

Motion Capture For Runners



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Executive Summary:

The team is tasked to design and test a product to capture the motion of runners. This product will analyze the form of a runner and compare it to an elite runner under various running conditions. Through motion sensors such as Inertial Measurement Units (IMUs) placed throughout the body in the form of a body suit and real-time feedback, the runner will be given a visual alert of improper running form. Sponsored through the Air Force Research Laboratory, the team is challenged to find an innovative and low cost solution to capture and analyze motion. This technology could be used to further understand motion of flexible structures of aircraft and spacecraft.

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Introduction

Many people have little knowledge of the efficiency of their running form. By improving their form, runners can significantly improve their performance. Runners can improve upon their efficiency by comparing their running form to that of an elite athlete. To achieve the measurements necessary for this analysis, inertial measurement units (IMUs) can be placed along the body to capture limb and joint motion. IMUs contain numerous gyroscopes and accelerometers that electronically measure position and movement of the runner (3). Different size and types of IMUs are used for different applications. The data collected by the IMUs must then be analyzed to provide feedback to the runner. Data collected from gait analysis is comparable to data collected from sensors on flexible portions of an aircraft. Therefore, the motion of flexible aircraft can be better understood through this similar analysis of running form.

The objective of this project is to design a motion capture device that can be worn by runners in order to improve their running form. The device must be portable and unobtrusive to not impede the runner's form. The product must be able to send real time data about the runner's form to provide accurate feedback with which improvements can be implemented. The product must also be able to function with different sized runners, as not all runners will have the same proportions. The feedback provided must also be easy to interpret, in order for the runner to make alterations in their form at will. Lastly, the product should be as low-cost as possible, making it accessible to many different users.

A similar study had recently been published in SICE Annual Conference 2012 by researchers from University of Hosei in Japan. They mainly focused on measurement and analysis of running form using three dimensional acceleration and gyroscopic sensors. The authors defined an efficient running form to be one that can carry a person's center of gravity forward with the least amount of effort. In this research, a small-size, wireless sensor equipped with three-axis acceleration sensors and three-axis gyro sensors was mounted on subject's back. The collected data was transmitted to a PC via Bluetooth, and then analyzed in MATLAB (1). A similar concept will be applied in the proposed solution to obtain the data necessary to accurately measure running form.

Motion Capture Background

Motion capture is the process of recording the movement of objects or people that can be analyzed or modified using computer software. Motion capture systems are used in video games and film making industries to transfer human movements to animated 3D models. Motion capture systems have even been developed and used in military applications along with entertainment, sports, medical, and robotics industries.

There are two main types of motion capture technology; optical and non-optical systems. Optical systems involve using a camera or a system of cameras to capture the body's movements. The Microsoft Kinect for the Xbox360 is a prime example of this technology. A built in camera captures the body's movements and replicates these movements on the animated character (2). In other systems, small markers are placed on the body and then are continuously captured by the camera and computer software. There are two main types of optical marker systems. Passive marker systems use markers coated in a retro-reflective coating that reflects light and is then captured by the camera system. Active marker systems use small LED markers placed on the body that emit light for very short periods of time (4). These systems are more effective due to the increase in distances and volume for capture.

Non-optical systems use inertial sensors that are then wirelessly transmitted to a nearby computer. These systems use sensors that are measured on multiple axes and are often used in a full bodysuit that is worn

by an individual. These systems are most popular for video game developers due to the quick and easy setup, resulting in more accurate measurements. These systems require no cameras, are more versatile, and quickly becoming the top choice for motion capture systems.

Objectives and Design Specification

The following criteria will be used to judge which design best fulfills the requirements of a motion capture system with feedback. These criteria influence the practicality of our design and other important points.

Battery (Size, Life)

The battery is a crucial part of the design, as it provides power for every sensor on the product. Since the battery must be worn on the runner, the battery's size should be as small as possible. However, the battery must also be able to last through multiple testing cycles so a minimum of an hour of battery life is recommended.

Wireless Communication (power consumption, bandwidth, and distance)

The wireless communication for the design should have low power consumption, as it will also be battery powered, but also a large enough bandwidth and range to transmit measurements.

