03B010I

IQP FB-48-1000

The Virtual Conductor

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Introduction

The Virtual Conductor intends to implement a method in which a music conductor can accurately relate his/her intentions to a computer-based music realization network. The Virtual Conductor must perform without error, because it is a performance based device, and will be used in live performance environments. Creating such a system will benefit the creative aspect of live performance because it will give the performer a new form of expression. Such a perfect system will also benefit the technical aspect of live performance because it will allow one human to have control over more aspects of the performance.

. The goal of the Virtual Conductor is to capture the physical gestures of a conductor or performer. Each gesture will control a specific function of the computer. A sub-goal of the Virtual Conductor is to make the system wireless to provide maximum freedom of movement for the conductor. This will allow the conductor to gesture naturally, while still allowing the Virtual Conductor to capture his gestures. The Virtual Conductor is meant to supplement the conductor, not replace the conductor. Another sub-goal of the Virtual Conductor is to make it cost effective, and practical. Monetary limitations could be a hindrance to the creation of a perfect, errorless system.

The audience that will benefit from the Virtual Conductor is broad. It includes conductors most specifically, but can also be used by performers such as dancers or musicians. The Virtual Conductor may be used by future research groups. These groups can use the research and technology as a stepping-stone in their own research or project.

The results of the Virtual Conductor will be presented in a written project and by the possible way to implement the Virtual Conductor system itself. These results could then be used by others as a basis for further research on this topic, to actually build the Virtual Conductor apparatus, and to derive solutions to any existing problems or limitations to the Virtual Conductor

Literature Review

The ideology for projects such as the Virtual Conductor began with creation of other technologies. The Virtual Conductor, and similar projects, is the blending of these technologies. Creations such as MIDI (Musical Instrumentation Digital Input) and the want for creating new types of instruments was the starting point of this ideology. Soon, people are starting to become interested in new ways to play these instruments, and new ways to read music. But all this technology stemmed from innovations concerning sound recording, and sound playback.

Bell Labs is responsible for creating the first high-fidelity sound recording. This particular recording "extended the reproducible sound range by more than an octave on the high and low end" (Bell Labs). Once sound recording became possible, it was then a desire of researchers to end the silent film era of Hollywood. Bell Labs was the first to successfully synchronize film and sound. Sound for films were "recorded on wax disks, then replayed on a large turntable connected to a synchronized film projector" (Bell Labs). Bell Labs was also involved in the communications aspect of sound and sound technology. In 1933, the first live transmission of stereo sound was sent from Philadelphia to Washington D.C. And only four years after that feat, Bell Labs was successful in creating the first electronic speech synthesizer which recreated human speech. However, a technology that was most pertinent to the Virtual Conductor, and similar projects, is the creation of digitized and computer-synthesized music in

1957, Had Bell Labs not achieved digitized and synthesized music, there would be no need to create hyper instruments and other gestural input techniques. Although Bell Labs had contributed vast amounts of technologies to the modern world, including telephone, cellular, and laser technology, the creation of digitized and computer-synthesized music is most crucial to our project of the Virtual Conductor. Bell Labs developed another piece of technology that is vital to future work. In 1979, Bell Labs created the first single chip digital signal processor (DSP). Having said this, is reasonable to argue that the technology and research of today, would not be where it is had Bell Labs not made the contributions that it has.

In 1981, a computer vision system was created that could read musical scores. It worked on the basis that it "acquired external information about music in real time through computer vision" (Morita 44). This score was then played on a piano by a robot, named Mister Wabot-2, that received the musical score through this vision input. Mister Wabot-2 is pictured below reading music and playing the keyboard.

Figure 1-Mr. Wabot-2

Mister Wabot-2 “can sight-read music notation and plays organ with two hands and two feet” (P-ART Journal), and can also “accept song requests in spoken Japanese and follow in tune and in rhythm with a human singer” (P-ART Journal).

The men who created this vision system are important to the creation of motion capture as it relates to music. Their work on the computer vision system project, as well as their work described in the following paragraph, are cited throughout other projects. It seems that it was only a matter of time before people would have the desire to create new instruments, and to have new inputs to those instruments.

A major project done concerning motion capture as it relates to music was conducted by Hideyuki Morita, Shuji Hashimoto, and Sadamu Ohteru. These three men conducted a project named "A Computer Music System that Follows a Human Conductor". In this research project, the goal was as follows: "An electronic orchestra with a complex performance database and MIDI controllers responds to the gestures of a conductor through a CCD camera and a sensor glove" (Morita 44). The system is connected to MIDI controllers, and determines parameters such as tempo and compensation. This system can be used in live venues, even as a part of a human orchestra. The starting point and finishing point as described seem straight forward, but the route there is extremely complicated and contains a lot of physics and mathematics, of which a prior knowledge is required. However, the user of this apparatus, in this case the conductor, does not need a prerequisite knowledge of mathematics, physics, MIDI sequencing, or computer technology or programming. That was part of the value of such a system. It allows the conductor to use the apparatus without needing more knowledge than a typical conductor already has. The system as described can control volume, tempo, and instrument selection. The system can also recognize the personal expression each conductor has. The system recognizes musical performance expression (Mpx). According to the theory of this project, conducting music has two components. The first is called basic. Basic consists of static information with quantifiable symbols that is common throughout music. Mpx is subjective and dynamic. It changes from conductor to conductor. The system blends these two types of expression into MIDI outputs that control the music. Details of this procedure can be found below in the procedure section, where it will be compared with other possible approaches.

Research concerning similar systems has been completed at some major universities. However, the recent forerunner in this area is the Massachusetts Institute of Technology. There, Teresa Marrin has been working on similar problems using various methods.

Starting in the mid 1990's, Teresa created a device known as the Digital Baton. It was a "hand-held device which is used to control musical performances" (Marrin, The Digital Baton). This is a gestural input device, similar to our Virtual Conductor. However, Marrin encountered a problem that the Virtual Conductor is also likely to have. Marrin states that the digital baton "requires sophisticated software to map gestures appropriately" (Marrin, The Digital Baton). This is reasonable considering the complexity of the digital baton. The digital baton has eleven degrees of freedom including, position, orientation, and surface pressure. To complete the technical and hardware portion of this project, Marrin admits to having outside assistance. The programming designing was done by specialist Joseph Paradiso. This corroborates our assumption that people with special capabilities, outside music, will be needed to complete the Virtual Conductor. In all, the digital baton became a "large collaboration which included numerous designers, engineers, and software writers" (Marrin, The Digital Baton).

More recently, Marrin created a wearable interface called the "Conductor's Jacket". This project is more similar to the Virtual Conductor in the sense that the main focus of the apparatus is the musical conductor himself. One could argue that the digital baton could be used by anyone, even those with no prior knowledge of conducting. The purpose of this particular interface was to determine how a conductor uses his gestures to achieve a desired result from the musicians he or she is conducting. In other words, it is used to “answer certain fundamental questions about the nature of musical expression and how it is conveyed through gestures” (Marrin, The Conductor’s Jacket). The conductor’s jacket is not yet a wireless system and uses many sensors to track the conductor’s movements. This differs from our study in the sense that we want to achieve maximum tracking with as little devices as possible. Hopefully, our Virtual Conductor will not actually have physical contact with our conductor. The conductors jacket could be used outside the laboratory in similar ways to what we intend for the Virtual Conductor. The basic idea of motion tracking without using common methods is similar in both projects. The major difference between the conductor's jacket and the Virtual Conductor is that in addition to motion tracking, the conductor’s jacket also detects physiological movements and muscle tension, whereas the Virtual Conductor does not.

To capture such delicate movements, the conductor’s jacket uses many sensors. The jacket includes eight Polhemus UltraTrak Sensors (each having six degrees of freedom), four EMG sensors for muscle tension, one Galvanic skin response sensor for sensing sweat, two tissue perfusion sensors for blood flow, one temperature sensor, one respiration sensor, and one EKG sensor for heart rate.

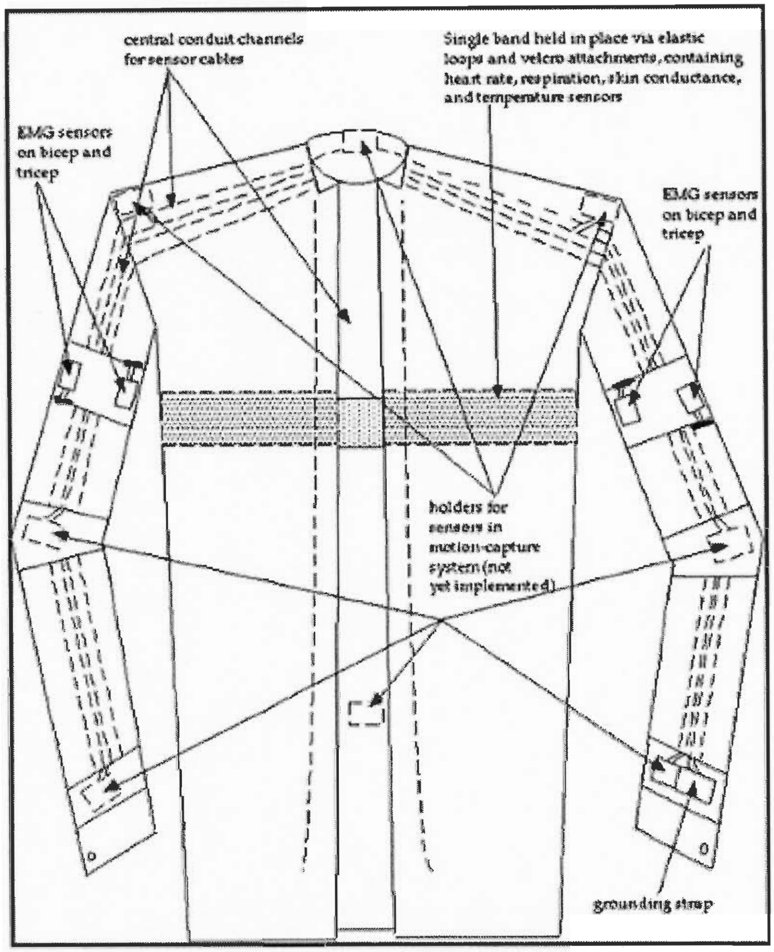


Figure 2-Sensor Placement on Conductor's Jacket

This picture indicates the position and basic schematic of all the sensors used. The sensors are woven into the jacket of the conductor, making it seem like there are not wires present at all. Although the system is not yet wireless, it can appear wireless to most that see it. The method of controlling the data given off by the conductor's jacket is done through a system of input controls and computers for data acquisition. The model below shows the route of the signals given by the conductor's jacket.

