mesh network.

    c) Devices shall set the current time of their clock according to the time received in a message over the network.

3) Each device shall gather data from onboard sensors.

    a) Each device shall pull data from the linear accelerometers.

    b) Each device shall pull data from the rotational accelerometers.

    c) Each device shall write information to their onboard storage.

    d) Data on each device shall be stored such that two or more nodes can be combined with time alignment during post-processing.

e) The device shall use accelerometer data to find the relative distance it has moved.

4) Each device shall be able to handle a passed configuration file.

a) Sampling rate of each sensor/peripheral shall be configurable in terms of the clock speed (i.e. sample every 4 clock ticks, etc.).

b) Data format of each sensor/peripheral shall be properly specified in the configuration file.

c) The configuration file shall be expandable to allow for the addition of more peripherals.

d) Devices shall be able to assess relative distance between one another.
   i) The signal strength shall be used to calculate relative distance between devices.

5) A GUI shall support data offload and device configuration.

a) Data shall be pulled off the onboard storage device via a GUI written in the Processing language.

b) Data shall be translated into CSV format.

c) The CSV formatted data shall be saved to the computer the GUI is running on.

d) The GUI shall allow the user to configure the KineTrax devices' peripherals.

e) The GUI shall allow the passing of configuration files to the device.

Performance Requirements

The following is the performance requirements for the KineTrax device. These requirements specify the execution of the functionality and deal with the requirements involving the sampling speed and time drift.

1) Devices shall sample at at least 100 Hz.

a) Sample rate must be at least this frequency in order to provide enough resolution to capture transient motions [10][11] (i.e. quick motions that could be missed with lower sampling frequencies).

2) Devices must be time synchronized down to millisecond precision.

3) Time drift must be stable, changing no more than once an hour.

   a) As drift becomes more frequent the need to calibrate the clock will result in using up valuable processing time and quicker depletion of the battery.

Environmental Requirements

The following are the environmental requirements for this project's development. These are requirements that constrain the programing environments, protocols, and hardware. Because the KineTrax hardware has already been created, we are constrained to the MSP430 microcontroller. Also, since this hardware requires specific programing languages and protocols we are constrained in that aspect as well. These environmental requirements are outlined in more detail below.

1) Software must run on Texas Instruments MSP430 embedded microcontroller.

   Since the KineTrax hardware has already been fabricated, we are constrained to those design decisions. This means that our software must be able to develop on the MSP430 microcontroller and/or development device with the same processor.

2) Embedded software must be coded in C.

   Since the most widely used and supported language for the MSP430 is C, we are constrained to accomplish all development in this language. Furthermore, since code already exist for the hardware in C it would not make sense to develop in other languages. However, it should be noted that other languages such as Python [12], Java, Ada and C++ also support embedded systems programing. But in many of these cases the embedded software is not well supported and/or requires special hardware.

3) Networking protocol shall be built on top of the SimpliciTI protocol.

   Since the device uses a proprietary radio transmitter that does not allow for third party protocols we are constrained to use their protocol.

4) Data offloading and device configuration shall be accomplished using the Processing programming language.

   This requirement was specified by the client and will allow for easy future development. The Processing language was designed for electronics and visualization, making it a perfect choice for GUI development.

Use Case

The following is a specific use case for the KineTrax device. This use case helps to clarify and motivate the requirements above.

Clinical Use Case: Say we have an individual A who is concerned that he/she might have amyotrophic lateral sclerosis, also known as ALS, and has been experiencing involuntary muscle contractions. They have been to the doctor, however, the doctor was unable to make a definitive diagnostic. So they decide to wear the KineTrax device with a goniometer for a couple weeks. They then take this data back to their doctor for analysis. Based on this analysis the doctor is able to diagnose the individual even before the symptoms were apparent. This early diagnostic allowed individuals to receive treatment far earlier than someone who had not worn the device.

V. Potential Risks

Now that we have outlined the requirements of this project, we will examine the potential risks of fulfilling these requirements. Below is a list of potential hazards and possible repercussions of the project if they were not to be addressed properly. These include health risks, data usability risks, and privacy concerns.

1) Devices are not time synchronized correctly and post-processing is impossible.
    a) Data is gathered but is useless because the times do not match.
    b) The data must be recollected delaying analysis and treatment for the patient/user.
    c) Data could be misinterpreted if the error is unknown resulting in inaccurate treatment.
2) Device could overheat, causing injury to users.
    a) Multiple devices are located on the user, overheating could cause burns and or injury to the user.
    b) If a device overheats the data may not be retrievable or inaccurate.
3) Uncontrolled access to data could have negatively impacts
    a) The data collected is personally and could be used to track or identify the user.
    b) If the data is altered, this could result in inaccurate treatment for the user or misdiagnosis.
    c) The data could be viewed by those that should not have access.
        i) The collected data could result in increased insurance costs if a user shows signs of a disease but is not yet diagnosed.
        ii) Job security could be affected if a company has reason to believe a worker is developing a disease that could cost them more money or impact the ability for a person to perform their work duties.

