

**A WIRELESS SENSOR SYSTEM FOR THE TRAINING OF HAMMER
THROWERS**

YE WANG

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YE WANG

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Dr. Hua Li (Co) Supervisor	Associate Professor	Ph.D.
Dr. Gongbing Shan (Co) Supervisor	Professor	Ph.D.
Dr. Robert Benkoczi Thesis Examination Committee Member	Assistant Professor	Ph.D.
Dr. Wenlong Yuan Thesis Examination Committee Member	Associate Professor	Ph.D.
Dr. Howard Cheng Chair, Thesis Examination Committee	Associate Professor	Ph.D.

Dedication

For my parents and all my teachers

I have been learning from you since I was born.

I am so grateful to have you as my parents and teachers.

Thesis Abstract

Hammer-throw has a long-standing history in track and field, but unlike other sports events, hammer-throw has not seen a new world record since 1986. One reason for this stagnation is the lack of scientifically based training.

In my thesis, we propose to establish scientifically described training targets and routes, which in turn require tools that can measure and quantify characteristics of effective hammer-throw. Towards this goal, we have developed a real-time biomechanical feedback device – a wireless sensor system – to help the training of hammer-throw. The system includes two sensors – an infrared proximity sensor for tracing the hip vertical movement and a load cell for recording the wire tension during a hammer-throw. The system uses XBees for data transmission and an Arduino processor for the wireless system control. It is hypothesized that wire tension and vertical hip displacement measurements would be sufficient to supply key features when analyzing hammer-throw.

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CHAPTER 1

1 Overview

1.1 Introduction

Wireless Sensor Network (WSN) is a very popular technology today. There are many people doing researches in this field. Piyare and Lee analyzed the performance of ZigBee wireless network by XBee ZB [1]. They evaluated the received signal strength indication (RSSI), throughput, packet transfer delay, recovery time of mesh networking and indoor energy consumption [1]. They also introduced the X-CTU software which can be used for configuring and testing the XBees. Keshtgari and Deljoo described a WSN system used for precision agriculture applications, which consists of a set of sensor nodes and a base station [2]. Their system can gather climatologic data and other environmental features in real time [2]. Ferrari, Medagliani, Di Piazza and Martalo introduced an evaluation of WSN's performance in indoor scenarios [3]. They used ZigBee as communication methods among the networks, and compared two kinds of network scenarios: direct transmissions and routers [3]. They showed the behaviors of the RSSI in both scenarios [3]. Dalila Pinedo-Frausto and Antonio Garcia-Macias performed experiments to analyze the results of the experiments, and they proved where ZigBee modules can be used and where ZigBee is not very applicable [4]. They used ZigBee software and hardware that are available in commerce to conclude whether ZigBee can meet the requirements of the various markets indeed [4]. A GPS-enabled WSN system for monitoring radioactive materials was developed by Ding et al [5]. They introduced this wireless system from both hardware and software aspects. The position of the sensor

nodes can be detected and marked on the map by taking advantages of the GPS technology [5].

WSN has been developed and used widely in diverse areas. In the area of sports, kinesiology scientists can also make use of WSN to do the research and analysis. For instance, Heart Rate Monitors (HRMs) can be used for helping training in various sports areas [6]. Wireless sensor networks can benefit HRMs, which may allow athletes to monitor themselves remotely and wirelessly [6]. They also discussed the advantages of wireless communication in [7] by introducing the centralized heart rate monitoring telemetry system. By understanding many other current applications and research works, we can see that WSN is very helpful in a large variety of fields. Our research purpose is to help coaches acquire the necessary data from the movements of the hammer-throw athletes so that they can make appropriate training methods for the athletes to improve their skills in the future.

Wireless sensors make things easier and more convenient than wired sensors to detect athletes' movements and collect data. WSN consists of various nodes which can communicate with each other. In our research, we have developed a WSN system, which includes a sensor node and a receiver node. The sensor node contains a device with any sensors that we need for capturing our desired data. The receiver node contains an end-user device to receive the data that the sensor node can detect and collect. We used Arduino Mega to control the sensors as a microcontroller, and use XBee RF modules to transfer data between the sensor node and the receiver node. During our field experiments, we tied our sensor node device on the waist of an athlete. When we start the device, it can

monitor his/her hammer-throw movements and collect the required data in real time. At the same time, the collected data can be sent to a laptop, which is used as our end-user device currently, for any further processing.

For the software development of our WSN system, we used MATLAB to make our main graphic user interface to produce a smooth curve graph while receiving the real-time data. We realized the communication between two XBee modules by using MATLAB and Arduino sketch. Consequently, by combining the software development and the hardware programming on a wireless sensor device, we initially accomplished our research goal. In next stage, we will try to minimize the size of our wireless sensor device to provide a more portable device for the athletes, and will try to develop a graphic user interface on a more portable end-user device, such as iPhone or iPad, to make it easier and more convenient for the coaches to use this system. Also, we will try to improve the accuracy of the desire data in terms of the hardware aspect, such as changing the sensors.

CHAPTER 2

2 Literature Review

2.1 About Arduino and XBee

A large number of other applications of using WSN with Arduino and XBee have been developed. In [8], the authors introduced data fusion which can decrease power consumption by testing a device that is based on Arduino and Xbees. As they discussed, a typical Arduino-XBee device can be treated as the microcontroller-RF module [8]. Eight bits can stand for both Arduino serial input/output command and XBee frames [8]. Their testing device, which consists of an Arduino Uno board, an XBee and two sensors, is considered as the sensor node. The two kinds of sensors are an integrated sensor for humidity and temperature and a distance sensor [8]. They are used for generating data and their data types are formatted as double with 1 precision point [8]. They performed some experiments and analyzed the experimental data to conclude that the data fusion method is beneficial for reducing data size [8].

Another research study involved with multi-sensors data fusion based on Arduino and XBees is provided in [9]. The authors analyzed a number of experiments by using an Arduino-XBee system to monitor the environment [9]. This system has a Visual C # program to be considered as the interface, which is able to catch the monitored data and store it into the database [9]. When the sensors get the data value over the specified threshold, a warning will appear on the interface and control signals will be sent wirelessly to a control device to make the switch so that the environment can be improved automatically and effectively [9]. They implemented the wireless control by

using XBees as the transmission method, which is their proposed first stage. Their future plan is to realize receiving information by smart phones or tablets and then uploading the collected data to the cloud database [9]. But currently, they use an XBee connecting to a computer as the receiver node. On the sensor node side, they have four different nodes to monitor different attributes (moisture, humidity and temperature, air quality and light) [9]. They use an Arduino board (ATmega328P) as the microcontroller [9]. Arduino hardware uses Wiring-based language to program, which is similar with C++ [9].

WSN is a popular and interesting topic in medical area as well. A type of remote health monitoring system has been introduced in [10]. Remote health monitoring system is very helpful in hospitals because it can reduce traffics, save waiting time, and the bill can be cheaper in the hospital [10]. In [10], the authors provided us a project of designing and developing a body temperature measurement device which can allow doctors to observe either in real time or by reading history data online with a warning of abnormal status. They use XBee as the wireless communication method. So, the temperature sensors will read the temperature and send data through XBee to a microcontroller – an Arduino Uno board [10]. The Arduino board is used with an Ethernet shield because they also use the wireless local area network (WLAN) in order to make sure of sending real-time data to the health monitoring database [10]. In their monitor system, there are three basic elements. The patient monitoring unit includes any devices that can measure patients' temperature [10]. A database system is used for storing data. The other unit is diagnostic analysis, which allows doctors to be able to read the information stored in the database through Internet so that they can analyze the data and diagnose patients

remotely [10]. They made a program for Arduino to enable the communication between the Ethernet shield and the database application [10].

Kioumars and Tang introduced a heart rate and temperature sensor system, which is also a WSN application for health monitoring system [11]. Basically, they have the sensor node including Arduino microcontroller, XBee and two types of sensors, and the receiving computer for storing and displaying the data [11]. In the sensor node, they use Arduino Uno board with an XBee shield for connecting the XBee module to the Arduino board. There are a temperature sensor and a heart rate sensor. The sensor node is supposed to be worn on the wrist [11]. On the receiver side, the computer is connected with another XBee module to make the wireless communication available, and the computer is used to monitor and process the data [11]. The temperature sensors are connected to an analog/digital convertor (ADC) to ensure that the temperature values can be read from the sensor [11]. However, they still need to calibrate the temperature sensor values so that the unit of the data value can be read in Celsius instead of voltages [11]. Thus, they could analyze and process the skin temperature measured by the temperature sensor to get the estimation of the internal body temperature [11]. For the heart rate sensor, they showed us how to set it up and then came up with an easier approach to get a digital output by using LM358 as a comparator [11]. Eventually, the temperature and heart rate values can be displayed on an ElectroLite 16*2 character liquid crystal display (LCD) [11]. They tested the sensor system with 50 volunteers to obtain the experimental data. They concluded many advantages of their system as well as some errors that may occur when using the sensor [11].