Sensors (power consumption, size, axes, sampling speed, and method for attaching)

The sensor chosen should keep its size and power consumption to a minimum. This would create less impedance in the runner's form as well as help prolong the life of the battery. The number of axes and sampling rate of the sensor should be high enough to ensure that the data is accurate and be processed effectively. Another criterion to consider is the manner in which the sensor will attach to the runner. A simple, yet effective mechanism is preferred.

Feedback (size, response time, ease of use, and power consumption)

When choosing the best option for feedback, several details should be considered. The feedback controller will be placed on the runner, so the size should be as small as possible. Also, since the runner is attempting to fix their form in real-time, it is critical that the feedback response time is quick and that the feedback is easy to interpret. Another factor to consider is feedback delay. Feedback delay is the time from when the initial measurement is made by the IMU to when the feedback is provided to the runner. In order for the runner to appropriately change their running form, the feedback delay should be minimal. Additionally, a low-power device is preferred so that the device lasts longer and requires a smaller battery.

Cost

The design should strive to be as inexpensive as possible. Given that the design of this project is a prototype and not one that will be sold commercially, the cost may be higher than any subsequent designs.

FAST Diagram

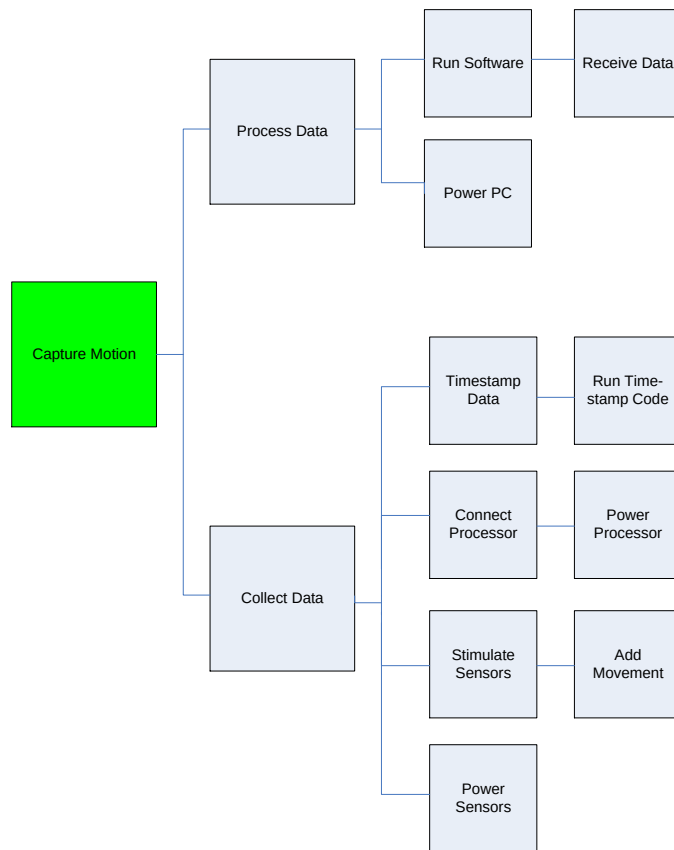


Figure 1: FAST Diagram

Conceptual Design

Sensors

The product must be able to acquire data efficiently and accurately in order to provide effective feedback to the user in a timely manner. Sensors with multiple-axis capabilities are extremely useful for measuring moving parts, including the limbs and body movement of a runner. Sensors such as accelerometers or gyroscopes fit the necessary requirements. Sensors such as IMUs combine an accelerometer, a gyroscope, and a magnetometer giving the user 9-axes of data (3 axes per sensor).

Placement

In order to get the most efficient data from the user, the team has agreed on using multiple sensors. This will ensure accurate feedback from the user as well. The placement of the sensors can vary significantly based on the number used, as well as the accuracy of the data provided from each limb of the user. Further testing will conclude the placement of the sensors.

Microcontroller

The design of the team's motion capture product requires the use of multiple IMUs. Due to consistently receiving data from multiple sensors, a separate microcontroller is required. In order to utilize real-time feedback, it is necessary for the microcontroller to timestamp and synchronizes the incoming data to its corresponding time. This will ensure accurate measurements and feedback. The two microcontrollers that are being considered are the Arduino UNO and the Arduino Due. The UNO is a standard microcontroller that can be used for multitudes of projects and processing. Compared to the Due, it has less processing power, less I/O slots, and less on-board memory, but the number of components available that can be connected with it vastly surpasses the Due.