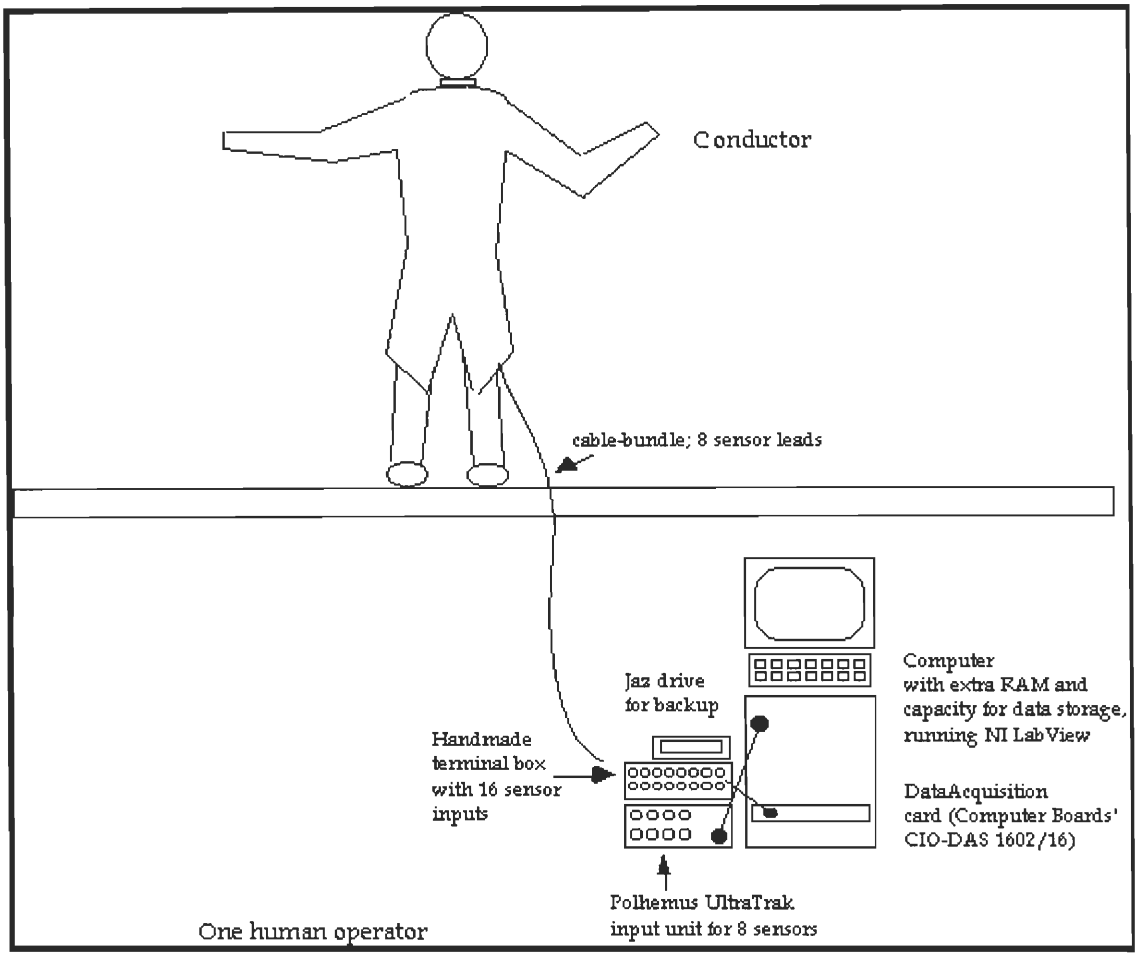


Figure 3-General Schematic for Conductor's Jacket Operation

The overall system design for the conductor's jacket contains five major steps. The first step is the 24-channel input box. The second step is data acquisition and A/D filtering. The third step is the analysis layer. Fourth is the application layer. And last is the musical output itself. The diagram below shows this process.

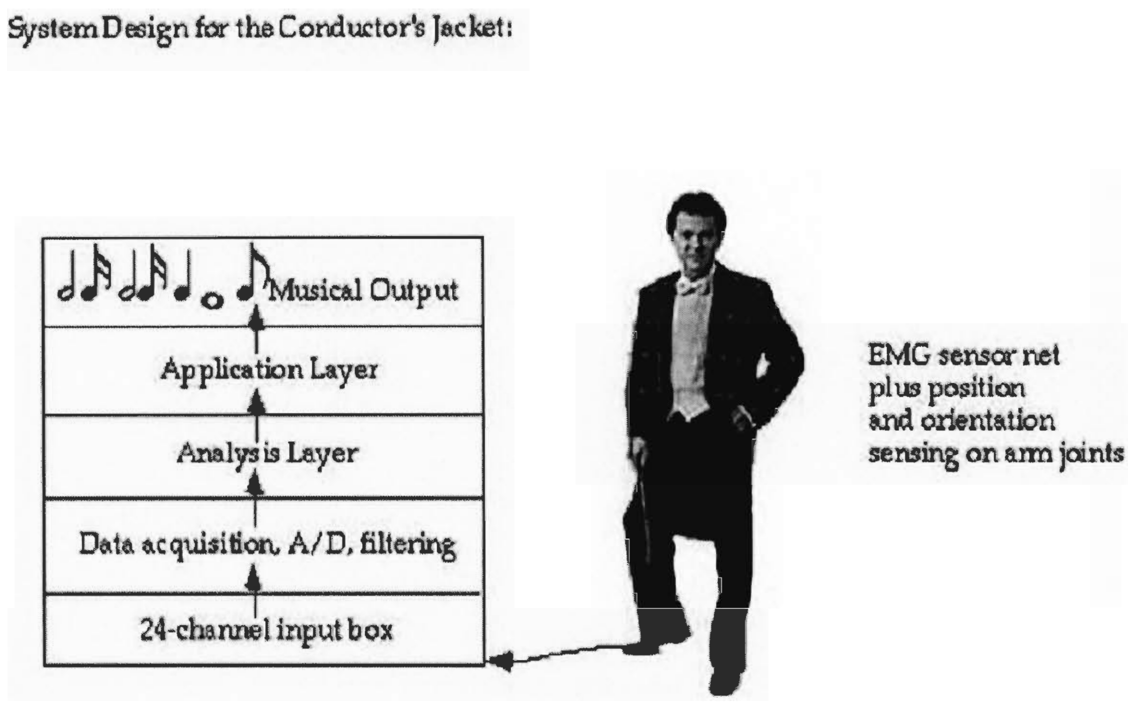


Figure 4-Input/Output Overview of Conductor's Jacket

The input signals themselves are more complicated than the schematic above. The signals sent from the conductor's jacket look like pulses. Marrin can actually correlate the musical scores with the movements of the conductor. More specifically, Marrin can use that information to identify transitions within the music itself. The EMG sensors used to measure muscle tension are responsible for the results below.

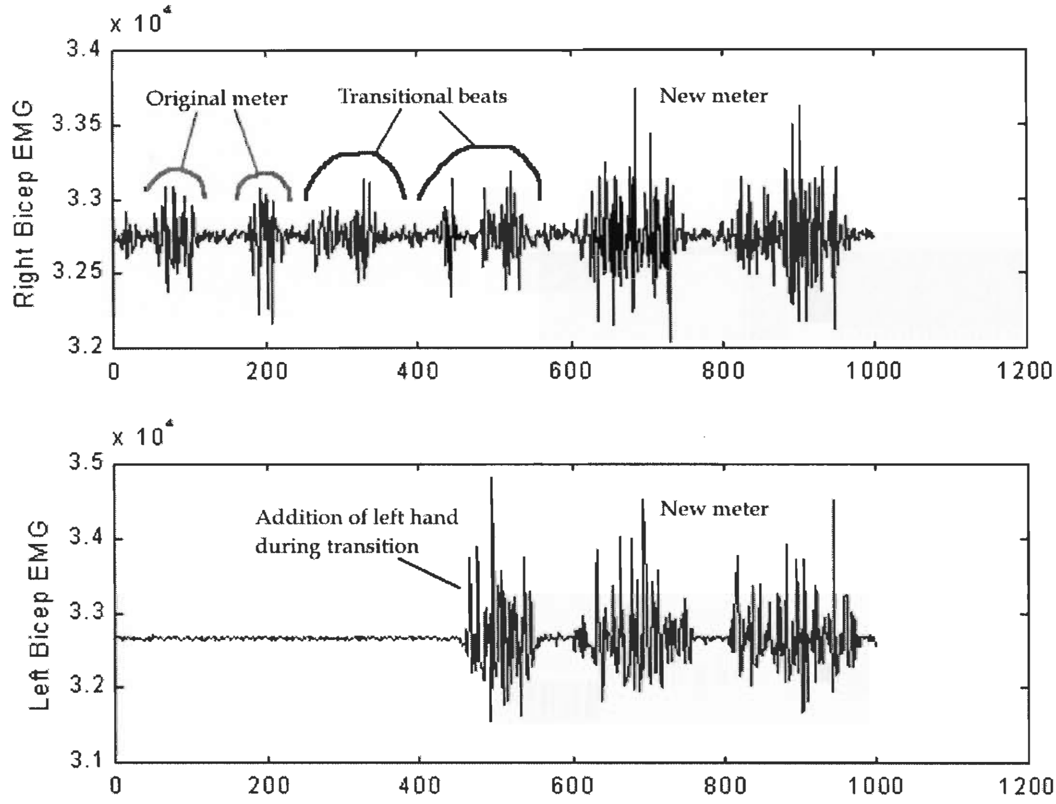


Figure 5-Sample EMG Reading

As one can see from the graph, the right bicep controls the original meter. Both biceps are used in the transition of meters. And again both biceps are used in the new meter. The pulses during the new meter, starting at the six-hundred mark, are in unison with each other. Marrin can then use this information to superimpose the signals from the conductor's jacket, onto the musical score.