VI. Project Plan

In this section we outline the milestones that we shall accomplish to fulfill the requirements of this project. The milestones are centered around five key aspects of the project which include: time synchronization, a self-configuring network, distance estimation, data recording, and device configuration. The list below are the key milestones and the specific dates that they will be accomplished. Milestones are organized with subgoals which are directly dependent. Figure 5 shows the timeline for the goals that we will accomplished in the months ahead.

Milestones:

1) Real-time clock functionality tested and deployed by January 22nd.
2) Serial communication (e.g. reading and writing) to GUI tested and deployed by February 12th.
3) SimpliciTI extended and self-configuration behavior tested and deployed by February 12th.
4) Time-synchronization algorithm tested and deployed by February 5th.
5) Distance estimation functionality tested and deployed by February 19th.
6) Data recording to on board SD card tested and deployed by February 26th.
7) Device configuration functionality tested and deployed by March 1st.
8) Vicon testing completed by March 19th.

Timeline

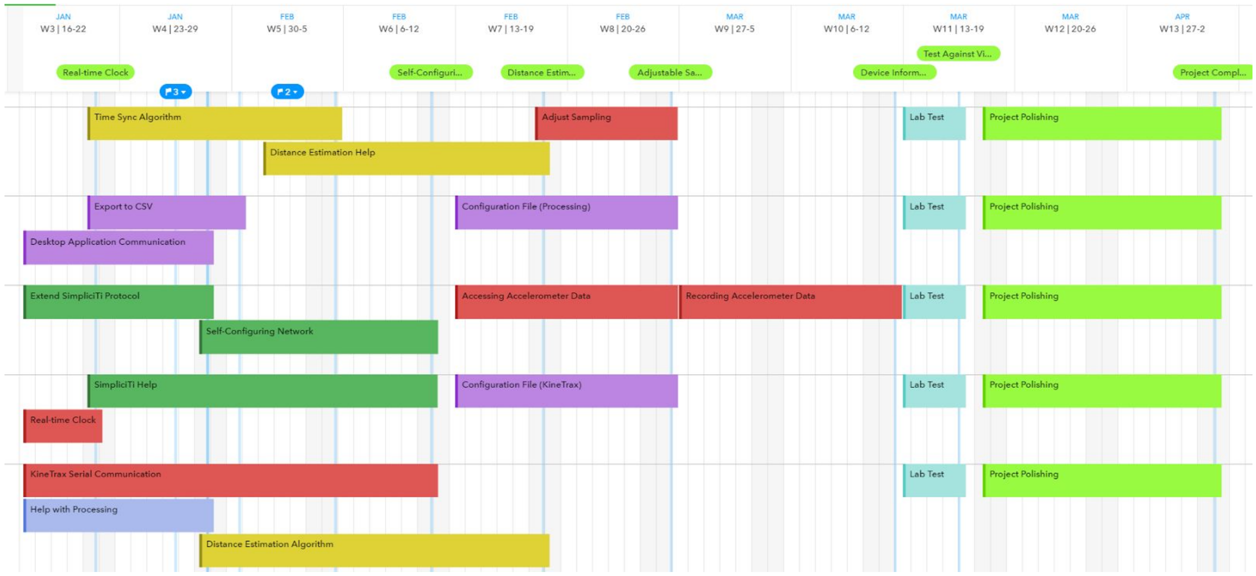

Figure 5: *The key milestones gantt chart for the Spring 2017. The figure shows the key components and the timeline for completion.*

VII. Conclusion

To conclude, the KineTrax will be an adaptable wearable device that can quantify gait and other distributed sensor data for an extended period of time. The project will make it possible for doctors to make more informed decisions when treating patients with neurological diseases. This is a problem that needs to be solved because the current methods of examination are extremely limited. This will address a problem that current technologies fail to solve and will greatly improve the lives of those affected by neurological movement impairments. Additionally, it will merge the domain of wearable technologies with motion capturing to give accurate gait information over time. We will also be laying the framework for a device that is expandable in it’s scope and will have a large scale impact on healthcare.

Currently, we have tested and created demos of some of the key aspects required to completed this project. This includes a demonstration of the team's ability to program the SimpliciTI protocol and use the protocol to communicate between the development boards (Figure 1). We have also implemented a time synchronization algorithm in Python showing that the algorithm is able to correct clocks with dramatically different times. We also have begun the early work of developing a Processing GUI that is able to use serial communication. We have tested this communication using an Arduino that outputs random numbers and have shown that the program is able to read in these numbers.

The complete solution to this project will revolve around key aspects that ensures that the device will be able to record accurate and precise data for a distributed network of sensors. We will make this solution a reality by using existing technologies and protocols to create mechanisms to implement time-syncing, the self-assembling network, recording of data, and the configuration of the device. The overall solution will combine all these aspects to create a complete system.

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