Type of Transmission

The three main types of transmission that the team is focusing on include Bluetooth, wireless (WiFi), or Zigbee (Xbee) wireless communication. Wireless communication is more widely used and able to send information much further away than Bluetooth. The downside is that wireless configuration can be rather complicated, especially when connecting multiple devices. XBee communication is specific to many microcontrollers, including the Arduino. It is a relatively long range communication medium with PC USB support. The only downside is its limited bandwidth, meaning it's not suited to transfer significant amounts of data consistently. With this in mind, the team has decided on using a combination of wireless and XBee communication since the distance between the user and the PC will be at a minimum, and overall XBee has a significant amount of components that are compatible.

Data Processing

The essential component of this project would be the analysis and processing of the data. As stated previously, the microcontroller will time-stamp and synchronize the data, which will be the preliminary processing stage. The primary processing will be done on the external PC. The data will also be compared with an elite runner baseline on software that will be written by the team. Programming languages that are currently being considered are MATLAB, LabVIEW, and Processing. Programming language will be decided after the team finds the output file of the Arduino microcontroller.

Runner Feedback Indication

Visual feedback would provide the runner with indication on whether they are currently running with proper or improper form. Visual indication would include a feedback system using LEDs or an LCD screen. LEDs can be used multiple ways, including using colors such as green and red to indicate proper and improper running form. Multiple LEDs may be included to give a more precise indication rather than just good or poor. An LCD screen would be more aesthetically pleasing and could provide more functionality, but it is also more complicated to set up.

Software

In order to process the data that is incoming from the Arduino microcontroller, the design needs software that is read and interfaced with the incoming data. Software programmings most suitable for real-time continuous calculations are MATLAB, LabVIEW, and Processing. All three programs are very universal and are able to successfully work with the team's design. The final decision on software can be changed at any time, but Processing seems to be the best choice because of its compatibility with the Arduino microcontroller.

Feasibility Matrices

The following matrices are composed of the team's different conceptual component designs. Each matrix has different criteria to rate each component on multiple aspects which were deemed based on importance. The ratings go from 1 correlating to low importance, to 5 being high importance. The value of each component also follows the same rating system. Below is an explanation of what the team interpreted each criterion as.

Implementation: The difficulty of working with and setting up each component

Accuracy/Consistency: The overall precision of the data being sent/ received by the component

Usability: The ease of use for an average user

Compatibility: How well the component works with other products/devices

Functionality: How well the component functions and its general usefulness

		Concepts	
Criteria	Importance	Wired Arduino	Completely Wireless
Implementation	5	4	2
Size/Portability	4	1	5
Cost	3	4	3
Accuracy/Consistency	5	3	2
Usability	4	3	3
Compatibility	2	5	3
Functionality	3	4	4
Overall Weighted Score		85	79

Figure 2: Wired vs. Wireless

		Concepts	
Criteria	Importance	LED Feedback	LCD Feedback
Implementation	5	4	2
Size/Portability	4	3	3
Cost	3	5	3
User Friendly	4	3	4
Compatibility	4	3	3
Functionality	2	4	4
Overall Weighted Score		79	67

Figure 3: LED vs. LCD Feedback

		Concepts		
Criteria	Importance	Wireless	Xbee	Bluetooth
Implementation	5	3	3	3
Range	2	5	4	2
Cost	3	3	3	3
Bandwidth	5	3	3	3
Compatibility	4	3	3	3
Power Consumption	4	4	4	4
Overall Weighted Score		77	75	71

Figure 4: Wireless vs. Xbee vs. Bluetooth Communication

		Concepts		
Criteria	Importance	Accelerometer	Gyroscope	IMU
Implementation	5	3	3	3
Size	5	5	5	5
Cost	4	4	4	3
Sampling Rate	5	4	4	5
Compatibility	5	3	3	4
Power Consumption	5	5	4	3
Number of Axes	4	3	3	5
Overall Weighted Score		128	123	132