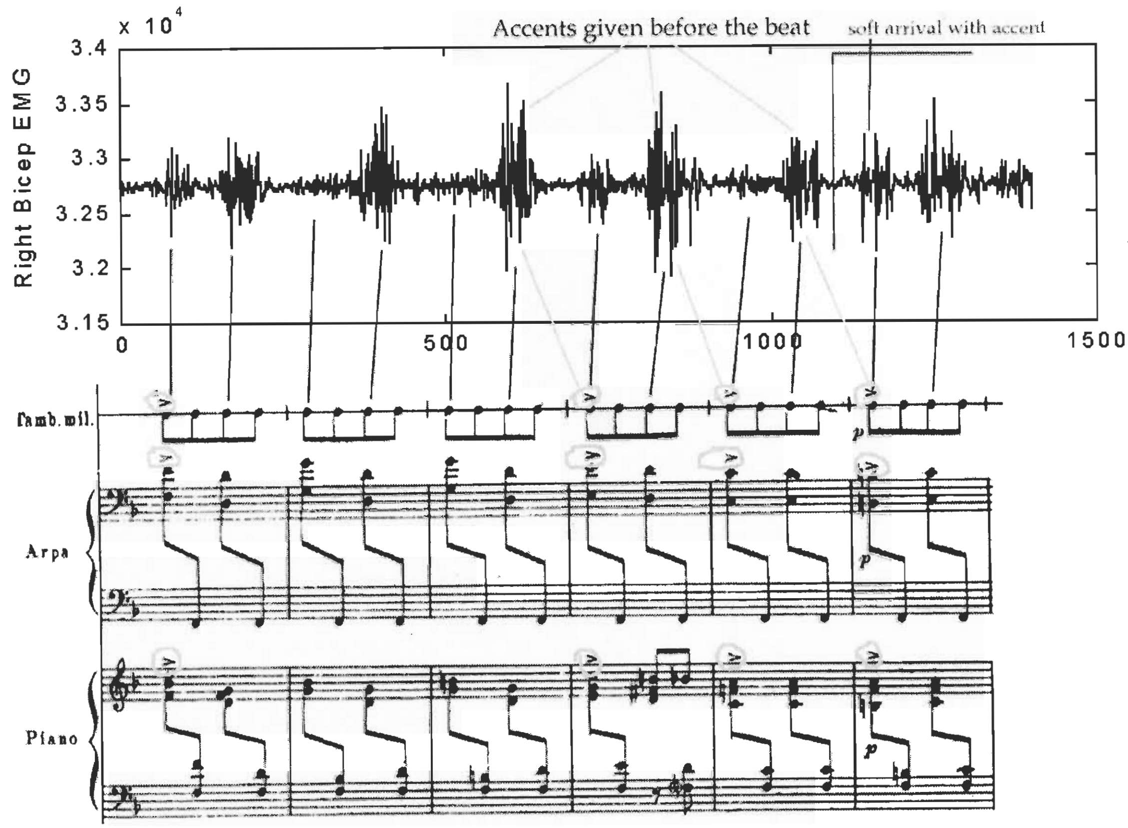


Figure 6-EMG Superimposed on Musical Score

Marrin makes the correlation using the red lines to show what musical notes and rhythm cause what muscle tensions. Marrin can also determine what motions are intended for musical purposes, and what motions are intended for non-musical purposes. In the diagram below, Marrin shows a stream of muscle movements, but indicates that the particular muscle tensions are not related to the music.

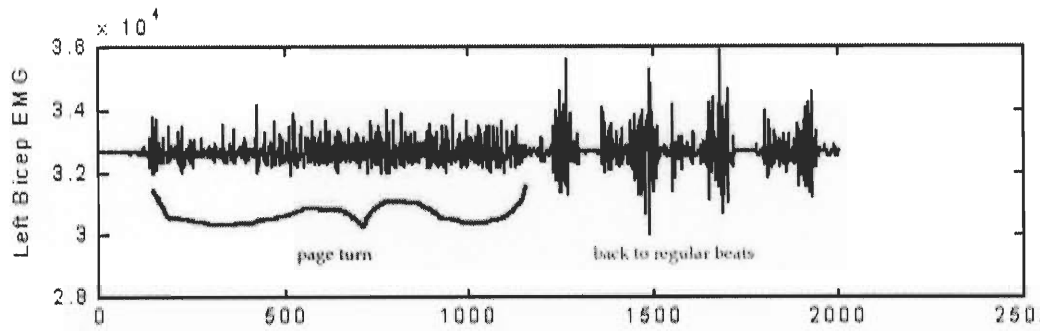


Figure 7-EMG-Nonmusical Data

Marrin indicates the subtle muscle tensions are a product of the conductor turning the page. After the page turn, one can see the obvious change back to the desired beat. Marrin has covered all based concerning the interpretation of data, and the filtering out of unnecessary movements.

The benefit of a system like the conductor's jacket is to map physical gestures to music. It provides correlations and data that are new to researchers. This interface is used on a conductor. For her application, Marrin chose Boston-area conductor Benjamin Zander. However, such a technology could be used on musicians to see how they gesture while playing music, instead of conducting music. Research such as this proves why Teresa Marrin is a forerunner in the creation and monitoring of gestural input devices.

To understand and complete The Virtual Conductor, one must have a general idea of the technology used. Also, one must look at our procedure section and understand why we abandoned other methods of motion tracking technology. The procedure section will then hopefully save time for other research teams, in their efforts to complete similar projects. In addition to understanding the technology, one must have a general understanding of musical conducting. It would be extremely difficult to map gestures to sounds, if one did not know what the gesture meant. Having knowledge of one aspect of the project without the other will lead to an incomplete and inaccurate system.

Finally, there is the concern of monetary limitations. It is reasonable to believe, although an actual figure was not printed, that the conductor's jacket was relatively costly. Considering the type and number of sensors used (18 individual sensors) one can conclude that costs ran high. In contrast to that, the Virtual Conductor could be made for a relatively low cost. The localized GPS and receiver would be most of the cost (when that technology becomes available). Computer software would round out the hardware needed to build the Virtual Conductor. In regards to other similar projects, money could afford any technology. One could obtain experts in many fields including computer programming, mathematics, physics, anatomy and physiology, and GPS technology. With a team like that and ample time, one could probably come up with a near perfect or perfect system. In general, time and money could produce similar systems, assuming those two elements were not important to the party involved. The appealing aspect of The Virtual Conductor as we suggest it would be that it could be built relatively quickly and cost effectively (as soon as the localized positioning systems (LPS) were available).

Procedure

As a general method of creating the Virtual Conductor, we realized that GPS technology in a localize environment is the best possible solution. However, after conferring with experts on the topic of GPS, we realized that such an accurate localized GPS system that could detect such small movements has not yet been invented. The plans to create such a system are currently being undertaken. This localized GPS, when created, will track a receiver placed at the end of the conductor's baton. This system is the basis for the Virtual Conductor, however it will have to wait for the technology to available. And once created, it is projected that such a localized GPS system could easily cost over ten thousand dollars. Other systems and methods are possibilities for the Virtual Conductor. However, some may be less appealing than localized GPS. These and similar concerns are addressed in the Procedure portion of this project.

In this proposal, I believe that to pick up the movement of our conductor, we need to use more than one sensor. This is because we are going to get a lot of unwanted data. I am convinced that a combination of sensors will help to determine the movement the hands of the conductor. The task of this project is to construct some electronic and mechanic devices that are capable to interpret the movement and transform them into data to be sent to a computer that will play the music. To capture these movements, we arrived to the conclusion to use some accelerometers and GPS (global position system). In addition, we were thinking to use photodiodes but we concluded that would give us a lot of error and noise. This is because the conductor can make very small movement with his hands and also the photodiodes are affected by dark noise. In the study of the conductor, we considered that our design has to be comfortable to the conductor in the way that the conductor can make any movement without any restriction. Therefore, we thought to use some thing that would be wireless, which can be attached to the conductor.

I. GPS

One of the methods to achieve our goal is to use a system that uses the principals of the GPS system to capture the hand of our conductor. First, we will try to explain what is a GPS (global position system), that is used today to calculate position to object and figure out its coordinate. The GPS can make measurements better than a centimeter. (Red Sword Corporation). Most of the sophisticated machines in this world have this kind of system, like, boats, cars and planes. This system consists of three satellites in orbit that transmits a radio frequency signal (RF) to a receiver, which will capture the signal. In the figure 8 shown below, it shows how the three transmitters found the location. The points where the three signals are intersecting is the location of the receiver (East Bay Builders).

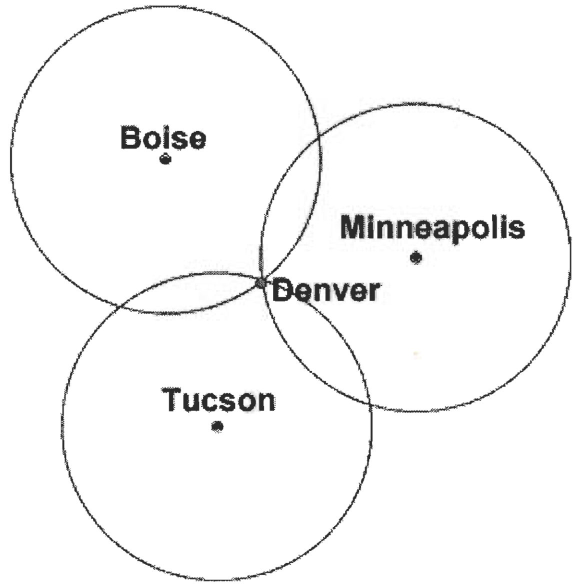


Figure 8. Positioning Concepts

The RF signal is traveling at the speed of the light. In addition, we need to find the time it takes the signal sent from the satellites to arrive to the receiver. The speed of light is about 186,000 miles per second. (Nova Stars Information Services). How we can measure the time, it can be easily explained. Suppose there was a way to get both the satellite and the receiver to start playing "The Star Spangled Banner" at precisely 12 noon. If sound could reach us from space (which, of course, is ridiculous) then standing at the receiver we'd hear two versions of the Star Spangled Banner, one from our receiver and one from the satellite. The two songs at the receiver are not synchronized; the delay between the two songs is the time it takes the signal to get to the receiver. We have the speed and time in which we can find the distance of the receiver. (Nova Stars Information Services).

Velocity (mph) x Time (hours) = Distance (miles)

(Nova Stars Information Services)

The difference of this is that our satellite uses some code called "Pseudo Random Code". The "Pseudo Random Code" (Trimble Navigation Limited) is a random digital signal that has high and low voltage, as the picture shows below.

