Virtual Control of a Robotic Arm via EMG Signals Processed Through LabVIEW Filter Circuit

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Summary

Today's technological climate changes about as rapidly as the daily weather. With large corporations leading the way, pushed by thousands of smaller start-ups, technological advancements abound. The field of medicine is no exception, being supported by engineered instruments and equipment. Every facet of medicine relies on the use of some advanced, precisely designed tool, whether you look at insulin injection pumps for individual use, or large operating theaters which provide surgeons with every tool imaginable. This project aims to help the latter, providing surgeons with yet another tool to drastically improve the medical field. Millions of surgeries are performed each year in the United States alone, and countless others take place abroad. Here in the United States, we pride ourselves on having the latest in cutting edge facilities and personnel. However, what about those individuals not fortunate enough to have access to these advanced and even state-of-the-art resources? What about our soldiers who travel the globe and get injured protecting the liberties and securities that we enjoy every day? Surgical procedures are necessary no matter where in the world one is located. For this reason, the development of a remotely operated surgical vessel would greatly enhance the quality of life worldwide. For impoverished nations where access to quality healthcare is a luxury if it is available at all, a device which can perform surgery under the control of an expert surgeon provides people with access to medical care rarely seen in these regions. The battlefield is a treacherous place and our wounded soldiers would also benefit from the expertise of a skilled surgeon. These surgical theaters are not always located in the safest or easiest places to travel to. The development of a remotely

controlled robotic surgical system would break down such physically restrictive barriers. Although robotics have advanced substantially in recent years, showing that mechanical devices governed by computers have redefined precision, speed, and efficiency, many will still argue that there is no replacement for human instinct and intuition. Humans can quickly react and adapt to the current situation, and such an important instinctual ability means that we can never fully replace Man in the surgical theater. With this consideration in mind, a surgical device governed by a computer and operated by a human would be the perfect merger between man and machine.

The movement of muscles generates an electrical signal similar to the EKG signal a heart produces, which most people have seen. The corresponding signal produced by skeletal muscles is called an Electromyogram (EMG). It is possible to measure these contraction signals by using either surface electrodes placed on the skin (to measure bulk activation of the muscle) or needle electrodes inserted into each particular muscle (to measure activation of specific muscle fibers).During muscle contraction these electrodes will measure the change in electrical potential of the muscle, and using a computer program and device developed by CleveMed (called the BioRadio) plots the information on a graph. This graphical information can be used for many quantitative analyses but our project will utilize this data in another fashion. Incorporating a graphical computer programming software known as LabVIEW, the EMG signal can be filtered to remove ambient noise and amplified. This filtered signal can then be interfaced with a surgical device, a robotic arm. The arm chosen is the Lynxmotion AL5B which will have five servo motors and a total of 4 degrees of freedom (DOF) to mimic the major joints of a human arm. By strategically placing electrode pairs on the muscles that control normal joint movement within a person’s arm, the different motors for the robotic arm can be controlled individually using the corresponding signals from an operator’s appropriate muscle group. In this design plan, the LabVIEW Virtual Instrument created on the computer is used as a relay for a human operator to control a robotic arm; this allows for human control with the correctional and precise abilities of a robotic device.

The concept of this design is to take the human element and enhance it with the technical advantage and precision of a robot. An expert surgeon could then operate the robotic arm remotely, using their natural muscle movements to perform the same tasks that would otherwise occur in person. The scope of this project seeks to establish a reliable means of relaying the EMG signal to a robotic arm via a computer program interface, which we will design.

Abstract

CleveMed's BioRadio Electromyography device and software will be used to capture EMG signals from a human operator in real time. This signal will undergo modifications to eliminate low frequency interference, and establish an average profile which corrects for signal degradation. Before outputting this filtered signal to the robotic arm, it will also be amplified to appropriate levels. These alterations will all be achieved through National Instruments' LabVIEW graphical programming software, in a virtual instrument (VI) which we will create. This graphical computer language will also be used to construct a relay for the signal to a robotic arm SSC-32 (serial servo controller) board, the type of servo motor found on the Lynxmotion AL5B robotic arm. LabVIEW software allows for customizable real time control over the signal during the relay to the SSC-32 board, meaning we can modify the signal and VI parameters without having to stop our VI. We will create our BioRadio/LabVIEW/Lynxmotion system in such a way to allow it to perform surgical based tasks. Error testing of a predetermined straight cut of specified length and depth will provide information on the accuracy and precision of the robotic arm under control of a human operator.

Introduction

The general advancement of technology over the last century has opened the door for rapid innovations in the medical community. Robotics is one of these fast growing technologies and within the last couple of decades has found a niche in the medical field as a powerful tool for surgery. Currently, robotics can be broken into three categories for use in surgery: supervisory controlled robotic systems, telesurgical systems, and shared control robotic surgery systems. Supervisory controlled robotic systems require the doctor to evaluate and image the patients by way of CT, MRI, Ultrasound, etc. Using these images, surgeons must then create a road map of precise movements for the robot to follow throughout the surgery, with no possibility for live interaction. Conversely, telesurgical systems allow the surgeon to control the robotic arms seamlessly and in sync with his or her own movements via joystick-like controls. The da Vinci Surgical System is the most recognizable example of a Telesurgical system, and the first robotic surgery system to be approved by the FDA and introduced in the United States in the year 2000. This system provides surgeons a means to operate less invasively and on a more precise level than allowed by the unaided human eye. The last system is shared control robotic surgery, which assists the surgeon by monitoring performance and giving feedback through active constraints. This system is typically used in orthopedic surgeries because the surgeon predefines areas around the bone of interest and as he moves further from the safe, workable region to the boundary region where soft tissue is present, the robotic arms give increasing resistance until the arm stops moving when it reaches the predefined forbidden region. All of these examples of robotic arms for use in surgery have greatly enhanced the abilities of the surgeons that employ them and provide an intriguing insight into the future of surgery.