Figure 5: Accelerometer vs. Gyroscope vs. IMU

Proposed Solution

Team has proposed a solution that will be composed of multiple IMUs, an Arduino microcontroller, wireless communication, and an external PC. The IMUs will be continuously collecting data based on the positions of the sensors while exercising. The IMUs will be placed at various locations on the user and directly wired to the Arduino microcontroller. This product will be running while users are exercising, so the product needs to be as manageable as possible, to ensure that the user's form isn't affected. By creating a running suit, or uniform, the product is able to be worn as clothing to decrease the issues of running while wearing the device. The clothing will be flexible and tight, to ensure that no connections come loose during exercise. The wires will be sewn into the fabric of the clothing, providing power, ground, and data transfer from the IMUs to the Arduino. This product will be used on a treadmill, due to wireless restrictions as well as the number of data points coming in at once. The team decided that it would be most convenient that the external PC will be nearby the runner for fast and efficient processing as well.

The Arduino microcontroller is added to the system to ensure that all the IMUs are provided with power, and a synchronized clock signal. The Arduino will be connected with a 7.2Volt, dual layer, and lithium ion battery. A synchronized clock signal is necessary to ensure that all the sensors are acquiring data at the

same rate, and time, to prevent conflicting signals from occurring. The incoming data from the IMUs will also be time-stamped, which will indicate which stream of data correlates to each sensor. All of these functions must be initialized using the Arduino programming software. Arduino has its own code format and requires the programs be initialized before it can function correctly. The data acquired will then be stored on a micro SD card because the total memory capabilities of the Arduino are too limited to continuously receive data from multiple sensors for an extended period of time. The SD card will be constantly written to, forming a writing loop that will run until the device is turned off.

The data on the SD card is then sent through a wireless device, known as an Arduino Shield. The shield connects to the Arduino and is one of many components that are compatible with the Arduino. The wireless shield connects to the external PC, creating a wireless connection that can transmit the data being collected on the SD card.

Once the data is received from the wireless connection, the external PC runs that data through previously written comparison software. The software will compare the locations of the sensors based on obtained measurements from a Michigan State University track athlete. The software will initially be used to compare simpler measurements such as angle, and stride length, and more complicated measurements given time constraints.

After the data is sent through the processing software, it is then sent back to the user via wireless communication. The communication used to connect to a feedback microcontroller will be XBee wireless communication. XBee communication requires two XBee communicators, as well as a USB device called an explorer. The XBee connected to the PC via USB will transmit data wirelessly to the feedback controller, which will also have an XBee communicator attached. The feedback controller will provide feedback to the runner based on the calculated and compared data on the external PC.