Figure 9. Pseudo Random Code

In this project, we want to construct a system that can work indoors, known as a Local Position System. This is going to use four transmitters located above the conductor. The first three transmitters are used to find the location, and the fourth transmitter is used for the clock time. Each of the transmitters transmits the Pseudo Random Code in a different channel, and the receiver (that will be our conductor) can identify from which transmitter a signal came from. The receiver identifies which transmitter by correlating known PRC codes with an incoming signal. Once the transmitter has been identified in the signal, the time shift of the signal is used to determine the distance between the satellite and receiver. (Trimble Navigation Limited).

Timing Pulse	Shift Register A	Shift Register B
Initial value	1 0 1 1	0 0 1 0
After T_1	1 1 0 1	1 0 0 1
After T_2	1 1 1 0	1 1 0 0
After T_3	0 1 1 1	0 1 1 0
After T_4	1 0 1 1	1 0 1 1

Table: Time Shift.

In the table above, it shows two shift registers A and B. Each of that has a signal sent by the transmitters. The register has one clock (timing pulse) that shifts the two signals (RPC) to the right for every timing pulse. To start, the clock (T1) is put at 1 to the left bit and shift the rest to the right. After, at (T2), it is replacing the left bit with the right and shifts to the right the rest of the bits. The register will continue to shift until the PRC matches with the original signal. The time it takes to put the two signals in phase is the travel time ΔT.

We are going to use a method called triangulation (figure 10), which is a method of finding your position by measuring the lines and angles of a triangle on a map. The figure below shows how the triangulation works. (Longman Dictionary, p. 1543)

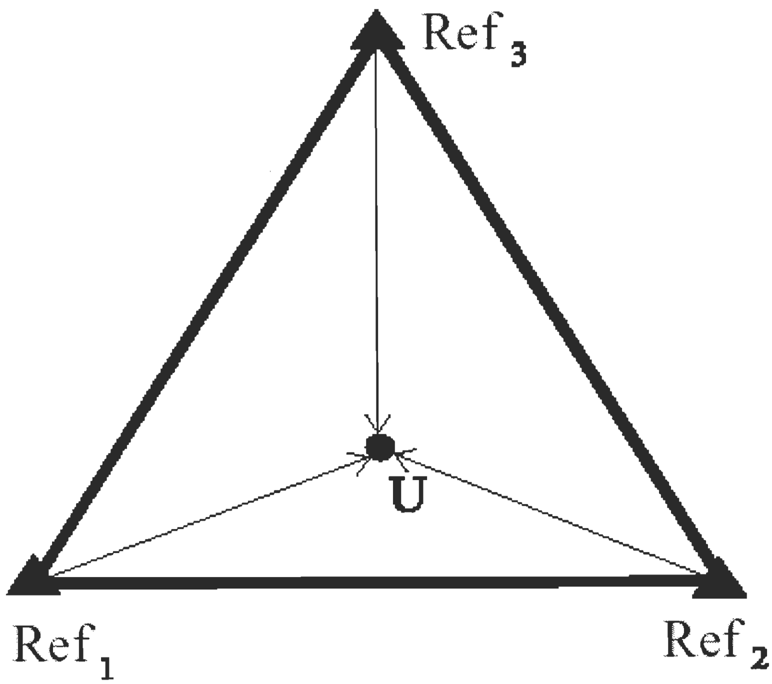


Figure 10: Ref123 are the transmitter .U is the conductor

The conductor is holding a receiver (antenna) in his hand. The receiver will be connected to a computer that can analyze the "Pseudo Random Code" and find the distance between the antenna and the transmitter.

Because our antenna is moving, the GPS can send to the computer the position of the antenna at any time. The computer needs to know where our transmitters are located, the distance between each transmitter and the distance of each transmitter with the ground. The distance between the transmitters and the receiver is calculated by using an algorithm. This algorithm was found from an old MQP. The algorithm will give us the position of the receiver in 2D. To do this, the algorithm needs the position of the transmitters T and the distance from the transmitter to the receiver D. We know the position of the transmitter and the position of the receiver is given by the method that was explained in the previous part. Also, we need a guess point were the receiver is located. In the figure 11 below, it shows all the points necessary to the algorithm. (Dasmah)

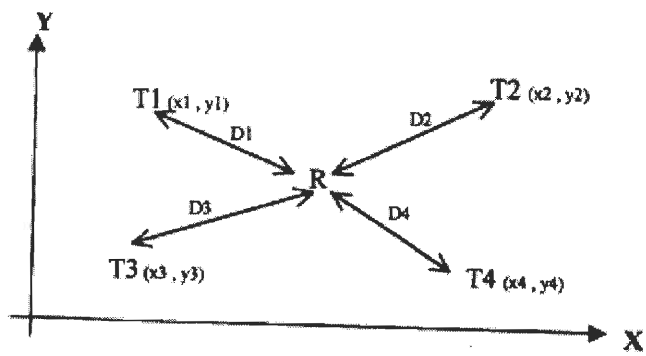


Figure 11 Measurement Necessary for Algorithm

The algorithm is going to give to us an approximation of the position of the receiver. In the figure below, it shows a block diagram of the geolocation algorithm for n receivers. (Dasmah)

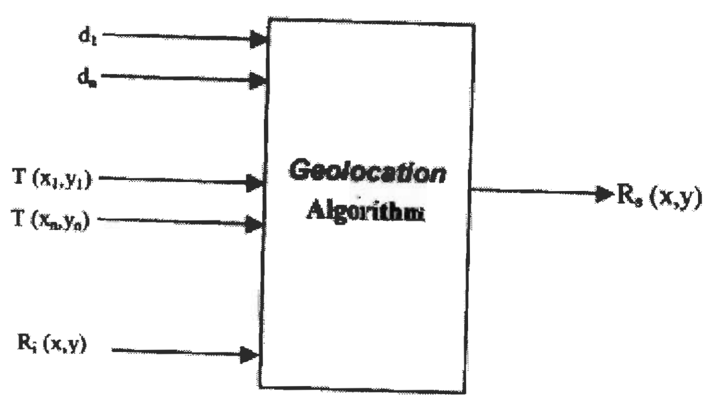


Figure 12.Block's diagram of a geolocation algorithm

Where:

d_i = represents the distance from the *ith* transmitter to the receiver calculated from Matlab.

$T(x_i,y_i)$ = location of the *ith* transmitter.

$R_i(x_i,y_i)$ = initial guess location of the transmitter.

$R_s(x,y)$ = estimated location of the receiver calculated by the geolocation algorithm

This algorithm is used for 8 transmitters. In our case we will use only 4 transmitters. The algorithm is using the formula to estimate the distance. The first example is shown in equation #1. (Dasmah)

$$d_s = \begin{bmatrix} \sqrt{(x_s - x_1)^2 + (y_s - y_1^{\,2})} \\ \sqrt{(x_s - x_2)^2 + (y_s - y_2^{\,2})} \\ \sqrt{(x_s - x_3)^2 + (y_s - y_3^{\,2})} \\ \sqrt{(x_s - x_4)^2 + (y_s - y_4^{\,2})} \\ \vdots \\ \sqrt{(x_s - x_n)^2 + (y_s - y_n^{\,2})} \end{bmatrix}$$

Equation #1

where

x_s = is the x-coordinate of the estimated location of the receiver
y_s = is the y-coordinate of the estimated location of the receiver
x_n = x-coordinate of the *nth* transmitter
y_n = y-coordinate of *nth* transmitter

The equation #1 is used to estimate the distance between the transmitters and the receiver. We are then going to use a matrix Δd, which is the difference between the actual position of the receiver and the estimated one. (Dasmah)

$$\Delta d = \begin{bmatrix} d_1 - d_s \\ d_2 - d_s \\ d_3 - d_s \\ d_4 - d_s \\ . \\ . \\ d_n - d_s \end{bmatrix}$$

Matrix.

d_n = calculated distance between *nth* Transmitter and the Receiver.
d_s = estimated distance between the transmitter and the receiver.

This matrix is going to make a loop until the difference of the calculated distance and the estimate get very close. When this happens, the result Δd is used in the next equation #3 that is shown below. (Dasmah)

$$\Delta d = G \times E$$

Equation #2

Where:

Δd = The difference between calculated distance and guessed distance of the receiver location.(2×N matrix)
G = A NX2 geolocation matrix where n is the number of transmitters
E = A 2X1 matrix of the estimated location of the receiver in x-y coordinate system

In this equation we are looking for the E so the equation can be change with. (Dasmah)

$$E = G^{-1} \times \Delta d$$

Equation #3

The G matrix is obtained by the use of the equation #4, shown below. (Dasmah)

$$G = \begin{bmatrix} \frac{x_1 - x_s}{d_1} & \frac{y_1 - y_s}{d_1} \\ \frac{x_2 - x_s}{d_2} & \frac{y_2 - y_s}{d_2} \\ \frac{x_3 - x_s}{d_3} & \frac{y_3 - y_s}{d_3} \\ \frac{x_4 - x_s}{d_4} & \frac{y_4 - y_s}{d_4} \\ \cdot & \cdot \\ \cdot & \cdot \\ \frac{x_n - x_s}{d_n} & \frac{y_n - y_s}{d_n} \end{bmatrix}$$

Equation #4

The next is to calculate the inverse of the G matrix (G^{-1}, a 2XN matrix). The equation for the G^{-1} is shown in the next figure. (Dasmah)

$$G^{-1} = \begin{bmatrix} \frac{x_1 - x_s}{d_1} & \frac{x_2 - x_s}{d_2} & \frac{x_3 - x_s}{d_3} & \frac{x_4 - x_s}{d_4} & \cdot\ \cdot & \frac{x_n - x_s}{d_n} \\ \frac{y_1 - y_s}{d_1} & \frac{y_2 - y_s}{d_2} & \frac{y_3 - y_s}{d_3} & \frac{y_4 - y_s}{d_4} & \cdot\ \cdot & \frac{y_n - y_s}{d_n} \end{bmatrix}$$

Equation #5

The next equation is the final output of the geolocation algorithm. (Dasmah)

$$E = G^{-1} \times \Delta d = \begin{bmatrix} X \\ Y \end{bmatrix}$$

Equation #6

The output result can be plotted with the use of matlab. The matlab's program is shown in the appendix. In the figure below, it shows the location of the receiver and the transmitters. In this case we start with only three transmitters. (Dasmah)