Our project will fall under the umbrella of a telesurgical system, and will rely on electromyography (EMG) in order to obtain signals from the operator. Before discussing how these signals will be processed by the LabVIEW algorithm, it is important to establish a solid, fundamental understanding of how EMGs work and how they gather signals. The instrument which actually obtains EMG signals is an electromyograph. When muscle cells are activated, they produce an electric potential which the EMG can detect and record. These signals are recorded on an electromyogram. Different muscles produce different membrane potentials. The range of these potentials is also dependent on the type of electrode used to obtain the signal. There are two main types of electrodes which are routinely used to gather muscle signals: surface electrodes, and intramuscular (needle) electrodes.

Surface electrodes are, as their name implies, attached to the surface of a patient's skin. This is normally accomplished by a self-adhering disposable patch to which an electrode wire attaches, or by medical tape, conductive gel, and a conductive metal electrode. When using needle electrodes, a needle with one or two electrodes is inserted through the skin and directly into the muscle of interest. Benefits of needle electrodes are that the signal gathered from them is substantially cleaner than signals gathered using surface electrodes. Also, because needle electrodes are placed directly into the muscle of interest, this EMG signal is substantially larger than that obtained from surface EMGs, since the signal does not have to pass through an insulating material (i.e. the skin).

Another advantage of needle electrodes when acquiring an EMG signal is the specificity of these electrodes. Whereas surface electrodes can only record electric potentials for entire muscles, needle electrodes can be used to record the membrane potentials of individual motor units, allowing for a much more detailed view of muscle activation. The main disadvantage of needle electrodes, however, is their invasiveness. People are much more receptive to placing an electrode on their arm, rather than inserting needles into their muscles. Also, for our project, we do not necessarily need the super precise motor unit activation information that needle electrodes provide, making surface electrodes the best, and most acceptable choice for data collection.

CleveMed makes a BioRadio EMG device which uses surface electrodes to obtain EMG signals for up to eight (8) channels, in addition to one ground channel located on the bony part of the elbow. This device is not only readily available, but compatible with LabVIEW, the graphical programming software which we intend to use as a platform for our project's algorithm.

The collection of data is useless without the ability to analyze or process it. The advanced mathematical capabilities of computers have made them a favorite for analyzing large quantities of data. Simple programs can take data and provide accurate and reliable feedback almost instantaneously. The EMG signals mentioned above begin as the differential electrical potential within muscle cells and are transmitted through electrodes as an electrical current. Many software programs display EMG data as a continuously running graph. This project necessitates the conversion of this EMG signal into a data type that can be recognized and processed by the robotic arm, which is controlled by a separate processing unit. The software program chosen for this project is

LabVIEW by National Instruments. This program uses a language defined by graphical objects. These objects range from simple mathematical equations such as addition and subtraction, to more advanced functions that can be used to control third-party devices. To control a device a Virtual Instrument (VI) must be developed. A VI is a group of graphical components that work in conjunction with one another to process data from an input and provide an output. An important rule governing LabVIEW is data types must match between components to preserve the flow of information. A key component of LabVIEW utilized in this project is case structures. This was a source of difficulty initially as they have a complicated nature but when properly utilized advanced features can be used. For example a case structure can be dividing portions of a VI into segments that are executed sequentially; invaluable when using outside equipment to maintain order at USB ports, where information is transmitted. Case structures also provide platforms for certain functions to be repeated. This function is known as a loop and in real-time analysis a loop is essential to update the information being processed. A final necessity of developing a VI in LabVIEW is the use of Initializing and Ending functions. When writing a continuously updating program that has portions execute sequentially, having the ability to start and stop the program is beneficial. The advanced capabilities of LabVIEW combined with its' user-friendly graphical programming feature makes this an excellent platform to relay the signal between the EMG capture and Robotic Arm output.

Problem Definition

There is a global need for specialized surgeons; this demand is not any less significant in underdeveloped regions, where surgeons are at a technological disadvantage. Medical procedures are typically performed in hospitals, yet this can potentially hinder a patient's ability to obtain proper treatment; patients are spread worldwide, but qualified practitioners are clustered together, commonly in more developed regions. As a result, many patients are unable to receive the life-saving operations they require. Particularly affected by this localized scarcity of specialized surgeons are patients in third world countries, or military personnel on the battlefield.

Several obstacles further impede a patient's ability to receive quality surgical care: time, money, and safety. A patient may require immediate medical attention, perhaps requiring a complicated and risky life-saving operation. By the time a surgeon with the right skills can fly on-site to perform the surgery, it may be too late. Also, the travel and surgical costs for an expert surgeon to fly out and perform a certain operation would most likely be tremendous. Lastly, doctors would probably be more hesitant about travelling to more unstable areas of the world, or to battlefields, due to the associated safety concerns.