In the agricultural field, Rani and Kamalesh described an automatic irrigation system which involves in the wireless sensors and Arduino-XBee microcontroller in their paper [12]. This system has a web based service to monitor the soil moisture [12]. Once the specified moisture threshold is reached, the system will provide enough water from the pipes automatically [12]. They use a water flow sensor to detect the water pressure to let them know whether the water flow is appropriate or not [12]. If not, they can make proper changes to the water flow controller, which will either prevent damages or avoid the lack of water [12]. The information will be updated in real time, which allows users to check and control the moisture level at any time [12]. They use two XBee modules as the wireless communication method, and use a GSM mobile device to control the water flow [12]. Their irrigation system makes good use of WSN with Arduino and XBee to realize automatic irrigation system which can be controlled remotely [12]. It is very convenient for the farmers. Wireless sensor technology plays a critical role in the agricultural field to help farmers manage soil moisture better so that they can obtain higher-quality crops [12].

2.2 About Hammer Throw

Hammer throw is one of the oldest games, and it is originated back to 15th century. It was first included in the Olympics games in 1990 games in Paris [13]. The game has evolved since then, and the new version is enjoyed worldwide. However, unlike other games played, hammer throw is still left behind as not much is being done to improve the game. For example, in some games like soccer, the modern technology and scientific work have been applied, and the game eventually became more sophisticated to attract more people. On the other hand, the same thing is not happening in the hammer throw.

Science and scientific methods are being applied virtually in every field, which include in the hammer throw as a track event [14]. The following paper work will try to evaluate the studies and research done and those underway in the effort to improve hammer throw and players' performance while engaging in throwing in track and field.

Hammer throwing usually involves complex actions performed by the players. There are three main parameters that are used to determine the distance the thrower is likely to throw the hammer. These parameters are; velocity of release, the height of the hammer at the time of release and the angle between the horizontal plane the thrower is standing on and the velocity vector. On average, the velocity of release should become maximum during the angle of the plane and velocity vector of forty three and forty five degrees on average [15]. The angle, however, will largely be determined by the height of the thrower much than other underlying factor of the track. Additionally, it is better for the person analyzing the parameters to consider the position and velocity curves in time function for better understanding of the throw.

According to [16] analyzing the kinematics of throws of athletes, it includes the analysis of the center of mass and most importantly the hammer throw system. The information is very important especially in training sessions as the distance that the thrower can manage can be regulated by these factors. In the effort to prove kinematic analysis of hammer throwers, Gutierrez-Davila and Rojas-Ruiz [17] presented a 3D kinematic analysis system of the best thrower in Seville World Championship. However, the analysis was found challenging because of the methods put in place to measure specific variables in the competitions. It was expected that the 3D system would provide

a measure which should be accurate and with automatic or semi-automatic tracking of the hammer with high resolution cameras.

An analysis of the kinematics in hammer throwing was conducted during the Brazilian official competitions in 2006 [18]. In the analysis, six throwers, including three male throwers and three female throwers, were the center of the analysis. In the kinematic analysis, the Dvideos and digital video cameras with high resolution were planted strategically approximately 70 meters away from throwing area. Due to the calibration of the cameras, 30 control areas were used, and their coordinates were measured by topographical equipment with high accuracy level. Tracking of the hammer head was done automatically. A low-pass second order Butterworth was used to smooth the coordinates of the hammer head, with a cutoff frequency of 6 Hz. Numerical derivations was used to obtain the velocity curves. Additionally, the velocity vector and the hammer head were calculated at the release [19].

According to the study by Dapena [20], the distances that were reached by the Brazilian throwers were much lower than those of the world class throwers' analysis in Seville. The parameter that was associated with this disparity was the velocity involved in both competitions. The Brazilian averages were 24.59m/s for male throwers and 23.59m/s for female throwers while at the Seville International competitions were 29.60m/s for male athletes and 28.89m/s for female athletes. However, all throwers in both competitions had a release angel lower than the predicted optimal angle [20]. It is clear that the release velocity is reached through the increment of each turn's velocity. Each turn made by the thrower presents a double support of the athletes' feet, and that

allows for acceleration of the hammer. When the support is simple, the acceleration of the hammer gradually starts to decline. It is the reason for shorter throws from the Brazilian athletes as there was a deflection of the velocity curve.

Both Seville and Brazilian studies presented a methodology that allowed trainers and athletes to quantify release variables of throws and velocity curves while considering time function. In the two studies, the Brazilian throwers had difficulties in maximizing their throw distance since establishing high release velocity was a problem [17]. Comparing the two studies, coaches and athletes should strive to maintain high release velocity while still maintaining the double support of the feet. It will greatly help in optimization of the throw in any competition.

Pascolo [13] discusses that the hammer speed is another research work that has been directed to improve the mode of hammer throwing as a track event. The speed at release contributes greatly to the distance the hammer head is to land with the basic objective of the athletes and the coaches during training sessions. Hammer speed comes as a result of increasing trend when an athlete is making a throw, with a single turn per fluctuation. It is crucial to analyze the impacts of gravity on speed fluctuations. In a study to investigate the impact of gravity on the speed of the hammer, several experienced athletes were studied with three-dimensional video recording methods [14]. Simultaneously, the data of the head velocity and speeds were evaluated from the data collected. Finally, the rates of change in speeds of the hammer due to gravity were computed and used to calculate the accumulated impact of gravity to hammer speeds at instantaneous throws [15]. The values were then subtracted from the initial values of the

hammer head speeds. It was observed that the fluctuations declined in the corrected speed functions. The conclusion to this was that gravity had a great contribution towards the original fluctuations of the hammer head speeds. Additionally, the disparities were also present in the previous speed functions that indicated involvement of other casual factors.

Based on the prior knowledge of kinematics and gravity, the coached should evaluate the athletes in a detailed manner of the level of performance. This would help in planning the future training sessions and better preparations of competitions [21]. The interpretation of data from the perspective of biomechanics research stresses the importance of integration of disciplinary in training science and biomechanics. Knowledge and ideas about the basics of hammer throwing techniques is critical for the development of coaches and athletes as well. It is the knowledge that will transform a regular hammer thrower to an international athlete performing global platforms. The unity of physical capacities and skills of the athlete underlies the technique training and strength. Therefore, biomechanical research accompanied by the training process can be used to improve efficiency in training by incorporating exercises in the analysis [19].

According to [17], the distance that a hammer head can go on an instant release can be determined by the mere interaction of velocity and the radius of the hammer is moving. Basically, the combination of the two factors generates the linear velocity of the head. In studying this interaction, a hammer thrower has to correctly know the right combination between the velocity and the radius of the hammer. In most cases where athletes perform poorly, the relationship between the velocity and the radius the hammer moves is not considered as it is supposed. This leads to a negative impact of the hammer

radius to the angular velocity. Hence, considering other factors are not affected, short distance throws can be made by the athletes. The relationship between the two factors should be well known by the coaches and the hammer throwers, and the emphasis of this point should be made clearly during the training sessions [17].

Performance in hammer throwing is also influenced by the single and double-support phases of making a throw. In professional hammer throw competitions, long durations of the double-support phases indicate an effective throw. According to Dapena [20], the relationship between the double and single-support athlete's leg ground contact can be used as a criterion evaluating performance of athletes. During the single-support phase, it is critical that no movement of the upper body of the athlete should occur. The body of the thrower should rotate in the same velocity. The right foot should be moved up and over the left heel as quickly as possible. The double-support phase is where now the thrower gains stability as both feet should be on the ground ready to release. Both of the single and the double phases give the athletes the stamina to be able to make the throw in an angular velocity.

Energy and power transfer between the implement and the athlete is critical for training performance diagnosis [13]. Effective throwing of the hammer involves the acceleration of the hammer head and decreasing the force of inertia of the hammer thrower. When the athlete has a perfect throwing patterns, increase in linear momentum increases the velocity outcome [21]. Therefore, being familiar with the average time for power transfer gives further conclusions about the involved energy and the quality of the throw. Applying the kinematic knowledge, changes in hammer velocity and the legwork

duration can help obtain insights on power production and energy transfer. In hammer throwing, leg power is one of those essential aspects. It is shown that for a ten percentage of an improvement in distance, the power must be increased by at least twenty percentages. As the athlete makes each turn, there must be an accelerating transfer of kinetic energy from the thrower to the hammer within short intervals. Therefore, the power demand in each turn becomes greater increasingly [15]. It is assumed that the thrower's effectiveness is limited by the available power in the final two turns. Therefore, as the athletes' performance increase, they must learn to apply large amount of kinetic energy on the hammer in reduced intervals, which implies that they should make faster and faster turns as they are closed to the release [21].