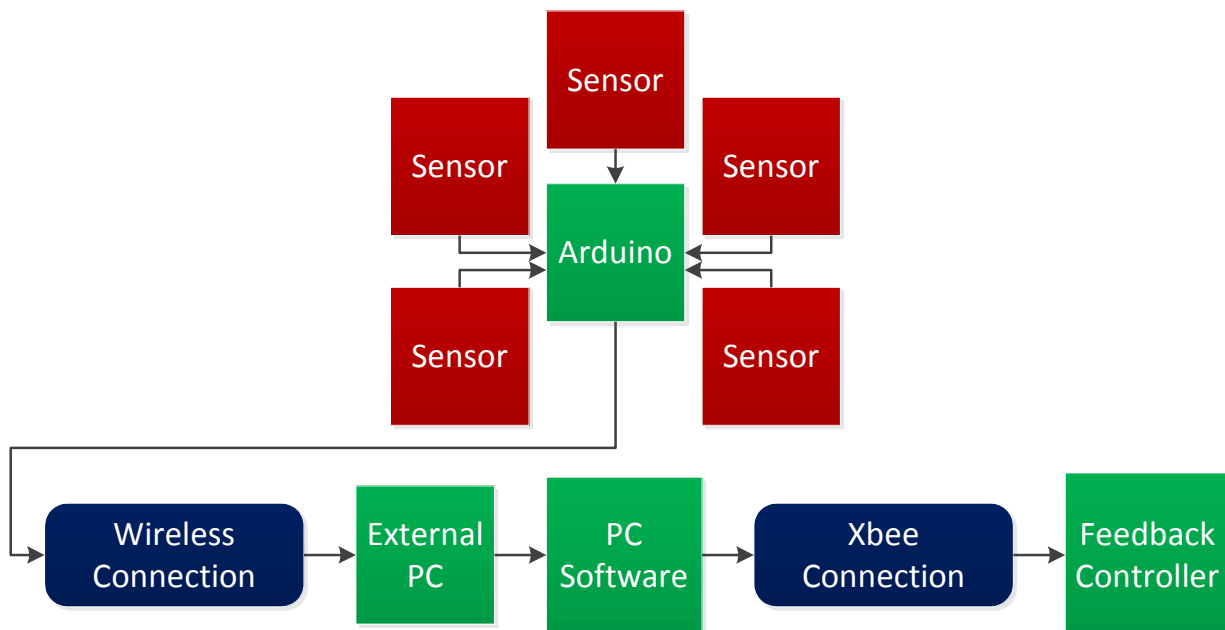


Figure 6: Block Diagram of Proposed Solution System

Testing Plan

The testing process for the team's design product consists of four main sections, which includes evaluating the data communication, software testing, the functions of the IMUs, and Arduino microcontroller.

Sensors

First phase of the test plan is to verify the consistent capturing of data from each individual IMU. Also, since the baseline model (the elite runner) will be captured by the IMUs as well, it is essential that it is consistent. The team plans to have different team members to have the IMUs, before they are sewn onto the bodysuit, to put on their bodies and repeat the same movement. By repeating the same movement on a software called Autodesk Motion Builder, the team will be able to have a visual and numerical confirmation of if the IMU is measuring movement correctly. Motion Builder is an optical system of motion capture, which will analyze motion by a camera, and generate a numerical value for each marked point of the body. This will give a 3D image of the user moving. In addition, each IMU's ability of continuously sensing and transferring the data to Arduino microcontroller also needs to be evaluated. This can be done by looking at the Arduino software to see any inconsistencies in the data.

Arduino Microcontroller

In this part of the team's testing plan, the proper time stamping function needs to be ensured. To be more specific, the team will first examine if the Arduino microcontroller is correctly recognizing the timing information of the original data from IMUs, then properly synchronizing them to a common clock signal. Furthermore, while the data is continuously being collected on the Arduino microcontroller, the integrity of the original data should remain unchanged after data is time stamped.

Communication / Interfacing /Feedback

The data transfer path for the team's design is from the IMUs to the Arduino microcontroller via wired connection, and then from the Arduino microcontroller to an external PC. The data is then fed back to a body-worn indicator on the user wirelessly. Among these three data communication paths, the wireless data transferring between Arduino microcontroller and a PC is critically important since it provides the data base for later running form comparison analysis. It will be necessary to focus on testing the communication to ensure a clean and effectively communication path. In addition, one of the main features of this design is to provide users a real time feedback on their running status, thus, the feedback path will be also evaluated to ensure on-time delivery of the feedback signal to user's body-worn indicator.

Software Testing

Two software testing processes will be necessary; the Arduino and the comparison software. The Arduino software will have to generate an organized form which will be able to be compared. The Arduino software will be tested to verify if the software is firstly capturing the timing information of the data, the position information of the data (includes acceleration and angle) as well as whether these data has been correctly aligned to the matrices after processing. The comparison software will be tested by numerous trials to see if it is consistent. By purposely having bad form, the comparison software should distinguish a proper from an improper form. Thresholds will be based on an elite runner's data. After evaluating different parts of the design separately, the team will move on to test if all the components work as what they do separately when connected together and if they perform the desired functionality on a continuous and consistent basis.

Risk Analysis

IMU Sensors

The design will be implemented on a moving subject, which can cause problems with the functionality and accuracy of the sensors if they move from their original position. The placement and security of the sensors is important to ensure that data will not be lost. The sensors will have to be properly fastened to the body suit as well to provide consistent measurements. If inaccurate data is measured, the form will not be processed correctly.

Bodysuit

The suit needs to be fabricated with functionality in mind, meaning the design should not hinder the runner in any way. In order to ensure this aspect, the suit will need to be comfortable, yet tight enough to get accurate measurements of the users' form. The wiring within the bodysuit should not conflict with the running motion of the subject. Any hindering of the runner will give inaccurate data which the team will have to take in great consideration.