Objectives

With such an intricate and revolutionary concept, involving the seemless integration of man and machine, it was important to first establish both general and specific goals for this project. Starting generally, this project aims to set the groundwork to progress towards a means for effective and cheap surgery worldwide. With the increased availability of this product in many different regions of the world, it might one day be possible to have a surgeon linked up to each available robotic arm, in much the same way that computers today are linked to each other via the internet. It is also important to create an interface, which would allow the operator (surgeon) to control the robotic arm with extreme accuracy and precision. This second goal is crucial to the entire project, due to the very delicate nature of surgery. Obviously, when someone is under the knife, a surgeon's slightest mistake could be fatal. We must therefore make accuracy and precision our highest priorities when developing the algorithm used to translate the surgeon's EMG signals into robotic arm movements.

Specifically, we can break our goals of development into three main categories. These include gathering the signal (input), developing the algorithm, and transmitting the signal to the robotic arm. Signal gathering forms the entire base of our project; no matter how good our translation algorithm is, if we gather the wrong signal from the start, the robotic arm will not perform the desired movements. It is therefore crucial that we try to reduce or eliminate any and all interference when we collect the EMG signal. Next, we must look to the algorithm, the brains behind converting the input signal into a clean signal that the robotic arm can understand. We must translate the electrical potentials from the EMG into appropriate commands for the robotic arm. We want the robot to mimic the operator's arm movements as closely as possible, so this algorithm plays a central role in the project. Lastly, we must transmit the signal from the operator to the robotic arm. Ideally, this transmission will be done in real-time, so that the surgeon can naturally operate the robot without any lag in the device. Also, this real-time signal transmission will allow the surgeon to quickly react to any complications, which may arise during the surgery. In such a sensitive scenario, even as little as one second can mean the difference between life and death.

Research Plans

One of the most important steps in product development is the research that goes into determining the path to the final product. It is imperative to do meaningful research to ensure that the development process goes as smoothly as possible. The three basic, yet necessary areas of research include acquiring an input signal from the surgeon, converting that input signal using LabVIEW, and obtaining a useful output for the robotic arm.

The end product device began as a considerably broad design plan; this plan has since been targeted more adequately to match the needs of our problem with the functional capabilities of our group. Initially, our group sought to outfit the robotic device with any tools it would need to perform varying types of surgery in the field without direct human support. Further brainstorming entailed elements of EMG, accelerometers, IR scanning cameras, and video-gaming technology similar to Sony's PlayStationMove in order to operate the device. The output visualization included multi-functional cameras to include light settings, night-vision, IR lens, vital sign monitoring, X-ray capability, audio feedback, and force sensors. While these concepts were detailed we determined that such particular information was better reserved for our product should it continue years down the road. Upon conferring with our advisor Dr. Abdel Bayoumi, from the University of South Carolina, and Joseph Guiffrida, of CleveMED, it was determined to focus our energies to a more feasible goal such as creating a signal linkage for such a device. The current plan our group is implementing includes the use of EMG for the input and utilizing LabVIEW software for integration and signal processing. This groundwork will be integral in the future success of this product and any possible modifications to our original brainstorm possibilities will operate along pathways we define.

There are several possible methods of obtaining an input signal from the surgeon, but the key is to find an effective yet simple way to acquire this signal. Our main research focused on using an EMG signal. EMGs are useful control inputs because they are easy to attach to the surgeon, and they are a proven method for recognizing skeletal muscle movements. In addition, there is practically no learning curve for surgeons using EMGs because in theory the robotic arm will replicate their previously acquired surgical techniques

The input section of our project includes both a hardware and software portion. The tangible need for the surgeon is the EMG unit. Through the Biomedical Engineering Department, Laboratory section under the supervision of Dr. Gonzalez from the University of South Carolina our group has acquired the use of a BioRadio system produced by CleveMED. The system is provided with software currently uploaded on computers within the facility; functional components such as disposable electrodes, conducting gel, and other necessities are also incorporated into the use of the facility.

Through research we were able to define the most basic and essential movements of the arm and to determine the placement of electrodes to ensure that all of these movements are accounted for. There are six basic motions that would give the robotic arm a wide enough range of motion to accurately achieve our predetermined task (elbow flexion(1) and extension(2), humerus up(3) and down(4), wrist flexion(5) and extension(6)). Upon further investigation, basic movements could either be added to or subtracted from the aforementioned list in future development of the device. The muscles that stimulate these basic movements and therefore will have patch electrodes applied to them include the Biceps brachii, Triceps brachii, Flexor carpi radialis, Extensor carpi ulnaris, Deltoids, Serratus anterior, Pectoralis minor, and Lattisimus dorsi. Our system will have to be calibrated to each individual surgeon because everyone is shaped differently so the exact location of the electrodes will have to be adjusted to pick up the best signal. Furthermore, EMG waveforms will vary from person to person because not everyone has the same number of muscle fibers per motor unit and skin resistance can also vary. Other methods were also considered but eventually discounted as possible control mechanisms for our design (e.g. accelerometers, advanced motion detectors, or hand controls like joysticks). While accelerometer gloves allow the surgeon to have instinctual control, they were found to be expensive and much more complex algorithms would be required to achieve success. Conversely, joysticks (or other hand controls) would allow for a much simpler algorithm but there would also be a steep learning curve involved. However, if allotted the proper amount of time and resources, these other control methods could either be used in place of the EMG or in addition to it in order to provide more precise and accurate control over the robotic arm.