In recent studies [16], it has been found that advanced athletes who can make throws by using heavy implements can be effective in increasing leg and trunk power. Increased hammer weight, shortening the wire and organized movement patterns influence in a great way of the biomechanical component of the coaching effect. On the other hand, throws with light hammers are essential in facilitating the speed patterns of the athlete. Further, there is the demand by athletes for lower power level as compared with the standard competition hammer. As a result, there is reduced efficiency in throws. For example, for an advanced male thrower, throwing with an eight-kilogram-hammer is more effective in enhancing the power capacity in event-specific requirements [18]. In the contrary, throwing with shorter and heavier hammers leads to increased straining and declining power to move the hammer faster. Generally, throws with implements of various masses and lengths are proved to have the same effects on male and female athletes. It is worth noting that individual movement patterns of making a throw using

hammers of different height and mass do not cause the variations required for the enhancement of the competition throws. The changes occur after evaluating the movement of throws with different hammers [21].

Accelerometers are used in studying various human movements. The most typical application of accelerometers for human activities and sports is the energy estimation of multiple applications [22]. In this point, a portable accelerometer was developed, which could be used to test energy in the sports like hammer throwing. Since accelerometers can also be used to measure the movement of rigid body parts, it was also introduced to study the dynamics of human body parts in hammer throwing. A method was developed to calculate the resultant force and body movement from the accelerometer data. Basically, the signals that were captured by the accelerometer included those of gravitation, linear and angular acceleration as well as the centrifugal force. However, to develop acceleration in a three dimension system, a minimum of nine accelerometers were required. The accelerometers enable the setting of a kinetic data required for inverse dynamic analysis [20]. The system allows time calculation of the inverse as well as the forward dynamics.

In the study [17], hammer throwing is used to test the effectiveness of the system. Integrated training sensors, wireless transmitters, signal processing, data logger and biofeedback systems in the training are used. The importance was to come up with strategies of determining circular movement and biofeedback of hammer throwers during their training sessions. In this case, micro-electromechanical systems accelerometers were used as the sensor platform. With the system in place, the throwers were able to be

registered in the system and the movement of the body muscles, the energy transfer from the throwers to the implements, and the power generated at each turn where the athlete made were clear and ready for the evaluation [18].

For the purpose of minimizing cable constraints and time monitoring, a wireless data logger was invented [14]. The wireless logger was used to transfer data from accelerometers with a frequency of about 400Hz and with the use of 12-bit analog to digital converter. The system consisted of analog microcontroller devices, a wireless system, a flash memory of about 256 MBs and a reserve battery. In addition, the sensor system connected to the logger through several connectors that was placed near the handle of the hammer. The connectors worked in a way that when the hammer thrower releases the hammer, the connectors will disconnect, and no signal could be transmitted further. However, the transmitted information of increasing acceleration was obtained as biofeedback data over a speaker to frequency conversion on the PC [22]. It is this signal that the thrower used as a virtual sensor that detected essential skill for throwing the hammer [16].

In addition to Newtonian gravitational force, two other forces that affect human activities are the centrifugal force and the Coriolis force [18]. These forces also affect sporting activities especially throwing track and field events. By analyzing the influence of air resistance, air pressure, temperature and altitude and ground obliquity carefully, the conclusion could be that different latitudes with different release directions by hammer throwers can be influenced by the effect of the Earth rotation. The normal variation of the environmental factors can be larger than the smallest increase in the world records. This

could suggest that at some point of earth rotations, performance can be enhanced. Therefore, it would be advantageous to throwers who perfect their throwing skills in different environmental set-up in order to prevent bad performances in some particular environmental conditions.

In addition, during the initial stage of throwing, the preliminary winds that the athletes create the throwing circle and the single-foot support phases during the full turns are very critical for the final result of the throw [19]. However, this contradicts the old belief by many coaches that these parts of the initial throw do not contribute much at the final result.

As discussed above, it is clear that the intervention of scientific researches and applications of modern technology will help improve the hammer throw. When coaches and athletes can make use of scientific tools, such as the sensor systems in their training sessions, it will enhance and help improve the performance of the athletes.

Therefore, another great contribution, which is involved with the sensor system, in hammer throwing was made by Sakr [23]. In his perspective, the game was fascinating and thrilling but was also complicated in the track events. He also suggested that the athletes' performance can be improved by analyzing the motion deeply from the perspective of biomechanics. There are two important parts involved in Marwa Sakr's study. Since the kinetic energy can be transferred through the human body step by step, the first part of the study is to quantify the kinetic energy of the body segments of the athletes. The second one is about measuring the accelerations, the angular velocities and the strain force in the wire by developing a Measurement Information System to help the

training of the athletes. Our research goal is based on this point. We try to develop and provide a system to the coaches and the athletes for helping them in the training session.

The system that Sakr developed had five digital cameras that were used to capture the thrower's motion, and uses Simi Anthro Model version 1.2 to calculate the athlete body segment masses and the location of the thrower's center of gravity [23]. The system also uses Simi 3D Motion Program version 7.5.300, which is similar to those that were used in Brazilian and Seville competitions, to analyze the motion. However, there were some problems and errors during the recording of motion, such as record location problems, calibration errors, and human errors (incorrect digitization) [23]. Due to these issues, Sakr introduced the concept of Microelectromechanical systems (MEMS) technology which could overcome most of the primary problems in the system [23]. However, when using MEMS technology, there are wires which are uncomfortable for the athletes. Additionally, through our pilot study, we found that wire tension and vertical hip displacement measurements alone may be sufficient to substitute 3D motion capture when analyzing hammer throw. Thus we used the wireless sensor technology to develop an analyzer that can 1) measure real-time wire tension and vertical hip displacement, 2) establish how to reach desirable tension and displacement, and ultimately 3) provide biomechanically-guided training plans customized to each athlete's anthropometrical data. This WSN system aims to be both a research tool and a user-friendly training tool for coaches and athletes.

CHAPTER 3

3 Methodology and System Configuration

3.1 System Architecture

The basic idea in our research is to establish a system of wireless sensor network to receive two kinds of data: the distance from the athlete's waist to the ground and the tension during the process of the hammer-throw movement. In this system, we use a sensor node to collect data and send the data to a receiver node via wireless communication.

Figure 1 shows the architecture of our WSN system. We can tie our system device to the athlete's waist. This device is the sensor node which is used for collecting data and sending data to the receiver node. We have a laptop for receiving and processing the data that is transferred from the sensor node. A critical part is the communication between these two nodes. We use one XBee for each of the nodes as a wireless transfer method. We used XCTU to configure the XBees in advance to make sure that they only recognize and communicate with each other. XCTU [24] is a free software application which is used to configure and test XBee RF modules through an easy graphical interface. We changed the baud rate, which indicates how fast the data can be sent or received in a serial line, from the default value (9600) to 57600 in order to get a faster transmission speed. Figure 2 shows the interface of XCTU. Under the option of modem configuration, once we read modem parameters and firmware, we can change the current settings of an XBee module. In Figure 3 we can see that the "BD – Interface Data Rate", which indicates the baud rate, in the menu of "serial interfacing", can be changed. The range

that we can change is from 1200 to 115200 and there are eight levels (0 to 7). Every next level is twice as fast as the previous level. After setting the baud rate, we checked the other properties to make sure all the properties of our two XBees match with each other exactly. We used the “Write” button under the menu of “Modem Parameters and Firmware” to save any changes of our XBees.