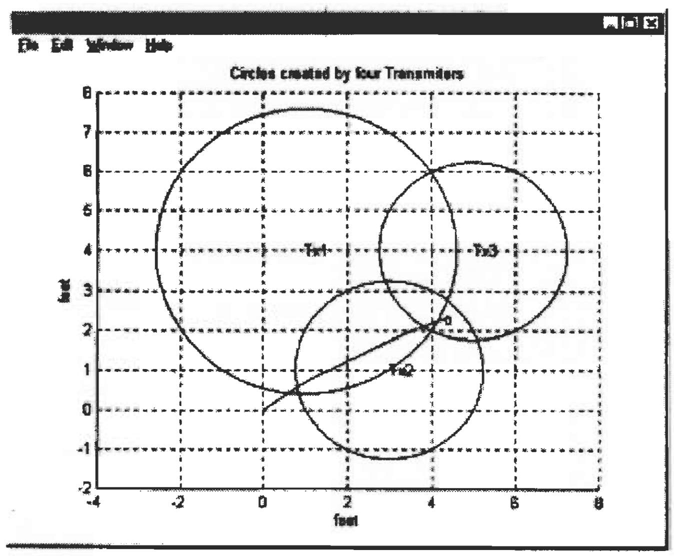


Figure 13. Output of the geolocation algorithm using 3 transmitters

We noted that the real position of the receiver is not at the point calculated by the algorithm. We increased the transmitter's number to 7 and we noted that circles and the point calculated by the algorithm were very close. This can be seen in the next figure. (Dasmah)

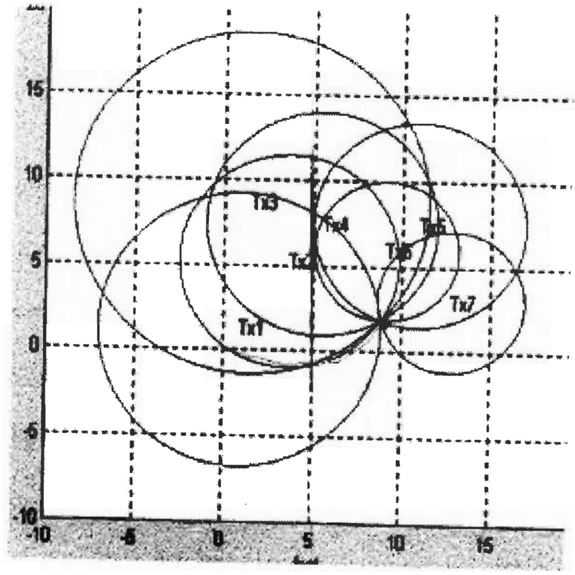


Figure 14. Output with 7 transmitters

The receiver is the one that elaborated the measurements and will send to the algorithm, which use these to localize the position of receiver. A block diagram of the receiver is shown in the next picture. (http://www.colorado.edu/geography/gcraft/notes/gps/gif/receiver.gif).

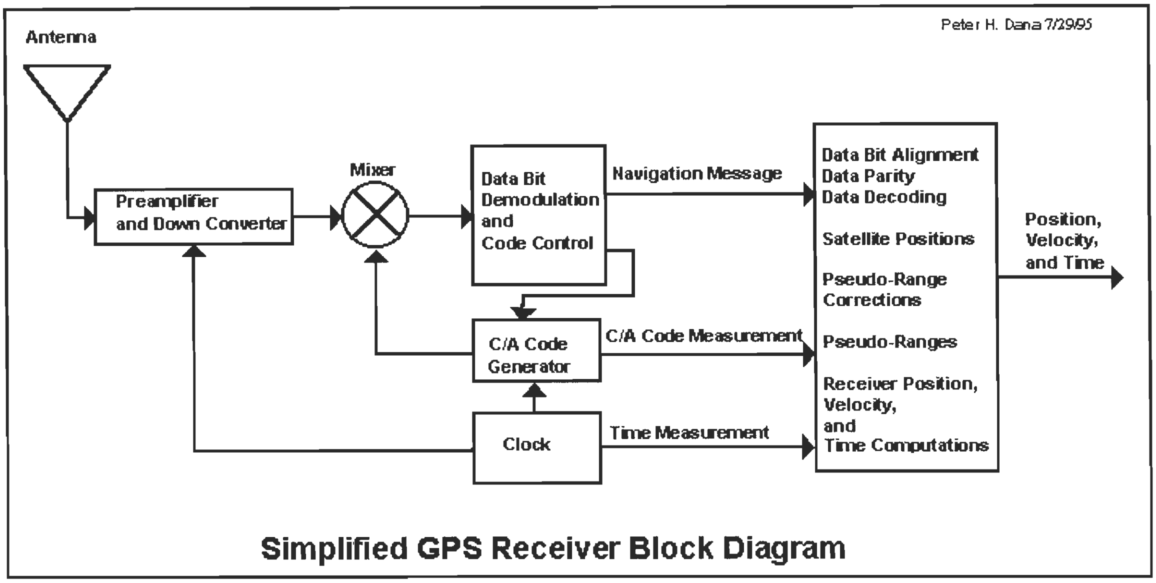


Diagram .1 Simplified GPS Receiver Block Diagram

Our next point is to elaborate a computer program that can analyze the position of the antenna at any time and to determine the velocity. The increase/decrease of the velocity will tell us how fast and how slow the music needs to be played. The antenna receiver that the conductor is holding in his hand will connect wireless to the computer, like the new wireless microphone. This system will allow the conductor to do any movement without any restrictions. The GPS system will pick up the position of the antenna in any circumstances. From our research, we tried to find one of the best receivers that are in the market. From our conclusion, we arrived at the most precise measurement that we can get from these receivers – which is about a meter and a half. The price of a system in this range is about $15, 000. (Red Sword Corporation).

The market is also showing that studies are being done to make receivers that can get more precise measurements to the centimeter. Our idea will work with the improvement of these machines.

II. Light diodes

One of the options that we study for our project is the use of photodiode. Photodiodes are analog sensors that are used to sensor light. Photodiodes, when exposed to a light source they can give a current to its output. When light strikes the photodiode, it will return with a low current at the output, and a higher value of current when less strikes. Those sensors are very sensitive to light and have a quite big field of view. In the picture below, a photodiode is shown. (RISS Institute).

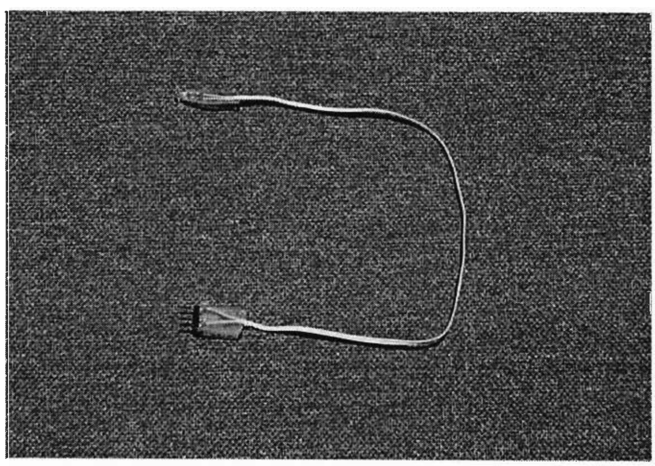


Figure 15. Photodiode

The photodiode will pick up a signal carried (a light beam) and produce a modulated current. The photodiode capture the variation of light intensity and display the reading to an analog devise like an oscilloscope or computer.

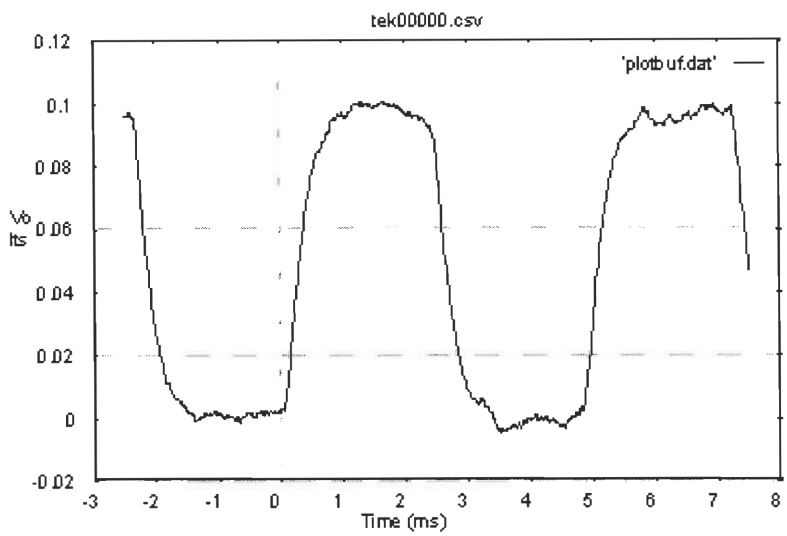


Figure 16. Response of a photodiode

In the graph shown above, we can see the reading of the photodiode output with the variation of the light. An initial idea was to give to our conductor a led that our conductor will hold in his hand and the photodiode will pick up the light that led is emitted. ("TILL Photonics Photdiode").

The photodiode when in contact with light emitted by the led produce a current at its output. This current can be changed in voltage because the resistor inside the photodiode is constant. The voltage that it is producing is very small and this can be solved by using an amplifier like in the circuit that is shown in the figure below. ("Singly Supply, Low Power, High Output, Current Feedback Amplifier").

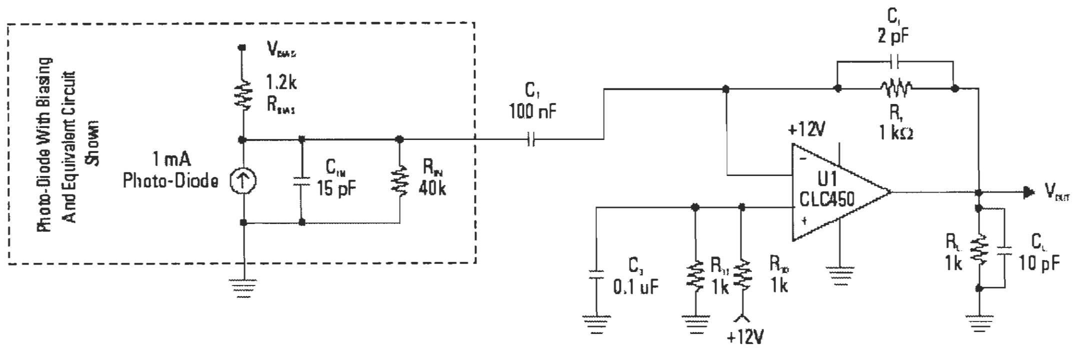
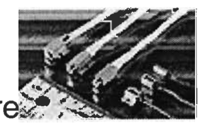
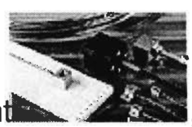
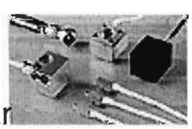


Diagram 2. Photodiode and amplifier signal output.