The surgeon will submit input to the device by means of Electromyogram (EMG) patch electrodes. The patch electrodes can provide an accurate reading of muscle-neural signal while maintaining a reasonable comfort level for the surgeon compared to probe electrodes, which are subdermal. The EMG electrodes will link with a CleveMED BioRadio that can transmit wirelessly. This technology allows the electrodes to be linked to the BioRadio attached on the surgeons' clothing, which increases the mobility and freedom of the operator. This system provides software to collect data and display this data in a graphical manner. However to integrate this equipment into LabVIEW, a Virtual Instrument (VI) must be developed. This VI is a program in LabVIEW which will take the BioRadio data directly from the receiver without relaying it through the CleveMed software. This direct path to LabVIEW allows for easier manipulation of the data and more seamless integration. The input will need to be calibrated to each individual utilizing the device, so as to match personal EMG signals with an accurate force, speed movement by the robotic arm.

In order for the robotic arm to move in response to the surgeon's input commands, the most critical part to the design process is developing the proper algorithm. Before the algorithm can be written we need to determine specific features that we can extract from the EMG signal use in the algorithm. Some preliminary research has been done on this topic and previous works have shown that some effective features are Integral Absolute Value (IAV), Average Slope of IAV (ASIAV), Variance, and Zero Crossing. IAV helps to determine the speed at which the surgeons arm is moving, which is one of the more critical problems faced in the design of a robotic arm. ASIAV determine if the muscle is contracted or relaxed, which is a key factor in establishing extension and flexion. While all of the afformentioned features would be helpful to translate EMG to arm movement, our group determined they are beyond the scope and time frame of this project. The signal from the BioRadio, will present the EMG signal as a waveform within LabVIEW. To integrate the arm in real-time using the signal as a point of extraction for our data will yield the best results. As an electrical potential signal there are positive and negative values; to eliminate this squaring the values is the best option. Then over a designated time value these numbers will be averaged; taking snapshots of the data allows us to control the speed of movement also. To bring these values to a manageable size the square root of the averaged numbers will be taken. This process can be accomplished by an RMS, root mean square function, within LabVIEW. This function has been shown to provide the most direct and simple method to extract the signal from each group of electrodes.

The hardware component of the robotic device has been narrowed down to a Lynxmotion AL5B robotic arm. The choice of this model was based upon the factors of compatibility, functionality, and price. The software package that can be purchased through Lynxmotion is integrated with LabVIEW systems, and the multiple axis of movement allow for limb movement comparable to human arm joints. Initially, our group aimed for two degrees of freedom. After determining that integrating a third servo motor was not as difficult as previously thought, we settled on using three degrees of freedom (wrist up/down, elbow, shoulder up/down). The Lynxmotion software, RIOS (Robotic arm Interactive Operating System), is controlled by a SSC-32 (Serial Servo Control, 32-bit) board. This program is installable onto a PC and then has calibration settings to protect the functionality of the device and the safety of the operators. Through this program each servo motor can be individually controlled, or complicated multi-axis pre programmed moves can be performed. Each servo motor represents a joint within the human arm; shoulder circumduction, shoulder adduction/abduction, elbow flexion/extension, wrist flexion/extension, and hand flexion/extension to mimic grip. The SSC-32 must be integrated with LabVIEW to allow control of each servo motor by the corresponding muscle groups. Integrating this program directly as a VI within LabVIEW allows for more direct control and integration of our signal.

The perception by a surgeon during surgery is an irreplaceable skill. In person visualization during surgery used to be by the process of making large cuts in the patient in order to provide the surgeon with a wide field of view. This technique progressed over time into the utilization of fiber optic cameras inserted into much smaller incisions; similar to endoscopic surgery. Using smaller incisions improved both patient care and recovery time. Our goal of making simple incisions is only the first step towards the final operational concept of a remotely operated robotic device. The progress toward such a strong final product however demands more of a sophisticated method of visualization than personal field of view testing. Since the device is operated remotely, the surgeon will not have a direct view of the patient, or more importantly, inside the patient. We therefore considered the incorporation of this fiber technology into our design, by attaching fiber optic cameras to our arm at the point of instrument attachment. Also, in order to allow the surgeon to have a general view of the patient, we decided another camera placed either further removed on the device via a moveable mount would provide an encompassing view for the surgeon. A more removed view point will allow the surgeon to have a general view of their surroundings to allow greater manipulation which also viewing first hand their procedure. The use of fiber optics for our device has transitioned into the possible use of wireless micro cameras. The use of fiber optics still remains pressing issue, however due to the time constraints of the project we were not able to integrate it into the device.

Integration of input and output is essential for the flawless functioning of our device. To facilitate the smooth operation of our robotic arm we employ the use of LabVIEW software. This program allows us to input EMG data in both prerecorded and real time formats. The program also is compatible with the BioRadio and the potential robotic arm our group will purchase. The LabVIEW program will take the signal from the EMG and put it through the circuit our group designs; this circuit will filter, amplify, and convert our signal. Upon conversion the software will relay the signal via a wireless channel to the robotic arm software providing instant real time data flow to the device. The input from the fiber optic camera will provide real time visual data from the surgical area to the surgeon conducting the procedure. Another form of input will be a force censor which can provide the surgeon as well as our circuit will pressure sensing data from the robotic arm. The force data is essential for automatic modification by the signal through the software to ensure the safety of the patient; the surgeon can also utilize this input to manually alter his motions.