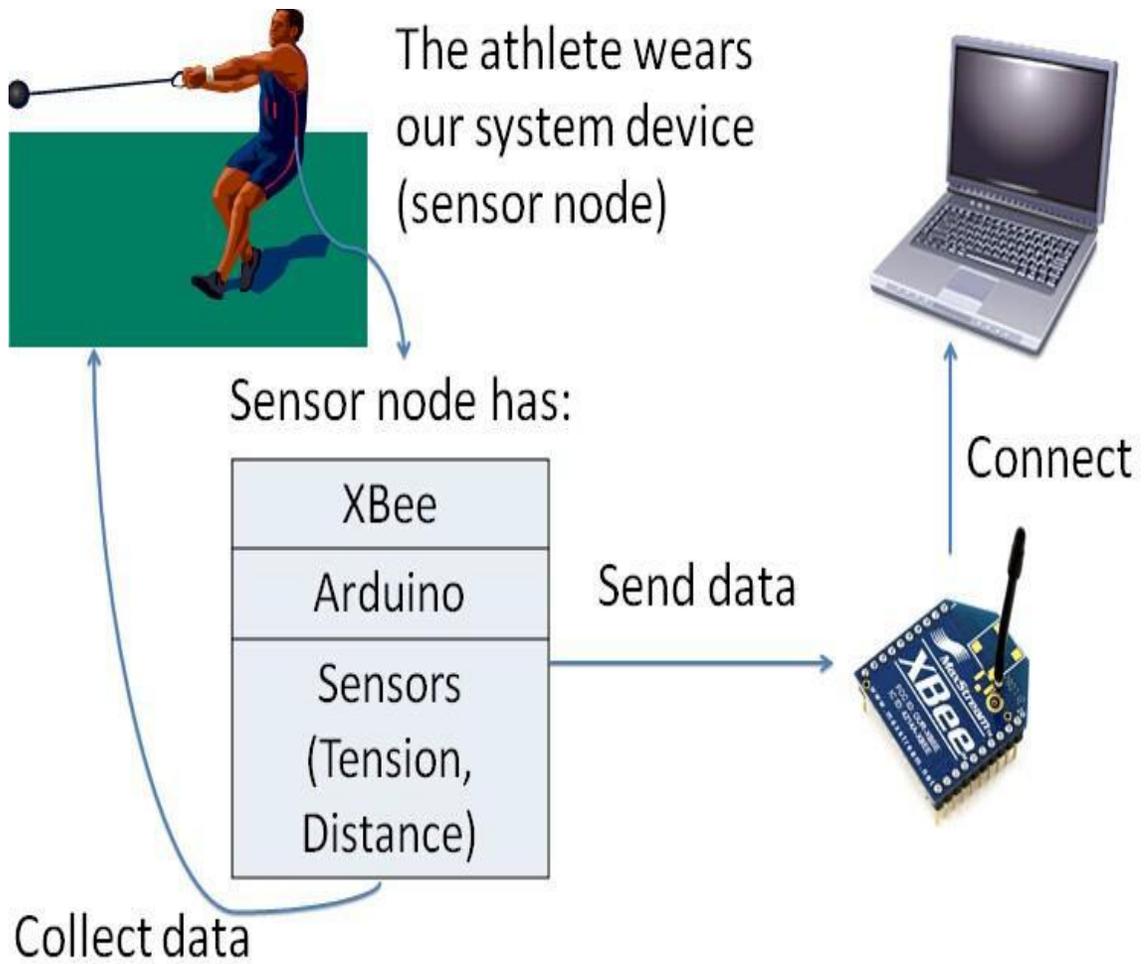


Figure 1: The architecture of our system

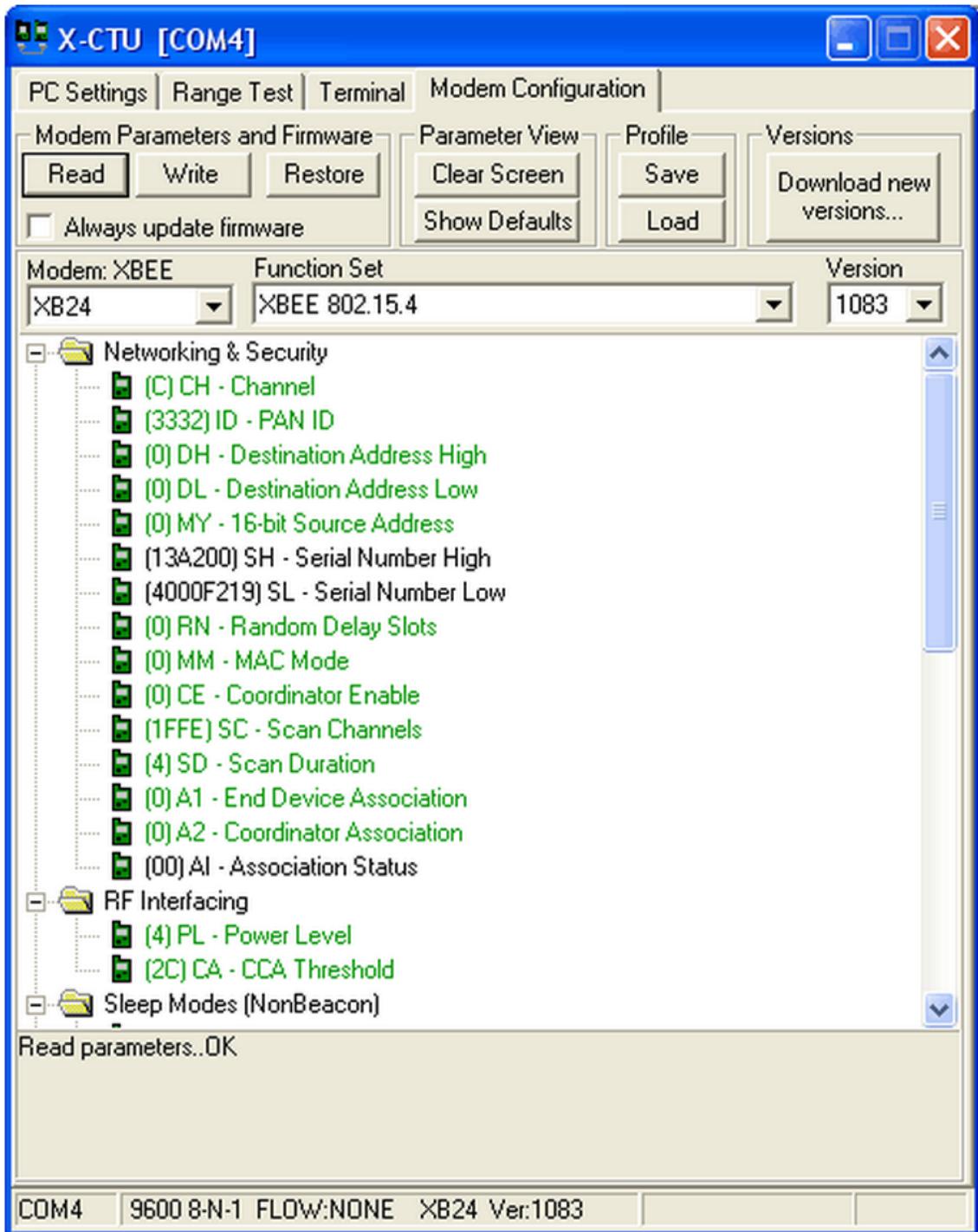


Figure 2: XCTU configuration of XBee

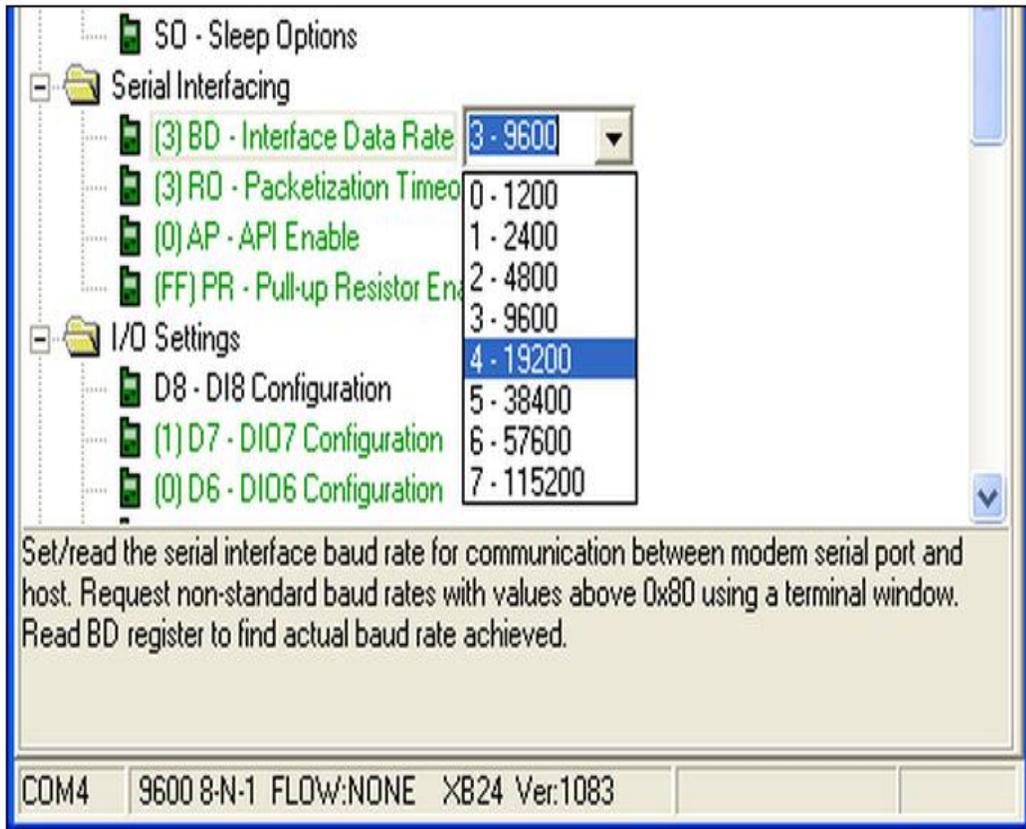


Figure 3: Baud rate change in XCTU

3.2 Sensor Node

We implemented the hardware of the sensor node which is shown in Figure 4. The Arduino Mega (ATmega1280) board can be regarded as a micro CPU. There is an XBee module installed on the Arduino board. It connects with two sensors. The distance sensor occupies the analog input pin 8 on the Arduino board, and the tension sensor occupies the analog input pin 9. The distance sensor shares power together with the Arduino microcontroller. We used two additional 9 volt batteries to supply power for the tension sensor. In addition, we set a ten voltages regulator to provide the operating voltages for the load cell (tension sensor). It must be very precise for the load cell to provide the proper transfer function, so that the output of the load cell is within its calibrated limits according to its calibration sheet. We installed a special electronic component (amplifier) which can bring the up signals from the load cell to generate the exact ten voltages as it requires. It allows us to avoid collecting the wrong data values if the batteries become old, which cannot supply the load cell with the correct operating voltages. We also installed an external SRAM (static random access memory) component onto the Arduino board to make sure we have enough memory to collect data. It turns out that the real-time data collection is fast enough to transfer all of the data in real time, so the extra memory is not used actually and is not necessary.