By looking at the output function that we have in figure of the photodiode response, we can see that the voltage is zero when we have the maximum light intensity and vice versa. These points can be our time beat of the music because our oscilloscope is measuring the time between the maximum voltage and minimum. The problems that we have with this system are the errors made by the light that are surrounding the room that will possibly give the same variation of the output voltage. To avoid the errors, we need to put our conductor in a complete dark room because a minimum change of light can change our output current. In addition, the led diode has to be in the same direction of the photodiode to pick up the light and if the conductor is moving on the side, the photodiode cannot see the light. This will make our system fail and we need a system that can see the position of the antenna in any moment. The option to use photodiode was not considered a very good idea.

III. Accelerometers

Accelerometers were our team's first idea for capturing the movements of the conductor to give us the desired beat. The team was going to place 3-5 accelerometers onto the subject in several different locations: 2-3 on the arm and 1-2 on the conducting unit using a possible wireless system. The first problem that the team ran into was which accelerometer to buy. In the market there are several different types of accelerometers: miniature . High performance , severe environment , multi axial , and automotive/ vehicular  accelerometers, all of which are extremely expensive. Our team made a decision to choose the multi-axial accelerometer in hopes of reducing the number of units we would have to use. The multi-axial units would handle g-forces up to 10000g so they were going to be affective in capturing the desired information.

Our team met with another WPI MQP group who was working on a similar project and was using automotive accelerometers. The MQP group had managed to construct a unit and wrote software to analyze their results. The group also ran into two severe problems. They first spent nine months writing the software and adapting it to the accelerometers, and after the software and the needed filters were written, they were still getting results with a great amount of error. The error they were getting was the accelerometer coupled with the software was having trouble-finding zero on the coordinate plane. With trouble finding zero, there was a huge problem for our group because without zero and the large movement that a conductor makes we would be getting a potentially large amount of error from the software and the accelerometers.

The second problem that we would run into was that we didn't have a computer science team member to write the specific software. According to Coventry University who did some research on accelerators said "A major problem that is associated with systems comprising large numbers of accelerometers, or other acoustic sensing devices, is that of data analysis bottlenecks. The data analysis generally includes Fourier analysis or signal averaging, both of which are computationally expensive processes. Although the computational power of signal processors continues to increase, the processing requirements of large accelerometer systems continues to outstrip the rate of increase." http://www.mis.coventry.ac.uk/research/imd/projects.html. The university is having a similar problem with the software, as we are. It is getting too complicated to write.

IV. Infrared Video Camera

Another possible type of device for capturing the information that we need was a video camera that utilized inferred and made a skeleton figure to track the motions of our conductor.

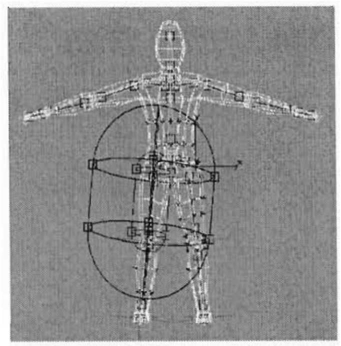


Figure 17-Infrared Camera Display

Video motion is an extremely effective way of capturing the movements of an object. The system uses a specialized video camera along with body markers and computer software to interpret movements within the subject. Enough markers must be used to get a proper computer image. Also a minimum of two cameras must be used. Even with professional highly sensitive systems, algorithms can be confused and markers can be mixed up but, in our case only one sensor will be used and thus only one algorithm will be employed.

Camera applications have been extremely helpful and one of the more important applications has been on the medical field, mostly in biomechanics and medical aspects of sports. By using video imaging, a doctor can analyze joint movements and correct the joint movements and analyze post-surgery results. Again the problem that our team had here was the prices of the cameras and the prices of the sensors. Our team could not afford the proper equipment. And it was possible that after experiments and relating it to software, it could be possible that it would not give us the proper information that we needed to complete our virtual conductor. After researching and reading other projects, we concluded that a video camera will be one of the best options that we have to capture the movement of the hands of our conductor. For example, "A Computer Music System that Follows a Human Conductor" by Hideyuki Morita, Shuji Hashimoto, and Sadamu Ohteru, is doable. Their project was successful and by using some of their ideas, we can build and achieve our project. The movement of the conductor will be very precise. Our conductor will control a MIDI (musical instrument digital interface) by using the gestures of his hands. The MIDI is standardized to mutually convey real-time musical performance information between electronic musical instruments. This is divided in two messages, system and channel. Each channel message plays different instruments and the system message is controlling the whole system performance. To capture human gesture they process a system that memorizes basic gestures that the conductor will make when directing an orchestra. (Morita)

The figure below shows some of the stored gestures of the conductor.

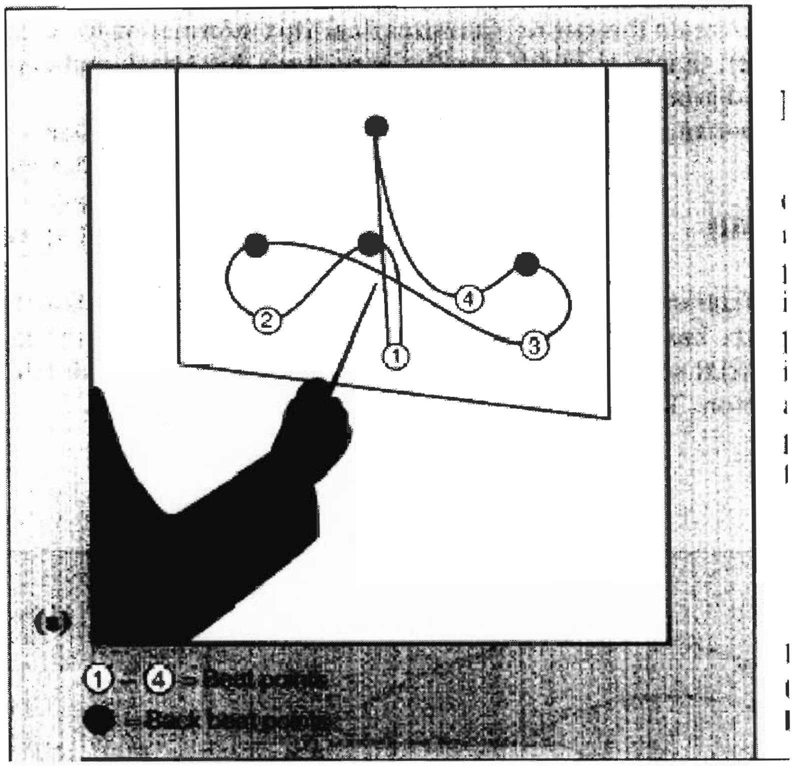


Figure 17- General Conductor Movement 1

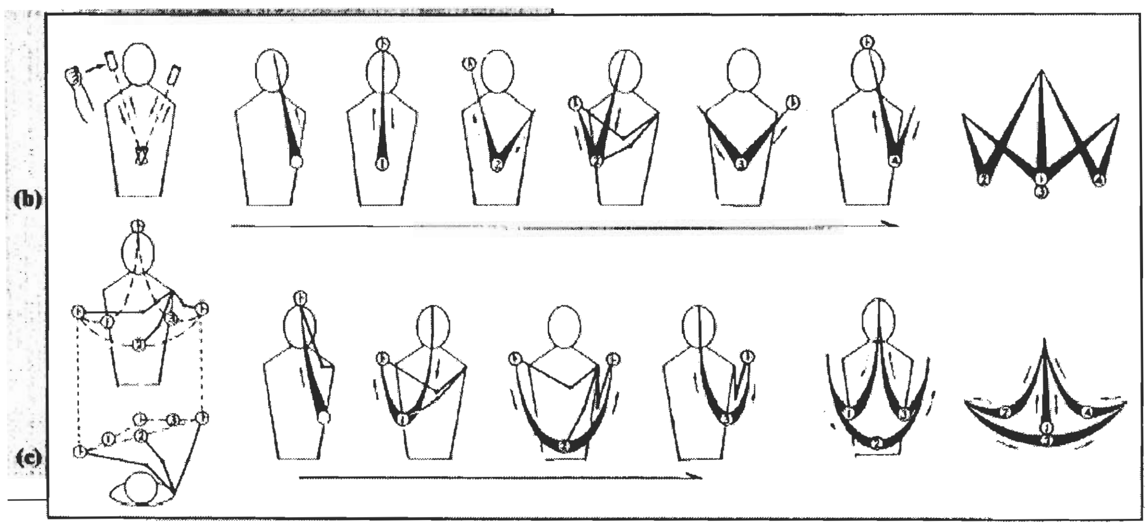


Figure 18 – General Conductor Movement 2

The system was called MPX (musical performance expression). This will store in memory all the symbols and gestures that a conductor will use when playing music. The MPX will match the movement of the conductor with the one store in the memory and tell the computer. The computer will control the MIDI that it will play the music. The figure below shows how the MPX works. (Morita)