Results

The initial stage of our project was primarily related to research into the problem background, and solution possibilities. From this point our attention widened to include the task of acquiring various information and equipment for further research and eventually testing. The problem we identified was a need of access to specialized surgeons across the globe particularly in third world areas and locations of hostility.

In order to measure the capability of our final product our group sought to design a structured system of goals to fulfill with our prototype. The initial assessment called for the inclusion of incisions of precise length and depth along progressive difficulties. This assessment was updated to correspond with the functional progress of the prototype; it stands currently as a goal of making a 2 cm deep incision, for a continual 8 cm broken into three different trials sets. This will demonstrate control over the robotic device for duration of time and during separate movements.

Administrative progress of our project is equally important with research progress. The documentation of all of our work is recorded in the journal entries of all team members with our project leader Don Groves maintaining the master journal. These journals are maintained up to date with accurate email summaries of correspondence with supporting individuals. The development of a timeline is utilized to track our progress as well as to maintain our groups work focus. The conceptualization of a budget is being used to project the cost of our project and also to center our energies on a realistic tangible end goal; a budget adds an element of reality to the project. Our administrative progress is essential to our practical progress.

The signal conversion of this project is the most difficult component and as such was essential to possess the necessary software and knowledge. The strength of our groups' computer background was lacking. The assistance of Nicholas Goodman was invaluable in pointing our group in the right direction through his informative based class sessions. Additional background research our group became familiar with the LabVIEW software program. This program is compatible with our EMG/BioRadio system and the robotic arm Lynxmotion AL5B, detailed earlier. Our group initially worked on developing a model within the LabVIEW software that can filter and amplify this signal to remove noise and provide for accurate signals corresponding to accurate motion.

The VI utilized in LabVIEW for the integration of the BioRadio was developed using a basic VI shown to our group by Joseph Giuffrida. This component had to be altered to incorporate more channels of input from the electrodes; initially there were two input channels but now we utilize six channels of input which is equivalent to three muscle groups or three servo motors. These signals had to be filtered to remove electronic noise from the environment. Then to process the signal further an RMS value is taken which is detailed below.

The necessity of accurate functionality is paramount for the application of a remotely controlled surgical device. The remote controlled arm could potentially function along specific axes. This style of movement provides specific knowledge of the potential paths the device can travel; however, it reduces the arm's ability to perform complex actions, and fosters a more rigid path of motion. To address this problem, two-way motion at a particular joint is achieved through signals of antagonistic muscle groups; Biceps and Triceps will function as a unit for example. Each of those muscle groups will have their own set of electrodes so the two signals must be compared to generate one signal that will have the final governance of that robotic arm joint. The two RMS values will be taken and put through a simple subtraction function, to then yield either a positive or negative number. This number generated will be representative of which muscle group is in dominance at the time. For example with the pairing of Bicep and Triceps muscle groups where the Triceps signal is subtracted from the Bicep signal the following results can be found. During flexion at the elbow joint, when the Bicep is contracting, the value from the Bicep will be greater than the Triceps value therefore yielding a positive number. If extension of the elbow joint is the process, then Triceps contraction will yield a signal greater than the Bicep and thus the final number would be negative. This simple distinction can be applied to the robotic arm motor to either contract or extend. A visual confirmation of which muscle group has a stronger signal is given by a multi-colored waveform graph containing inputs from each muscle group.

The remaining portion of the LabVIEW program is the relay of this converted data to the robotic arm SSC-32 board. The Lynxmotion system was chosen for its compatibility with LabVIEW programming and as such has VI components specific to connecting these two systems. In short there is a sequence of command components that must be included with a LabVIEW program to function properly; initializing, reading data, writing data, ending session. There was a basic structure of a VI to control a servo motor using a sliding bar, very similar to the control panel in the RIOS software included with the robotic arm. To integrate our data taken from the BioRadio input, the sliding control needed to be replaced. The RMS value, discussed earlier, serves as a bi-directional indicator for a single servo motor. Utilizing the difference of RMS values in opposing muscle groups gives positive and negative values providing for both directions to be covered. A single motor was controlled using EMG signals from the forearm muscles, governing wrist motion, to verify RMS values served as a valid figure for control. The comparison of antagonistic muscle groups allowed for movement between extremes of the servo joint; this capability increases the freedom of motion and precision with which an operator can utilize the device. Initially the RMS values were significantly large and would only yield motion of the motors to their extremes. The RMS values are filtered to a reduced level to align the servo motor motion with the motion of the operator's joints and include middle range movement.