Figure 4 shows the hardware of the sensor node. It contains three basic components: two sensors, an Arduino board and an XBee. There are two sensors in this system. One is for measuring the distance from the waist of the athlete to the ground. We use the infrared proximity sensor made by Sharp, which has an analog output varying

from 2.8 V at 15 cm to 0.4 V at 150 cm [25]. The other one is a load cell (tension sensor) for testing the wire tension during the athlete holds and throws the hammer. The load cell is produced by Omegadyne and we use the type of LCFD-1K, which can support at most 1000 LB [26], because the tension can be very strong during the athlete throws the hammer.

We use Arduino Mega (ATmega1280) board [27] as the microcontroller of our system device. It has sixteen analog inputs (Analog In pin 0 to pin 15). Because we have two sensors, we just use two pins (A8 and A9) of those. The clock speed is 16 MHz. According to the datasheet of Arduino Mega, the ADC clock speed of a 16 MHz Arduino is set to 125 KHz. Each conversion in AVR takes 13 clocks, so the theoretical maximum sampling rate is about 9600 Hz ($125000 / 13$). The ATmega1280 board has 128 KB of flash memory for storing code.

We use XBeeTM produced by MaxStream Inc. as the transceiver in our system. The outdoor range of XBeeTM is up to 100 m, and the radio frequency (RF) data rate is 250,000 bps [28]. In order to put it on the Arduino board, we also need an Arduino XBee shield shown in Figure 4, which is right under the XBee. The shield can be placed directly on the Arduino board and then the XBee can be embedded on the Arduino board via the shield so that Arduino can have the access to the wireless communication.

We set a condition to our microcontroller to realize a kind of event-trigger idea in our sensor node. Once the tension sensor feels any analog signals above 15, which we believe it means the athlete is beginning to throw the hammer, the sensor device will be able to start working and collect data automatically. By using this idea, we resolved the

issues of how to avoid receiving too much junk data. Because we do not know when the athlete will start to perform the movement of hammer throwing, we have to keep our device on, and thus this may produce a lot of junk data.

Another critical idea used in our sensor node is an easy-release connector installed between the hammer and our system device. When the hammer is thrown away by the athlete, the connector will be released along with the hammer, which means the tension sensor cannot feel any tension and the sensor node will stop collecting and transmitting data. If we reconnect the connector, the sensor node will work again. During the athlete performs a movement, the sensor node keeps sending data to the receiver node in real-time. By applying the above two important techniques, our system will be more convenient and accurate for both the coaches and athletes. Since there is no need to ask the athletes to start and stop their movements during a specific time, they can start their throwing movements when they are ready and our receiver node will also be easy to control. Therefore, it can benefit both the hammer throw athletes and the coaches, and help with their training.

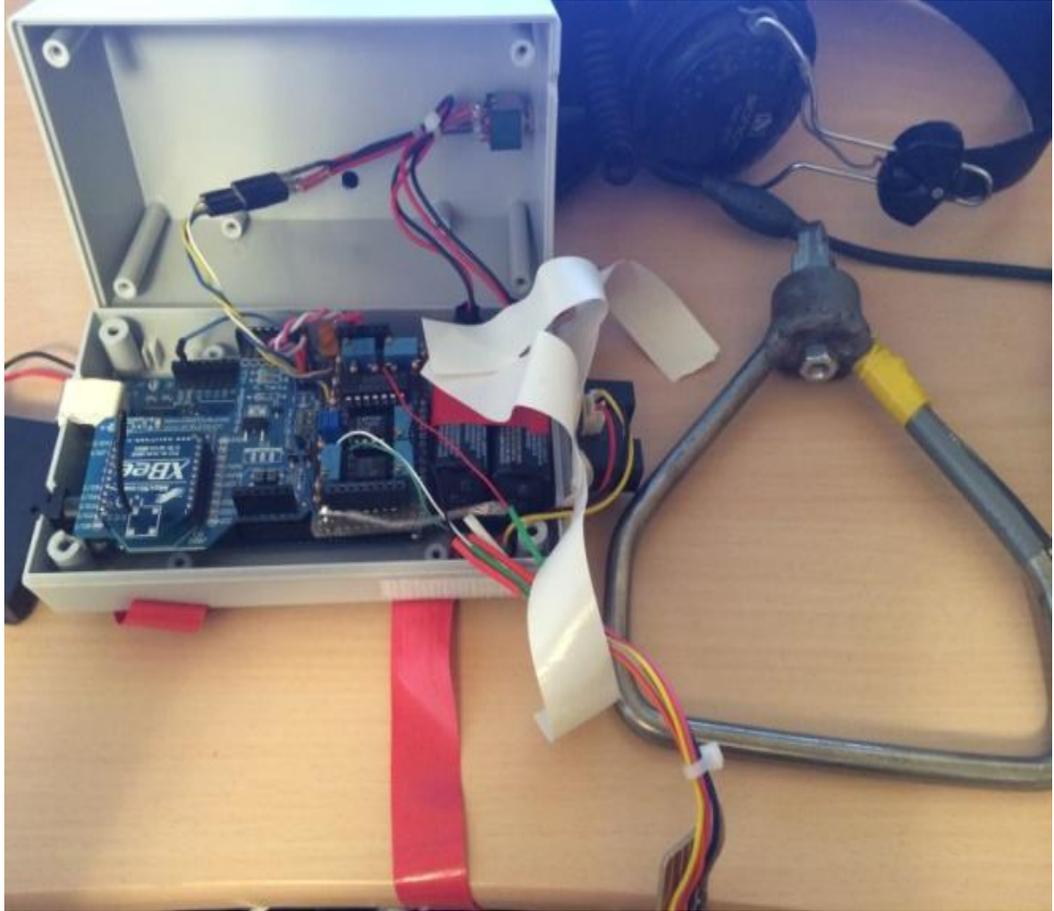


Figure 4: Sensor node

3.3 Receiver Node

We show our receiver node in Figure 5. The receiver node consists of an XBee, which is the same type with the one used in the sensor node, and a laptop. The XBee in the receiver node also needs a shield shown in Figure 5, which is right under the XBee module, to be connected to the computer via a USB cable. The end-user computer is used to receive, monitor and process the data sent from the sensor node.