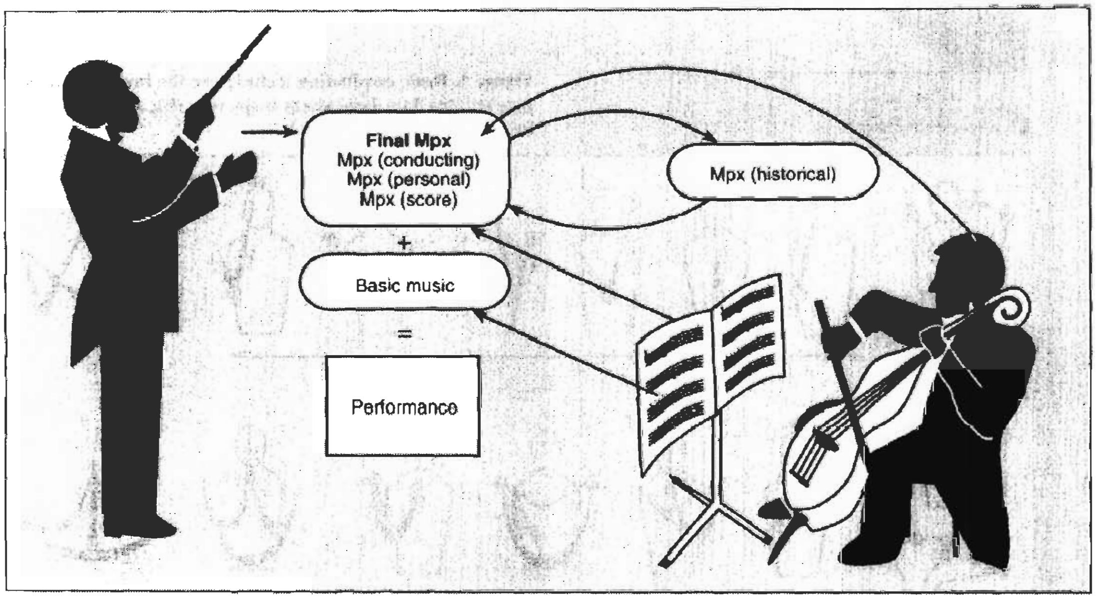


Figure 19 - Mpx

The conductor is using a baton in his right hand. On the top of it will be installed an infrared LED and a glove on his left hand, the glove has an optical fiber sensor and a magnetic position sensor. These are captured by a video camera (CCD camera) which will give us all the data. The camera will filter the data and will let by only the infrared light of the baton and the light of the glove. From this, the computer will find the notation (velocity, acceleration and trajectory) in two or three dimension, depending on how many cameras we are using. (Morita)

The two figures below show – 1) the movement of the baton and 2) the glove structure.

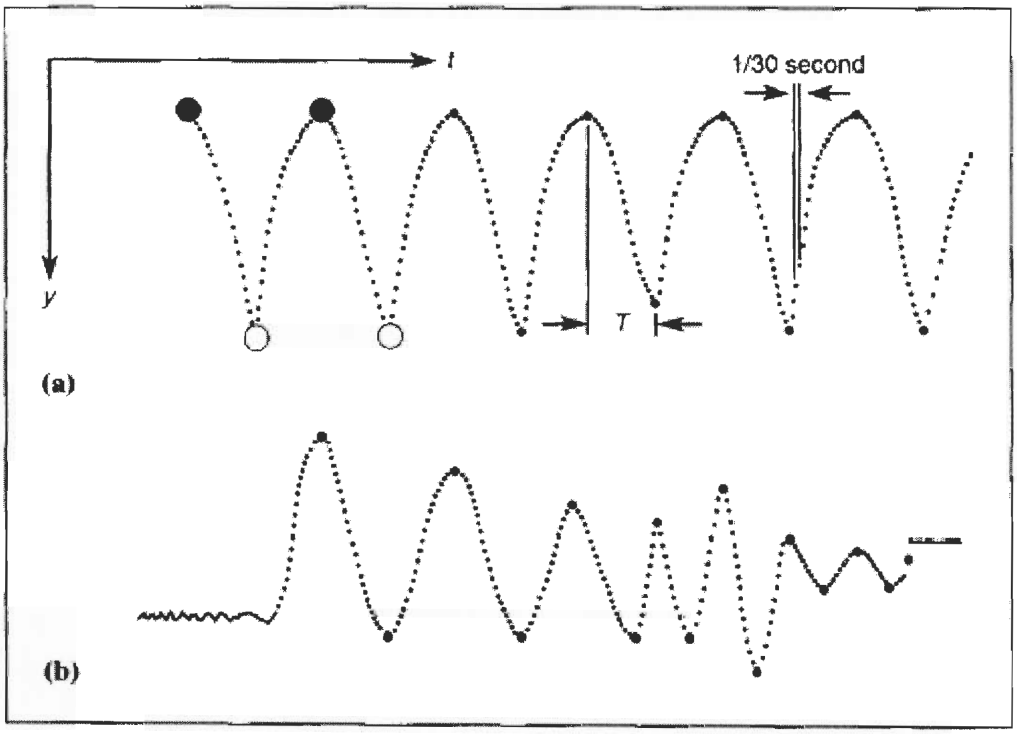


Figure 20 – Baton Movements

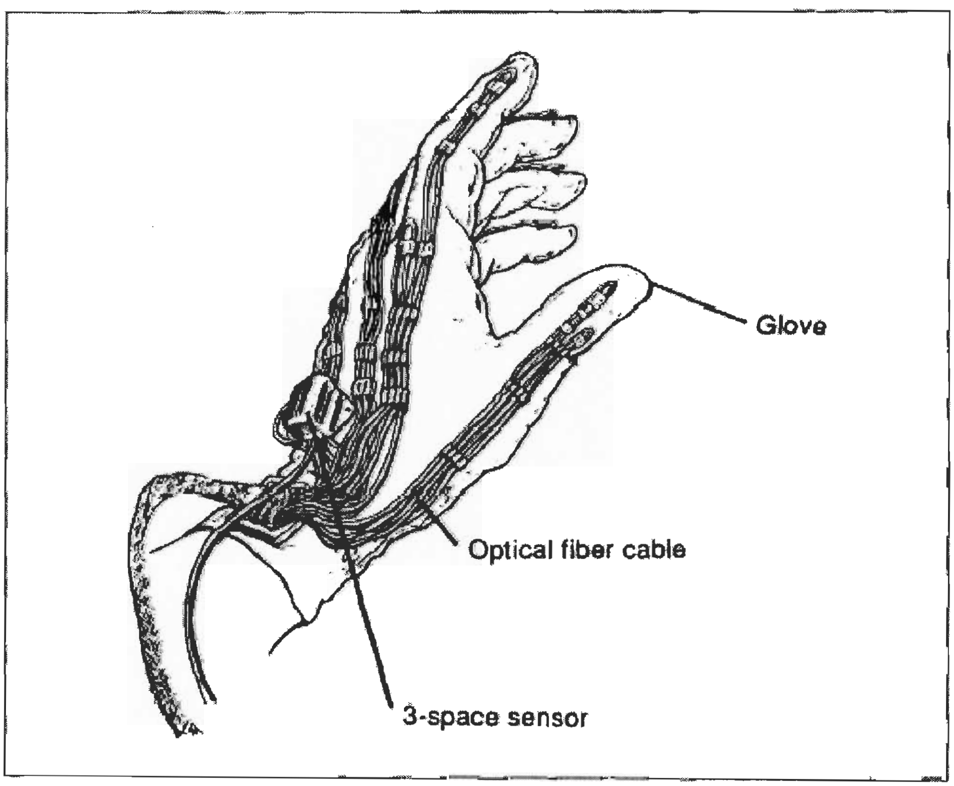


Figure 21 – Sensor Glove

The baton given has the beat (tempo) of the music in figure #A. You can see how the beat is taken. In figure # B it shows the changing of the beat.

The glove use the positions memorized in the MPX. These positions are represented with the change of the movement of the glove. In the figure below, it shows some of the positions. (Morita)

Value	Description
S_0	Vertical position
S_1	Horizontal position
S_2	Sum of five previous values of a vertical velocity
S_3	Sum of five previous values of a horizontal velocity
S_4	Sum of five absolute previous values of a vertical velocity
S_5	Sum of five absolute previous values of a horizontal velocity
S_6	Crooking of the thumb ([first joint] + [second joint])
S_7	Crooking of the index finger ([first joint] + [second joint])
S_8	Crooking of the middle finger ([first joint] + [second joint])
S_9	Rotation of the palm
S_{10}	Facing of the palm (up, down)

Figure 22 – Position Channel

Also with the use of the glove, we can use it to change volume and change the performance of the music, like if we want a vibrato or a crescendo. Also you can select the instrument that you want to perform in the moment. In the two figures below, it shows some examples of the conductor's gesture and how it is used the point to change the instrument. (Morita)