The process continued to include more servo motors under the control of the program simultaneously. The number of inputs to the BioRadio capture program was increased to six in total, equivalent to three groups of joints. Parallel sequences of servo control were added in LabVIEW for the communication with the SSC-32 board to incorporate the addition of BioRadio inputs. The addition of more data groups to travel through the USB port was a problem initially as it overwhelmed the capacity for data transfer. Altering the data collection rate addressed this problem and also smoothed motion of the robotic arm. A new problem arose from this fix however. The USB port now addressed each channel of data as a separate communication function and would have to close the port to the previous channel to allow a new communication vector. This disrupted the motor movement by essentially only allowing control of one motor at a time. To correct this problem all four segments of the LabVIEW VI that would communicate with the SSC-32 board were grouped into the same loop of functionality in the program. This allowed multiple channels of data to be transmitted simultaneously. At this point all four motors of the robotic arm could be controlled by each separate muscle group of the operators arm. The tasks outlined by our group to determine successful operation of the arm are three-fold; moving the arm to a point, making a movement to a depth of 2cm, and making a cut maintaining a constant depth over a distance of 8cm. Data from our trials can be seen in Tables 1, 2, 3 in the Appendices. The pointing test showed that a majority of times, ~60%, we were able to reach under 1cm of our target. In the test to reach a specific depth of 2cm, we had difference in depths ranging from 2.5cm (125% error) to 0.1cm (5% error). The test in which a mock cut is performed at a constant depth yielded a difference in lengths of 5.6cm (70% error) to 0.20cm (2.5 %).

Conclusions & Future Work

The integration of EMG signals using a CleveMed BioRadio and surface electrodes, through LabVIEW and relayed to a Lynxmotion robotic arm has been successful. We were able to successfully obtain and process an EMG signal for each of six different channels of muscle activity. These signals were arranged into three pairs of opposing muscles, corresponding to the three (3) servo motors on the arm which we aimed to control, the shoulder joint, elbow joint, and wrist joint. When controlling the Lynxmotion arm, we were able to isolate the robotic arm to only 3 degrees of freedom (DOF), successfully minimizing the possibility for error throughout our continued work with the arm. We were able to successfully design our LabVIEW VI in such a way to allow us to use an opposing muscle pair to control each of the three (3) corresponding servo motors on the robotic arm. In order to quantify our results, we performecd a series of three (3) final tests to measure the precision and accuracy of our control over the robotic arm. Each test consisted of ten (10) trials and aimed to measure a different aspect of our design's performance. The "pointing test" we performed indicates a need for more accurate and precise control over the arm in order to pinpoint a specific desired location in the 3-D plane. The "depth test" showed the large variability in control over the arm. While movements came close to the pre-determined mark, the consistency of vertical motion at this point in time fluctuates too greatly. The "mock incision test" provided encouraging results. All tests except one yielded a percent error of less than 32%. This result shows that the arm can be successfully controlled at a constant depth for a significant distance.

The performance of the robotic arm to date needs to be improved as maintaining motion is difficult, because muscles often provide assisting roles for multiple activities of the arm aside from their primary function. In order to operate the robotic arm to perform the desired movements, we found ourselves exaggerating our movements, in order to ensure that one muscle in each opposing pair had substantially more activation than the other in the pair. This exaggerated movement made the overall control of the robotic arm less intuitive and less natural, since the operator had to focus more on how to get the robotic arm to move how he/she wanted it to, and less on how he/she wanted to move his/her own arm. Future work could incorporate a suppression of signals not directly being used for a motion. The problem with this signal suppression lies in determining what motion requires which muscles, and how quickly this can adapt to allow the operator to move without a significant delay. We could also try to incorporate an additional control component, such as a video camera, which would monitor the operator's command movements and serve to integrate this data with that received from the EMG, in order to create more natural robot movements while requiring less-exaggerated input movements. We could also try to incorporate better filters to make our input signals from the EMG even more noise-free than those which we had used in our final design thus far. Perhaps a certain combination of filters would provide cleaner input signals than those which we obtained. Another way which we could get cleaner input signals is to use needle electrodes instead of the surface patch electrodes.

An important aspect of our project which we need to address is the issue of lag. Our final project did not provide true real-time control of the robotic arm. We had to set the data collection interval to no quicker than every 300 milliseconds, meaning that a new control calculation would be performed a little more than three times every second. Although this control speed was quick enough to show a proof of concept, we still had to tense the appropriate muscle groups slightly in advance to achieve the desired movements. In order to create a marketable version of our project, we need to make the data collection interval much quicker. The quicker it is, the more closely we can control the robotic arm in real-time. The addition of force sensors would be a great benefit that our group was not able to address; this capability would allow the surgeon another measure of feedback aside from visual cues. Camera mounts as discussed previously would contribute to the device being able to operate truly wirelessly. Without a camera to provide visual feedback the surgeon would have to be in the presence of the device, negating the benefits of having a remote surgery tool. On the same note, we would need to figure out a way to make the entire system truly wireless. The CleveMed BioRadio EMG device is wireless in the sense that the CleveMed Computer Unit connected to the computer wirelessly connects to and collects signals from the BioRadio EMG device from within the same room. The computer is linked via wires to the robotic arm, however, meaning that a surgeon still has to be in the same room as the patient, again making the robotic interface somewhat unnecessary, especially at this stage of development. We would need to wirelessly send a surgeon's command signals to the computer and arm over the internet, and simultaneously be able to receive video monitoring and other forms of feedback in order to create a truly wireless surgical system. To improve the accuracy and precision of this device, we could investigate the details and benefits of incorporating fuzzy logic as a method of better isolating data to control the servo motors and increase their response speed, rather than decreasing data collection time.

Another addition to this project which would greatly enhance its functionality is the incorporation of programmable constraints. With these added, we could outline a restricted section before surgery which we would not want the robotic arm to cut into. The robotic arm would therefore have a boundary which it would not be able to cross, increasing the safety of these remote surgeries, and protecting vital organs from accidental damage.