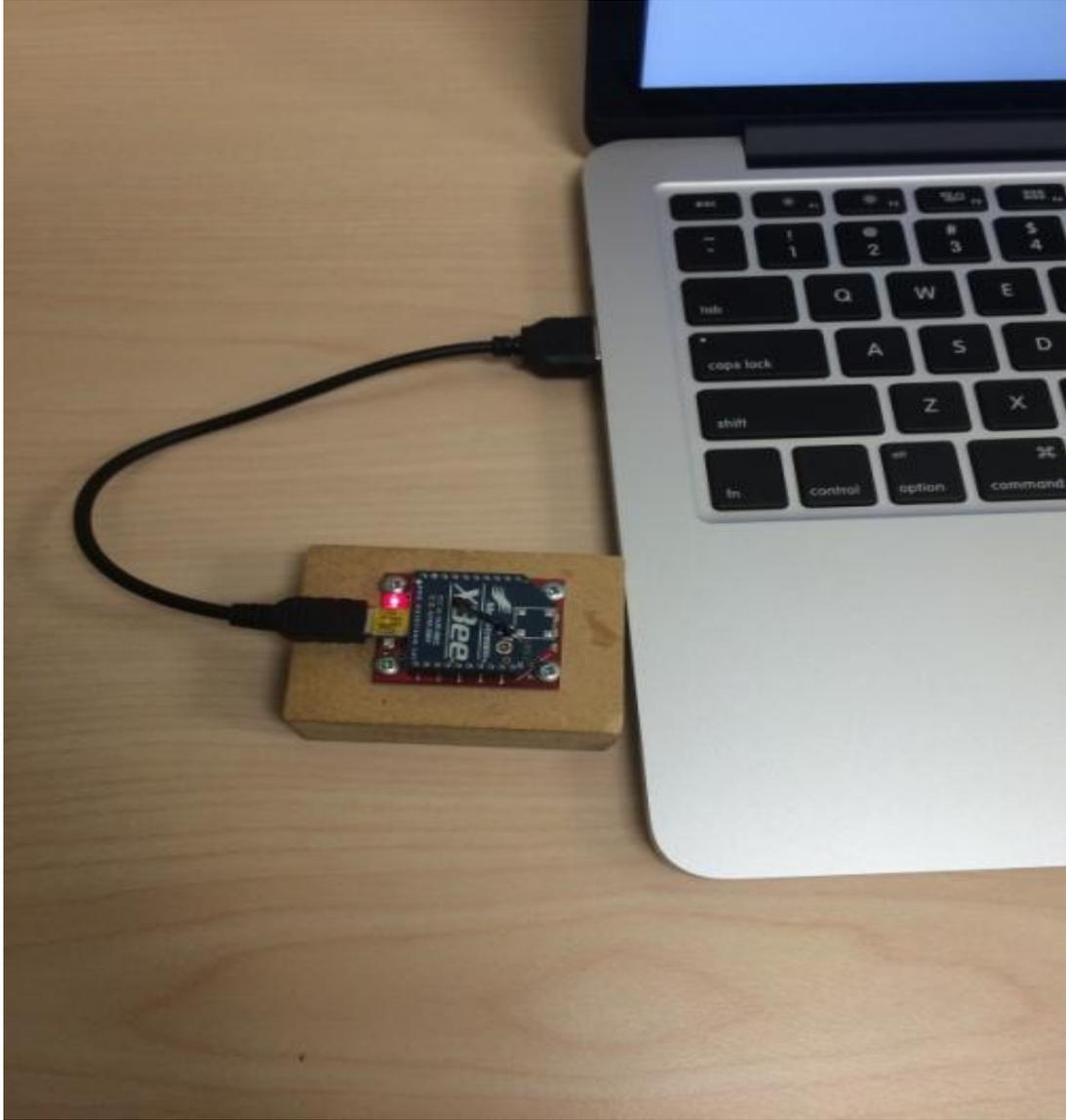


Figure 5: Receiver node

CHAPTER 4

4 Programming and Interface

4.1 Program

In the sensor node, we can write codes in Arduino sketch which is a kind of software integrated development environment based on C/C++. Its library is related with AVR Libc and allows people to use its functions [29]. We can upload the program directly from the Arduino sketch to our Arduino Mega board so that we can control our sensor node and make an initial process when collecting and sending data. In Figure 6, it shows our program of Arduino sketch. My program was implemented based on the AnalogReadSerial in the Arduino sketch library examples [30].

```
void setup() {
  // initialize serial communication at 57600 bits per second
  Serial1.begin(57600);
}

// the loop routine runs over and over again forever:
void loop() {
  // Read the input on analog pin A8 and A9:
  if(analogRead(A9) > 5) {
    Serial1.print(analogRead(A8), DEC);
    Serial1.print(",");
    Serial1.print(analogRead(A9), DEC);
    Serial1.println();
    delay(10); // Delay in between reads for stability
  }
}
```

Figure 6: Arduino sketch program [30]

4.2 Interface

In the receiver node, we use MATLAB as our programming tool. We made a graphical user interface to show the data values of the two sensors in MATLAB. We also implemented a program to process the data and plot the data in a 2-D graph. We applied the Butterworth filter when plotting the data. After the sensor node stops to collect and send data to the receiver node, the filter will start to be applied on the real-time plot. We set the cut-off frequency of the Butterworth filter in MATLAB to 0.2, which can provide us a nice and reasonable curve based on our assumption. An example of our interface is shown in Figure 7. We use it to monitor and process real-time data on PC.



Figure 7: MATLAB GUI

CHAPTER 5

5 Experiments

5.1 Calibration

Since the sensor node detects the electrical signals and then the signal values are converted by the analog-to-digital convertor, we get data in the unit of digital value. We have to convert the digital unit to the actual unit. For example, the unit of the distance values can be cm (centimeter), and the unit of the tension values can be lb (pound). Based on this point, we need to do the calibration. For both of the sensors, we finished the calibration tests in three different days in order to examine the reliability of our calibration, because the environmental conditions or human errors may affect the results of the calibration tests. So, on each calibration day we performed two tests for the sensor system, and the time on each day when performing the calibration is different from each other.

As Figure 8 shows, considering the practical cases, we tested 60 cm, 70 cm, 80 cm, 90 cm, 100 cm, 110 cm, 120 cm, 130 cm, 140 cm and 150 cm to get the distance sensor voltages for each of the distances. We used the regression interpolation method to get the equation of converting the digital values to centimeter values. Assuming the original data value is O and the actual data value is A , the equation is

$$A =$$

$$\frac{-0.01579057581 \times O^2 + 33.31143294 \times O - 319.9862609}{O - 141.2605379}$$

The RSS (residual sum of squares) is 2.488469061. Since we have known that our system device cannot collect data linearly from the distance sensor, the equation of the distance is not linear. There will be a small error. However, we have tried to shrink the error range to make it acceptable.

As Figure 9 shows, we have also calibrated our tension sensor values. In contrast with distance sensor, our tension sensor has high linearity. Hence, we just need to test a few weights to examine it. We tested 10 lbs, 15 lbs, 20 lbs and 25 lbs to get the digital values respectively and calculated the linear equation. Similarly, assuming the original data value is O and the actual data value is A , the equation is

$$A = 0.6031 \times O - 4.8064$$

After we got the equation, we verified it by testing 30 lbs, 35 lbs, 40 lbs and 45 lbs. The error range is very small, which is also acceptable.



Figure 8: An example of calibrating distance sensor values



Figure 9: An example of calibrating tension sensor values

5.2 Field Tests

We have applied our system device into the training field. We used our system device in twenty-four field experiments with four hammer-throw athletes. We tested two male athletes and two female athletes in three different days in order to examine our device in different environment conditions. We asked them to wear our system device when they performed the hammer throwing movements during their training session. On each testing day, we did two tests of each athlete by using our system device. We also recorded several videos of the field tests in so that we can have a more straightforward view compared to the data analysis. We have obtained twenty-four datasets from the field tests. We analyzed and evaluated the data according to our hypothesis that the tension should be stronger after each turn that the athlete performs. Also, the velocity should be higher as the tension increases. Two examples of our results will be shown in the next Chapter that we have proved our device reliable in the training of hammer-throw.

CHAPTER 6

6 Results and Discussion

6.1 Results and Discussion

We have analyzed all the datasets obtained from the field tests. Since it is not necessary to describe all the results of the twenty-four datasets, I just show two of them in my thesis to demonstrate that our wireless sensor device works well in the real training session. However, due to the hardware limitation of the distance sensor, the original idea of combining the wire tension and hip displacement to analyze hammer throw cannot be realized. We found that the system device cannot be fixed strictly on the waist of the athlete after doing the field tests in the training session. Thus, this weakness leads to the error of measuring the hip displacement, because we cannot make sure the distance sensor always towards to the ground vertically. Therefore, we only used the tension data to analyze the results. Since the hip displacement is only used to help analyze the results, we can still provide useful information to the coach by applying this system into the training. We used the Butterworth filter to process our raw data, so that we could get rid of the noisy signals and get a smooth curve. The blue curves in Figure 10 and Figure 11 were drawn from the raw data, while the red curves were the results of the filtered data.

The first result is one of the tests from James Steacy. He is a male hammer thrower whose best result, achieved in May 2008 in Lethbridge, Alberta, still stands as the current Canadian record. In Figure 10, we can see that there are several peaks before reaching the maximum take-off point. Comparing to the video, James performed four and half turns, and the hammer was released at his 4.5th turn. It means that the tension

increased a portion per turn, and reached the maximum when he released the hammer. However, before he started to turn around, he needed to pull up the hammer from the ground at first, and then he threw the hammer for two circles as a preparation. These movements reflecting on the graph are the first three peaks in Figure 10. We can also notice that his rotation speed increased gradually in the video. If we do not consider the first four peaks, it is shown on the graph that the tension grows almost equally between every two peaks, and also between the last peak and the maximum value (which is the release tension). The reason why the fourth peak is still low is that he just started to turn around. There are supposed to be four peaks on the graph, but we see five. We watched the video carefully to figure out that he had a trunk over-extension right before he released the hammer. This might produce the last peak. So, we only calculated the fourth, fifth, sixth and seventh peak values because these values indicated the tension of his each turn, and calculated the maximum value which was at the release time. The results are shown in Table 1. In addition, we used the equation

$$F = \frac{m \times V^2}{r}$$

to calculate out the velocity (V), where F is the wire force which can be calculated out from the tension data values (T) by using the equation

$$F = 9.8 \times 0.453592 \times T$$

m is the mass of the hammer head (for male, it is 7.26 kg), and r is the radius which was measured as 1.931 meters (his arm length plus the hammer length which is about 121.5 cm). The results are also shown in Table 1.