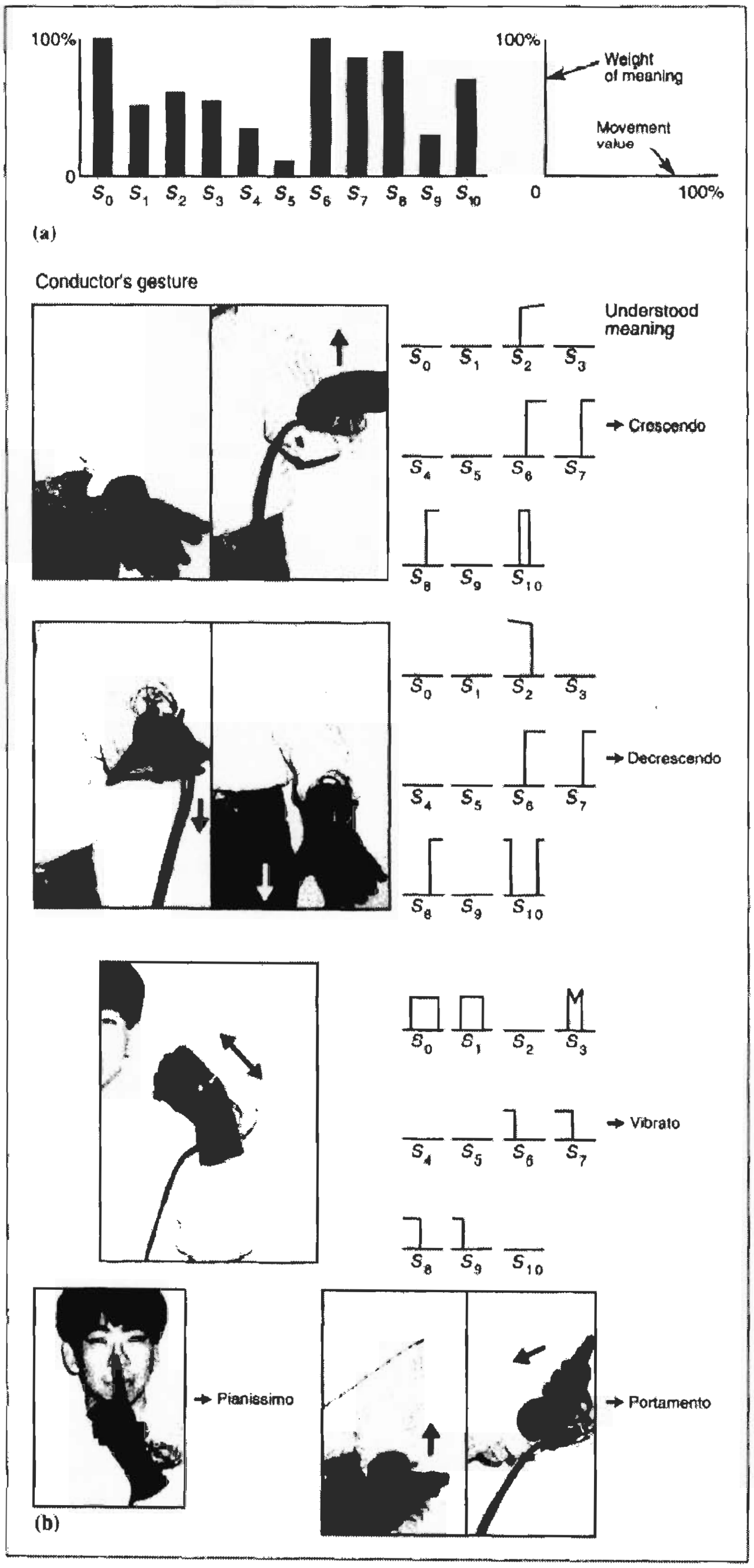


Figure 23 – Stored Symbols in Mpx

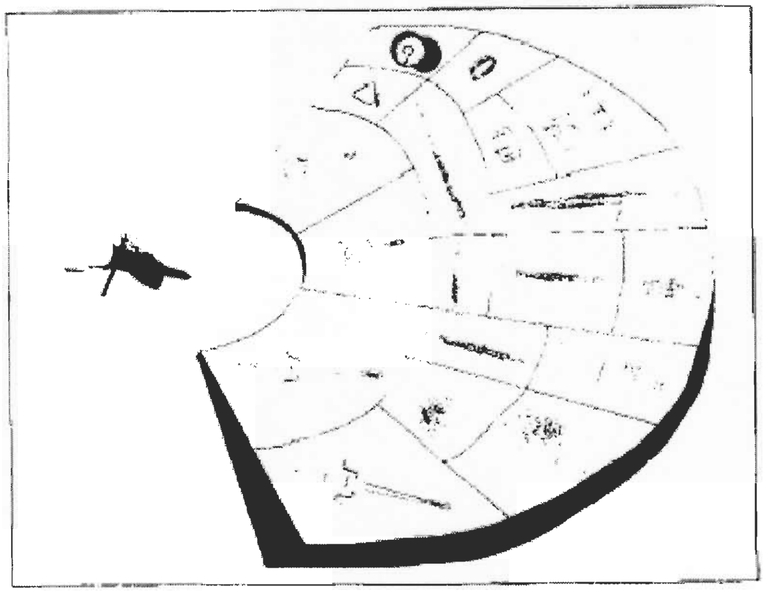


Figure 24

The system using the video camera can be considered one of the best choices to achieve our project. The system can be built and data can be easily processed. Also the MIDI and MPX can be used for any of the different methods examined in this project. Once we have the velocity or acceleration and sending this data to the computer, the other two programs can select the beat of the music. For the glove part, this can not be done with the other method. (Morita)

V. Doppler Radar

The idea of the Doppler Effect is similar to the theory presented in GPS. The Doppler Effect uses sound waves to determine the shift in frequency and wavelength of the waves. The Doppler Effect is given by the formula where the

$$f' = f_0\left(\frac{v \pm v_0}{v \pm v_s}\right)$$

Equation #7

perceived frequency is (f'), the actual frequency is (f_0), and the relative speeds of the source is (v_s), the observer is (v_o), and the speed of the waves in the medium is (v). There are interesting cases where the velocity of the source is equal to or greater than the velocity of sound, but for our application this is certainly not a concern. Also, one could modify this formula since the Doppler Effect works with other waves as well, not just sound waves. To use radar waves would be best because it would not then interfere with the Virtual Conductor and produce a type of noise pollution. This would be similar to the technology used in meteorology in determining the position and speed of rain, hurricanes, or large cloud movements. By using the radar waves in conjunction with the Doppler Effect, one could determine the position of say a conductor's hand, sampled at certain times. However, studies have been conducted that suggest the types of waves and frequencies that are used, could be harmful to humans. This obviously makes this approach unacceptable, since it could cause harm to our conductor. The theory of this approach is promising, but the means by which it is conducted, is not.

Conclusion

After all the possible different types of systems were explored our team decided to go with the GPS system. The GPS system would be the best suited for the application and you gather the most usable information. The problem for the GPS is that localized system is still in the early stages of development and is hard to obtain. All of the other systems would work for gathering the data needed but the data would need a great deal of filtering and a large amount of the data would be unusable and give us a greater error. With GPS still in its early stages the inferred camera would be the best application that is now currently available. But as localized GPS advances it will prove to be the better system for our project.

Appendix

in this section use phase method to calculate the distance

```
function assignment()
   close all; clear all;
   % load raw data obtained from RT software.
   infile = input('Enter the file prefix (.raw) => ','s');
   d_i = input('Enter the actual distance(from .raw file)');
   d_toa =input('Enter the distance(from TOA)');

   fname = [infile,'.raw'];
   eval(['load ' fname]);
   rt = eval(infile);
   rt=sortrows(rt,[1]);

   t_rt = rt(:,1);
   amp_rt = rt(:,2);
   phs_rt = rt(:,3);
   ak=amp_rt.* exp(1j*phs_rt);

   %###########################
   fc=10e8;
   C=2.9979281e8;
   npaths=length(t_rt);
   %###################################
   % estimate distance by phase method
    Pt=0+0i;
    for i=1:npaths
      Pt_i=ak(i);
      Pt=Pt+Pt_i;
   end;
   ang_i=-angle(Pt);
     if ang_i<0
        ang_i=2*pi+ang_i;
     end;
   d_phase=(C*ang_i)/(2*pi*fc);
   %#####################################
   d_2pi=0.3;
   m=(d_i-d_phase)/d_2pi;% calculate m following the actually distance d_i
   n=round(m);            % round n, n=+-1,+-2,+-3....+-n
   d_phi=d_phase+n*d_2pi % estimate distance by phase method
   e_phi=abs(d_phi-d_i); % calculate error of distance by phase method
   e_toa=abs(d_toa-d_i); % calculate error of distance by TOA method
```

In this appendix using matlab to calculate the first peak TOA, estimated distance from transmitter to receiver, and estimate error as were decryption in section 3.3

```
function assignment()
```

```
close all; clear all;

% load raw data obtained from RT software.
infile = input('Enter the file prefix (.raw) => ','s');
act_dist = input('Enter the actual distance(from .raw file)');

fname = [infile,'.raw'];
eval(['load ' fname]);
rt = eval(infile);
rt=sortrows(rt,[1]);

t_rt = rt(:,1);
amp_rt = rt(:,2);
phs_rt = rt(:,3);
ak=amp_rt.* exp(1j*phs_rt);

BW=40e6; % PN chip BW.
N=5; % number of samples per chip.
Tc=1/BW; % period of chip.
Ts=Tc/N; % period of sampling.
Rs=1/Ts; % overall BW = BW x N.

T=1/BW;
B = 0.5; % raised-cosine roll-off factor.

t1=0; t2=200e-9;
t=linspace(t1,t2,500);

npaths=length(t_rt);
Ht=zeros(1,length(t));
for i=1:npaths
    Tm=t-t_rt(i);
    Ht_i=ak(i)*raisedcosine(Tm,T,B);
    Ht=Ht+Ht_i;
end;
mag_Ht=abs(Ht);
max_amp = max(mag_Ht);

pulse_rt_t=t;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Peak detection algorithm to extract the characteristics of the pulse rt
curve_mag = mag_Ht;
curve_time = pulse_rt_t;
curve_max = max(curve_mag);

range_db = 22;
range = 10.^(range_db/20);
threshold = curve_max/range;
n = 0;
for k=2:length(curve_mag)-1
    if curve_mag(k)-curve_mag(k-1)>0 & curve_mag(k+1)-curve_mag(k)<0 &
curve_mag(k)>threshold
        n = n + 1;
        peak_time(n) = curve_time(k);
        peak_mag(n) = curve_mag(k);
    end;
end;
peak_rt_m = peak_mag;
peak_rt_t = peak_time;
peak_rt_no = n;
```

```
    figure; hold on;
    stem(t_rt*1e9,abs(amp_rt)/max(abs(amp_rt)),'g');
    plot(pulse_rt_t*1e9, mag_Ht/max_amp,'b');
    plot(peak_rt_t*1e9, peak_rt_m/max_amp, 'ro')
    hold off;

    xstex = 0.5 * (min(pulse_rt_t*1e9) + max(pulse_rt_t*1e9));
    ystexm = 1;

    s=[' Time response  peaks of "',infile,'"'];
    title(s);
    xlabel('time in ns');
    ylabel('Magnitude');

    s=['First peak TOA = ',num2str(peak_rt_t(1)*1e9),' ns'];
    text(xstex, 0.94 * ystexm, s);
    calc_dist=peak_rt_t(1)*(2.99792*1e8);
    s=['Estimated distance = ',num2str(calc_dist),' m'];
    text(xstex, 0.88 * ystexm, s);
    s=['Actual distance = ',num2str(act_dist),' m'];
    text(xstex, 0.82 * ystexm, s);
    s=['Estimation error = ' num2str(abs(calc_dist-act_dist)),'m'];
    text(xstex, 0.76 * ystexm, s);

return;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [f] = raisedcosine(t,T,B)
%Raisedcosine function

    len_t=length(t);
    f=zeros(1,len_t);
    for i=1:len_t
       if t(i)==0
         f(i)=1;
       else
         if t(i)>6*T | t(i)<-6*T
           f(i)=0;
         else
           f(i)=sin(pi*t(i)/T)/(pi*t(i)/T);
           f(i)=f(i)*(cos(B*pi*t(i)/T)/(1-4*(B^2)*(t(i)^2))/(T^2));
         end;
       end;
    end;

return;
```

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