Wireless Communication

As with any wireless communication, there is always a chance of data loss through time-outs and dropped connections. The design will also require that the bandwidth of the wireless transmission and reception surpass the amount of data being transferred. The connection of the wireless communication must also be stable during the test to ensure the continuity of data. Depending on the environment, noise can also occur, which may interrupt the wireless communication.

Another issue related with wireless communication besides data accuracy is the communication range. The wireless transfer capability of Arduino is limited, and the use of designed product is limited inside on a treadmill.

Feedback

The feedback must be in real-time, as well as interpretable to allow immediate changes in form based on the provided feedback. Delayed feedback will be a major concern. To keep the delay at a minimum, different feedback options must be considered. Inconsistent feedback might occur as well, so further testing will be needed. Furthermore, the feedback read from the LEDs should be intuitive and easy to understand. While shortening the delay of the feedback, the message should also be correct to avoid the confusion. Any potential errors in the feedback system programming must be eliminated.

Power Consumption

The design is expected to be running at low power consumption so that the user does not need to charge the device frequently. The major parts that consume power will be the IMUs, the Arduino and the feedback system. The Arduino will be powering all the IMUs, therefore enough battery power will be needed for a full length of exercise. Also the battery on the Arduino board should be either rechargeable or easily replaceable. The LED indicators will be powered separately, but will still need sufficient battery power to maintain an accurate illumination. In order to provide both comfortable use and experience, the design faces a tradeoff between battery size and the comfort.

Project Management Plan

Proposed Schedule/Gantt Chart:

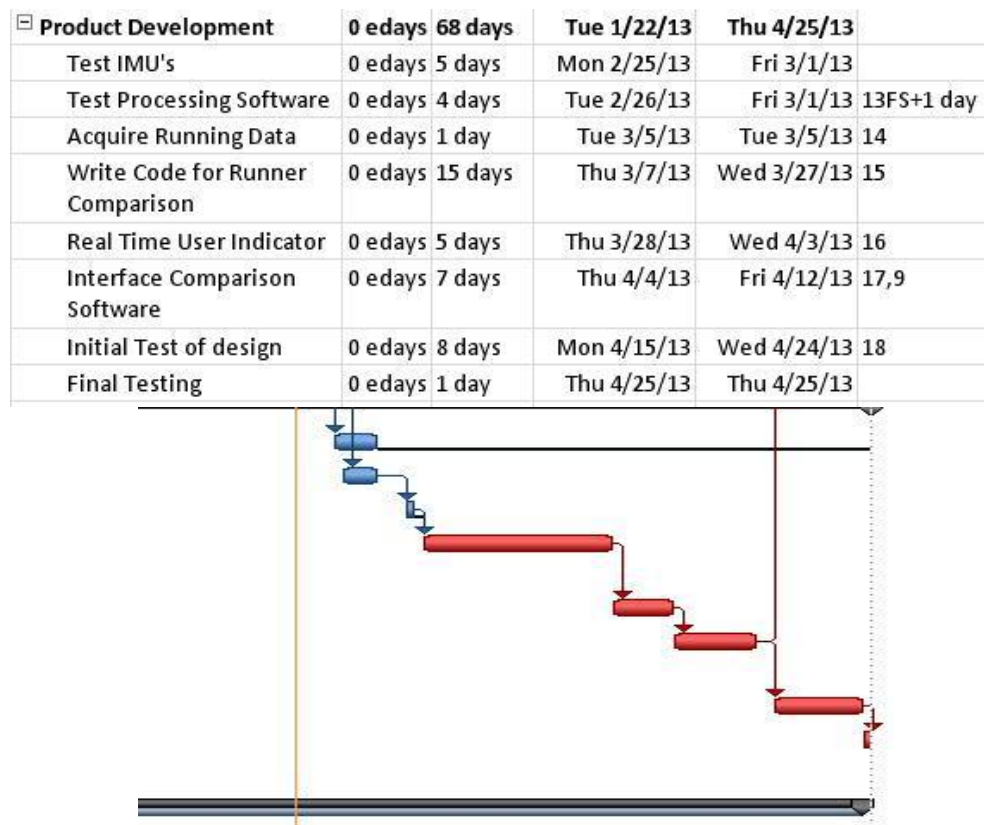


Figure 7: Proposed Schedule and Gantt chart

The team's project is broken into four main phases. Phase 1 is our fabrication phase. In the phase the team will research parts and components the project and come up with a feasible design. The ordering of all components, wires and sensors will be completed in the phase. The team will also complete initial fabrication of the bodysuit.