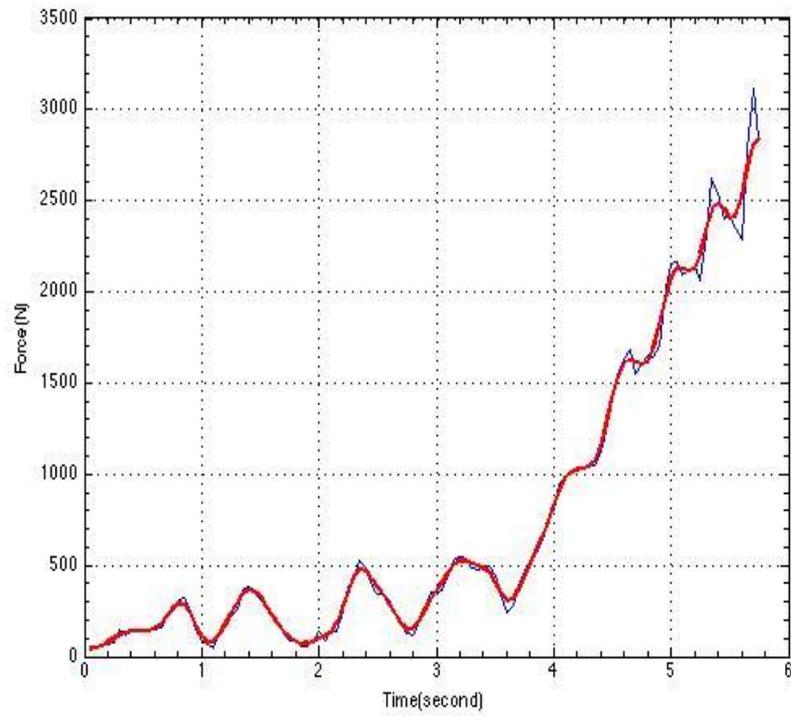


Figure 10: An example of James' tension data graph

Table 1: An example of the results from James' field tests

	Force (N)	Velocity (m/s)
Peak 1	542.63	12.01
Peak 2	1037.50	16.61
Peak 3	1632.22	20.84
Peak 4	2144.60	23.88
Max	2843.37	27.50

The second result is one of the tests from Montana Forsyth who is a female athlete. In Figure 11, we can also see that there are several peaks on the graph. Similarly, we compared our graph to the video to figure out the first three peaks could be ignored as she had not started to turn around during that time. Since Montana also performed four and half turns, the rest four peaks indicate the tension at each of her turns, and the maximum value is the release tension. We can see the difference between Montana and James that she did not have the trunk over-extension, so there are exact four peaks before the maximum release value. There is another difference to be explained. Comparing to the video, we obviously noticed that Montana's rotation speed increased suddenly in her fourth rotation. This can be reflected on the graph that after the fourth peak the data value grows by a significant amount, which is different from James' tension graph. Table 2 shows the tension and velocity at each peak and the maximum release point of Montana's performance. We used the same equations to calculate out the velocities. However, we must remind that the mass of the hammer head for women is 4 kg, and the radius is different among athletes. For Montana, the radius is 1.8192 meters. (Her arm length is about 60 cm, and the hammer she used is about 121.92 cm in length).

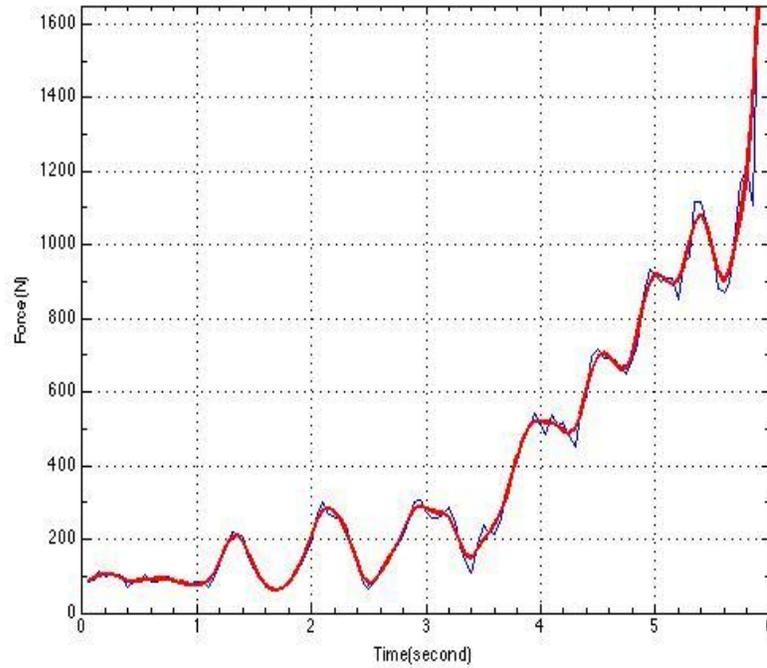


Figure 11: An example of Montana’s tension data graph

Table 2: An example of the results from Montana’s field tests

	Force (N)	Velocity (m/s)
Peak 1	503.56	15.13
Peak 2	716.27	18.05
Peak 3	933.32	20.60
Peak 4	1115.64	22.53
Max	1640.90	27.32

6.2 Alternative Technology

6.2.1 Bluetooth Technology

As our previous WSN system was developed and applied into practice, we realized that if we can use a cell phone or mobile device, like an iPad or other tablets, to control our system and receive and process data instead of using a laptop, it will be more convenient for coaches to record the testing results. Based on this point, we started to try to establish a new WSN system by replacing the XBee module with the Bluetooth module.

Bluetooth is a wireless communication technology which has a short range [31]. It was first introduced in 1994, and then in 1998 Bluetooth became a standard [31]. Bluetooth 0.7 was the first documented version and Bluetooth 1.1 became an IEEE standard [31]. From the version of Bluetooth 2.0, people can start transmitting files or play audio wirelessly [31]. From 2010 till now, Bluetooth 4.0, which includes Classic Bluetooth, Bluetooth High Speed and Bluetooth Low Energy, becomes very popular [31]. In [31], the authors introduce a heart rate monitor system using Bluetooth 4.0 technology. The system is comprised of a heart rate sensor, a Bluetooth module and an iOS platform [31]. The system is built on iPhone4S which is the first compatible mobile device with Bluetooth 4.0 [31].

In [32], the authors introduced a home automation system based on Bluetooth technology. They used a cell phone to control some home applications, which can be considered very convenient. The hardware of this system includes two main components: a cell phone and an Arduino BT board [32]. They set up an ad-hoc communication

protocol between the cell phone and the Arduino BT board [32]. There is a Bluetooth antenna module called Bluegiga WT11 in this system which is regarded as their transmission method [32]. The Arduino BT board is treated as the microcontroller. They can receive and send data packets from the cell phone to the test devices through the Bluetooth module to realize controlling home applications wirelessly [32].

6.2.2 System and Program

Figure 12 shows the architecture of our Bluetooth system. In the first phase, we have developed a prototype with an Arduino Uno [33] board, a Bluetooth Low Energy shield [34] from RedBearLab, a temperature sensor [35], a distance sensor [36], a breadboard, and an iPhone5S to set up the hardware part of our testing system. We built the circuit of the prototype which is shown in Figure 13.

We used the Arduino Uno board as the microcontroller. The operating voltage is 5 V. The recommended input voltage is from 7 to 12 V and it limits from 6 to 20 V. There are 14 digital I/O pins and 6 analog input pins. It has 32 KB flash memory of which 0.5 KB used by the boot loader. The BLE shield is designed by the RedBearLab to support Bluetooth transmission for several different Arduino boards, such as Arduino Uno, Arduino Mega 2560 and so on. It allows users to use a smart phone to communicate with Arduino boards through Bluetooth. It can work either under 3.3 V or under 5 V. We connected the temperature sensor to the analog input A0, and we connected the distance sensor to the analog input A5 on the Arduino Uno board. The distance sensor we chose is a high resolution, precision but low voltage ultrasonic range finder. The distance sensor has a maximum detection range of 5 meters.