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Acknowledgements

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We would like to thank our families for their never-ending support of our dreams and aspirations. Their ability to listen to our rambling explanations of our work, that often times made no sense, and their love and continual support proved to be invaluable.

We would like to thank our Project Director, Dr. Abdel Bayoumi, for his continued guidance throughout the project. His persistent attitude and expectations provided some much needed motivation at times and made us reach for higher goals.

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We would like to thank Dr. Francisco Gonzalez, the director of our laboratory facilities. His commitment to ensuring our project had all the attention and equipment support it needed was instrumental to our success.

Appendices

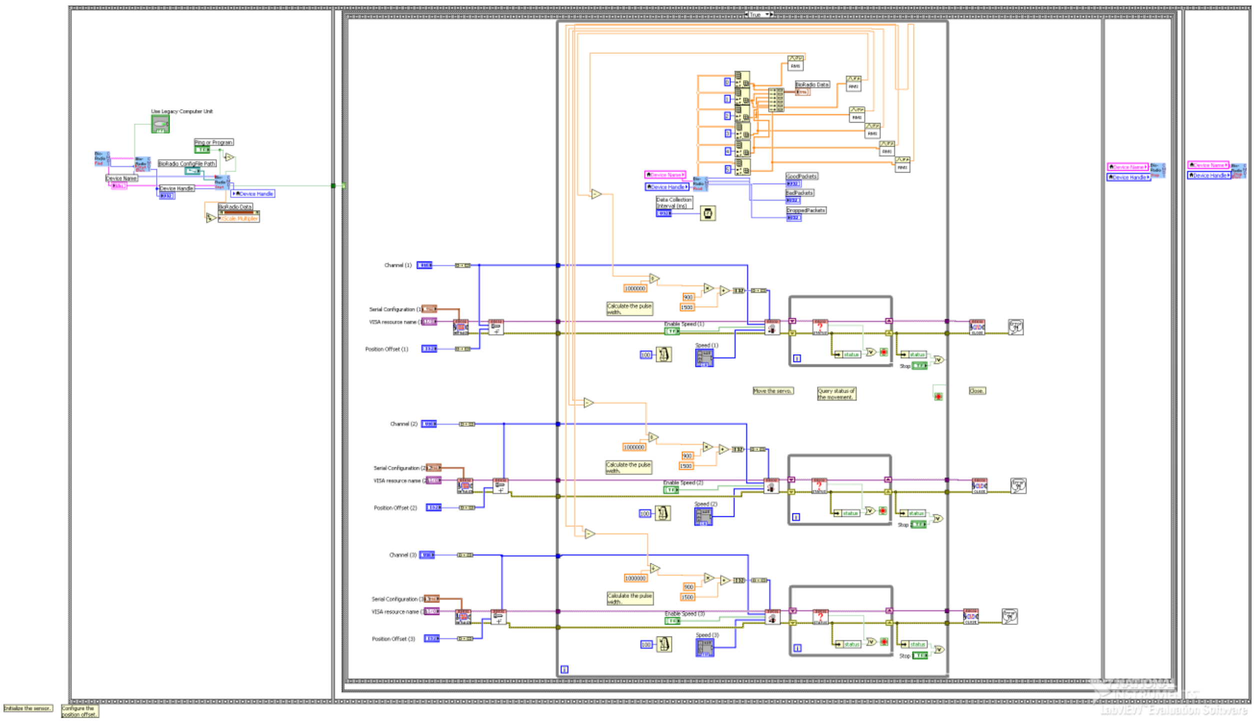


Figure 1: Complete program to relay EMG signal in LabVIEW

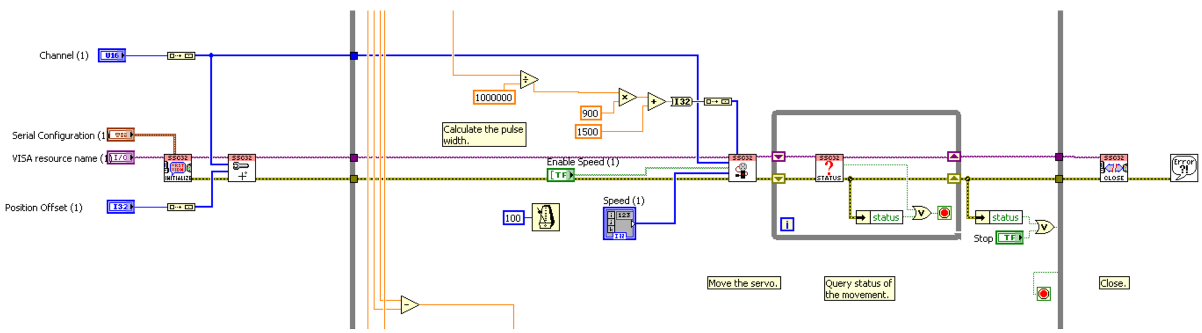