Phase 2 of the project is the software phase. Within this phase the team will be writing all of the necessary software for the microcontroller to communicate correctly with the sensors and the nearby computer. The comparison software (comparing an elite runner's form to that of the testing subject) will also be completed.

Phase 3 of the project is the interfacing phase. This is the most critical phase of the project. The team will interface all of the components of the system. This includes the sensors to the Arduino microcontroller, microcontroller to the computer, computer to the real time feedback indicator and both the comparison and 3D modeling software. The team expects most of the time spent will be in this phase.

The final phase of the project is the testing phase. The team will complete testing on all aspects of the project. The team will test every element of the project individually and once all of these tests are complete a final testing period will be held.

Team Roles

Blake Frantz - Presentation Preparation, Suit Fabrication and Demonstration Expert

Blake will be working as presentation preparation throughout the duration of the class. He will make sure that all presentations are formatted correctly and that all requirements of the presentations are met. He will also be in charge of the fabrication of the motion capture suit, making sure that all of the components of the suit are placed in a comfortable manner. The 3D modeling software that will be used for demonstration purposes will also be done by Blake.

Zhichao Lu - Documentation Preparation, Testing and Data Analysis

Zhichao will be working as documentation preparation throughout the duration of the course. He will confirm that all documents meet all of the specifications and that they are completed in a timely manner. He will also be in charge of testing and data analysis for the motion capture system. Zhichao will confirm that all of the data that is sent and received by the microcontroller is correct and that all testing is accurately completed.

Alex Mazzoni - Webmaster and Comparison Software Developer

Alex will be the webmaster for our capstone senior project. He will be running the team's webpage, uploading the team's documents as they are completed and the status of the project. Alex will also be in charge of developing the comparison software, making sure that the data collected from the elite runner is compared to that of person using the system.

Nori Wilkins - Manager, Comparison Data Collection and Arduino Software

Nori will be acting as the manager throughout the duration of the class. She will make sure that the project is on schedule and running as planned. She will also be in charge of scheduling meetings and coordinating the completion of all project tasks. Nori will also be collecting the data of the elite runner (to be used by the comparison software) and adapting the Arduino software to fit our project.

Chenli Yuan - Presentation Preparation and Wireless Communication

Chenli will be working as presentation preparation throughout the duration of the course. He will make sure that all presentations are formatted correctly and that all requirements of the presentations are met. Chenli will be in charge of the wireless communication technology of our project. He will make sure that all of the data is accurately sent between the computer and the Arduino microcontroller.

Dan Zilinskas - Lab Coordinator and Interfacing Technician

Dan will be working as the lab coordinator throughout the duration of the class. He will make sure that all components are ordered on time and will monitor the team's use of the design laboratory. Dan will be in charge of the interfacing portion of the project. He will make sure that all the components of the project are correctly interfacing with one another and that the software and hardware are communicating without any issues.

Projected Budget

Item	Price	Amount	Totals
IMU MPU-9150	\$49.99	5	\$249.95
Arduino Due	\$49.95	1	\$49.95
Arduino UNO R3	\$29.95	1	\$29.95
Arduino Wireless Shield	\$84.00	1	\$84.00
4 Xbee Communication Devices (ZB Series 2)	\$22.95	4	\$91.80
Miscellaneous Costs	\$380.00	1	\$380.00
Totals			\$885.65

Figure 8: Projected Budget List

The overall budget for the team's design is a bit higher than expected, or desired, but many of the costs were deemed necessary to provide multiple selections when designing the product. The most expensive parts of the project come from the IMU sensors, since multiple sensors were ordered, as well as the wireless devices necessary to transfer data from the Arduino to the PC. Miscellaneous costs include the parts required to fabricate the suit, as well as any additional costs deemed necessary to complete the design.

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