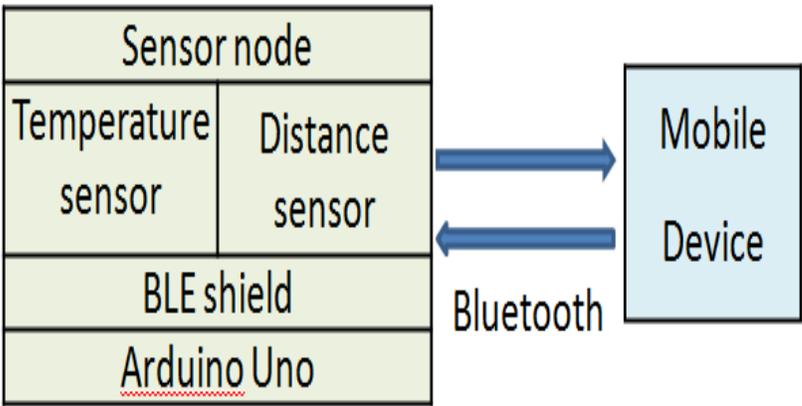


Figure 12: The architecture of our Bluetooth system

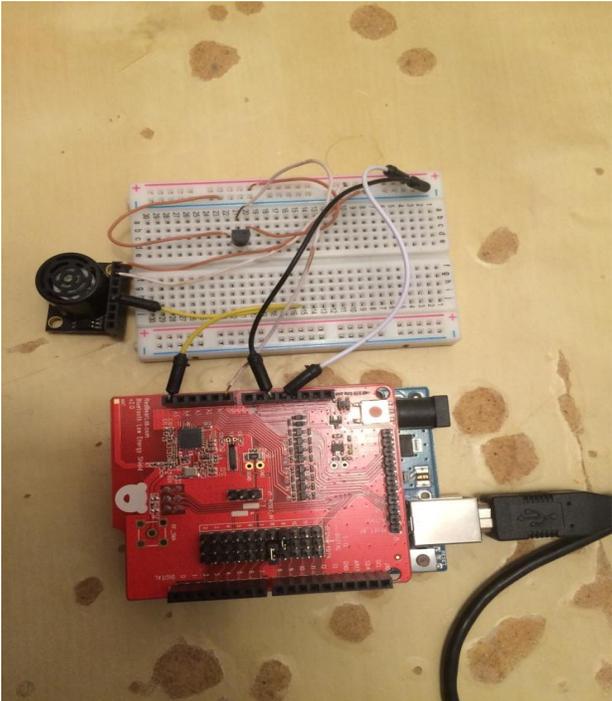


Figure 13: The circuit of the prototype

For the software part, currently we are using an application provided by the RedBearLab, which is called BLEController, to do the test. We are going to develop our own application in the future. In that case, we can change the BLE shield to any Bluetooth antenna module so that it will not limit the functions when using the Bluetooth transmission method.

By using the BLEController application on iPhone5S, we can get both the temperature data and the distance data correctly without any interference. From this positive result, we have the confidence to use the BLE shield or any other Bluetooth antenna module to improve our previous system by replacing the Xbee module and changing the operating platform from a laptop to a smart phone.

6.2.3 Comparison of Two Systems and Future Work

Although the first system is still in the research stage, it has already become a mature integrated system. Instead, the second system can be just treated as a theoretical idea. We only tried a BLE shield to realize the Bluetooth transmission method. We need to start performing more steps.

If we just think about the cost of the hardware part of the two systems, they are both cheap. However, a mobile device is more convenient than the laptop. Regarding to this, we can see the advantages of developing a new system with a smart mobile device application.

CHAPTER 7

7 Conclusion and Future Work

7.1 Conclusion

Wireless sensor networks can be applied in a large variety of research fields. In present study, we take advantages of this technology to implement an electronic device for hammer-throw athletes as well as the coaches to help improving the performance of their throw skills.

After learning and understanding the other research work both in the area of wireless sensor networks, especially about those designs using Arduino and XBee modules, and the area of hammer throw, we proposed our own design of using Arduino and XBees to help the training of hammer throw. We have shown the methodology and architecture of building our wireless sensor system. We presented our detailed program and interface, and how we performed the experiments. Eventually, we demonstrated the reliability of our wireless sensor system using in the training of hammer throw by discussing two examples of our experimental results. In addition, we introduced a new concept coming from our current design that we may improve our current system by using Bluetooth technology and developing a mobile device application.

While we are using wireless sensors to make easier lives for people, we cannot forget any troubles which may be produced from the network technology, like a hack. Therefore, we must consider the network security at the same time when we use wireless sensor technology.

7.2 Future work

We will try to use Bluetooth technology to implement our receiver node in a cell phone or a mobile device, such as iPhone, iPad or other tablets. In this case, coaches will have a more convenient way to collect and analyze the data transferred from the sensor node during the training. The idea of testing the usefulness of the final results from the athletes may be also improved. Currently, we can only show the plotting figures of the results to the coach. In the future, we may add the optimal curve of the results shown on the mobile device to compare it with the actual curve of the results from the athletes.

In addition, from the hardware perspective, we still need to look for a more appropriate distance sensor to become an auxiliary variable when analyzing hammer throw. We may try to make our own printed circuit board which can be much smaller than the Arduino Mega board so that the size of the device can be like the size of a USB flash disk. Thus, it will be easier and more convenient for the athletes to carry with the device. Also, in terms of the network security, we may develop a security system of the data transmission for our current sensor system. It will prevent the noisy signals and any other violations during collecting the data. As far as I know, we can apply the advanced encryption standard (AES) or RC4 (River Cipher 4) in XBee communication. However, for the Bluetooth communication we need to do more researches if we would like to improve the security for the system.

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Appendix A:

Informed Consent

Development of new biomechanical feedback tools for improving human motor skill learning and training

Hammer Throw Project

Biomechanics Laboratory

University of Lethbridge

We invite you to participate in a study that aims to develop new tools for understanding of fundamental processes in humans and modulating various human movements, ranging from daily activities to specialized sport and music skills. Learning how to move is a challenging task. Even the most basic skill of walking requires years to develop and can quickly deteriorate with age and sedentary lifestyles. Age-related falls are the cause of 70% of accidental deaths in people 75 years and older and is the leading (74%) cause of hospitalization for seniors. More specialized skills such as violin playing and soccer kicking require "talent" and years of extensive practice to fully master. These practices can easily cause career-ending vocational diseases if conducted improperly. Our research group uses the science of biomechanics and state-of-the-art motion analysis technologies to determine which muscle movements are critical for successful skill development and which expose us to vocational disease development. In this fashion, we are able to unlock some of the secrets of talented musicians and athletes and scientifically inform music pedagogy and sports coaching, while preventing the occupational disease to occur, i.e. biofeedback learning and training.

Biomechanical feedback can be broadly divided into two categories: real-time and post-measurement. Real-time feedback is more useful for practitioners and thus our ultimate goal, but its successful development hinges on robust post-measurement feedback. Therefore your participation in the project will be the post-measurement one.

Hammer throw has a long-standing history in track and field, but unlike other events, hammer throw has not seen a new world record since 1986. One reason for this stagnation could be the lack of scientific bio-feedback training. This study aims to develop a biofeedback analyzer that can 1) measure real-time wire tension and vertical hip displacement, 2) establish how to reach desirable tension and displacement, and ultimately 3) provide biomechanically-guided training plans customized to each athlete's anthropometrical data.

The experiment takes about 60 minutes. The test will be in the hammer training area located in UofL gym (the training area is protected by a surrounding net). You will be asked to wear a black garment made of stretchable material, which covers the upper and lower body. Affixed to the garment will be 42 reflective markers (reusable), each with a diameter of 9mm. The garment will be washed between each participant use. Before the test, you will be allowed to perform a sufficient number of warm-up exercises to get used to the test environment. After warm-up you will be asked to perform 6 throws

using a real hammer (like throws in your training). During each throw, the kinematic (3D motion) and wire tension data will be captured simultaneously. The kinematic data will be collected by a twelve-camera Vicon system. Wire tension will be measured by a tension sensor system developed at Biomechanics Lab. The tension sensor is installed between the Hammer grip and wire. There are no anticipated risks from participating in this study. Nothing is intrusive into the body. The tests are natural and do not use any sort of medication.

The information gathered from you during this study is considered confidential. To maximize your anonymity, you will be assigned a code, and this code will be used instead of your name at all times. Research assistants will also be required to sign a confidentiality agreement. All personal information (body weight, body height, age, and training hours per week) will remain locked in a file cabinet that can only be accessed by researchers involved in this study and will not be disclosed without your permission. We may, however, wish to use your data measurements for a research presentation or education purposes in the future. Your identity will be kept confidential. It should be mentioned that the twelve-camera system will not in any way videotape participants' faces, so that participants truly do remain anonymous.

Your participation in this study is entirely voluntary and you may withdraw from participating at any time. Should you decide not to participate in this study, your relationship with the Biomechanics Lab or any other department of the University of Lethbridge will not be affected in any way. If you choose to withdraw, any information collected from you up to the point of withdrawal will be deleted or destroyed. If you wish to see your performance analysis, we will supply you a CD containing your 3D dynamic analysis data. If you have any further questions about this research, please feel free to contact Dr. Gongbing Shan, at (403) 329-2683 or g.shan@uleth.ca. If you have any further questions regarding your rights as a participant please contact the University of Lethbridge Office of Research Ethics at (403) 329-2747 or research.services@uleth.ca.

Your signature below indicates that you have read and understood the information provided above, and that any and all questions you might ask have been answered to your satisfaction. Your signature also indicates that you willingly agree to participate in this study, and that you understand you may withdraw from this experiment at any time.

I have read the attached Informed Consent form and I consent to participate in the “development of new biomechanical feedback tools for improving human motor skill learning and training” research study.

Printed Name: _____

Date: _____

Signature: _____

Witnessed by: _____

Date: _____