Figure 2: Close-up of a single servo motor control sequence in LabVIEW

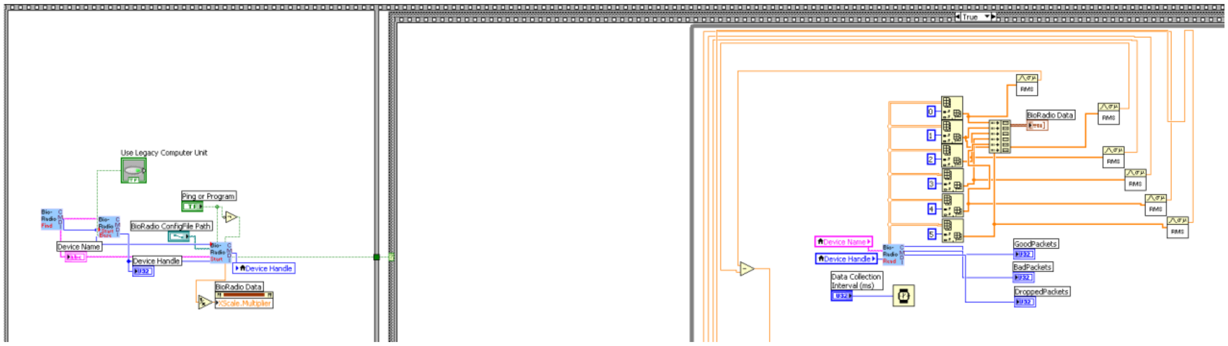


Figure 3: Close-up of BioRadio data collection in LabVIEW

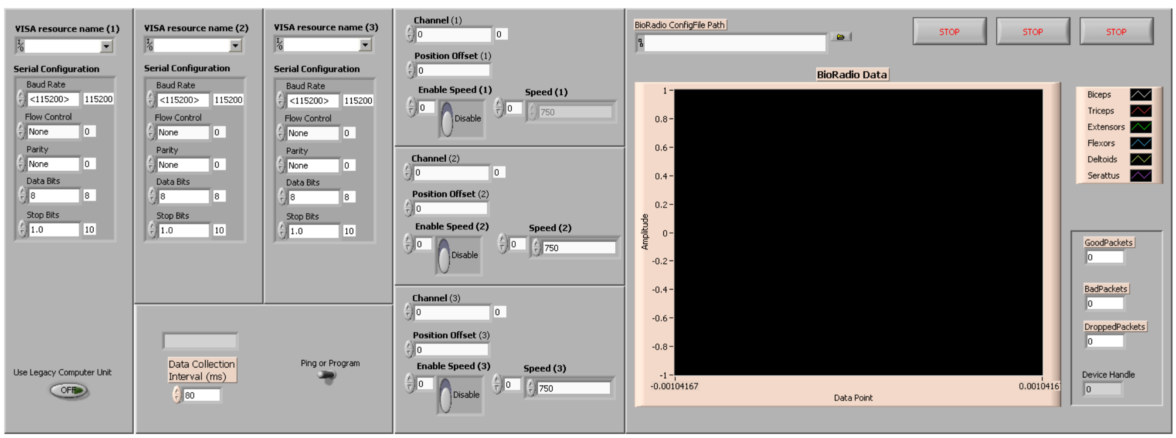


Figure 4: Control panel of algorithm in LabVIEW

Pointing Accuracy	
Trial	Distance from Target (cm)
1	3.00
2	1.20
3	0.40
4	2.30
5	0.80
6	0.60
7	1.10
8	0.50
9	0.20
10	0.80

Table 1: Test of accurately moving the point of the arm to pre-determined spot

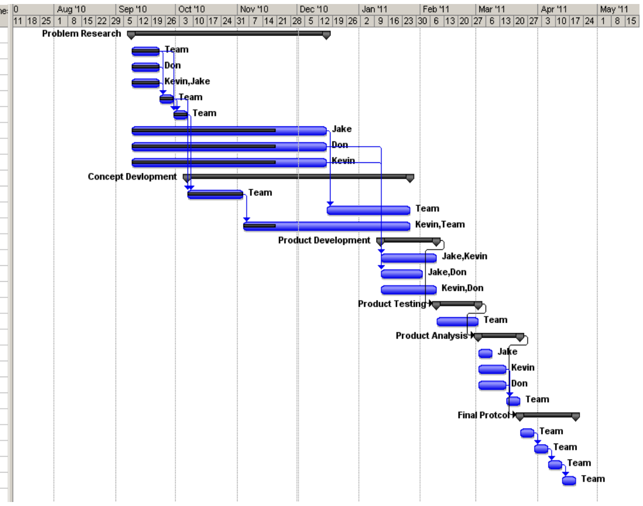
Depth Test			
Trial	Target Depth (cm)	Experimental (cm)	Percent Error
1	2.00	4.50	125.00
2	2.00	3.70	85.00
3	2.00	0.70	65.00
4	2.00	2.60	30.00
5	2.00	3.10	55.00
6	2.00	1.60	20.00
7	2.00	2.10	5.00
8	2.00	2.40	20.00
9	2.00	1.80	10.00
10	2.00	1.90	5.00

Table 2: Test of moving the arm to a pre-determined depth

Test Cut Length			
Trial	Target length (cm)	Experimental (cm)	Percent Error
1	8.00	5.50	31.25
2	8.00	2.40	70.00
3	8.00	6.00	25.00
4	8.00	8.50	6.25
5	8.00	9.30	16.25
6	8.00	6.90	13.75
7	8.00	7.60	5.00
8	8.00	7.20	10.00
9	8.00	5.80	27.50
10	8.00	8.20	2.50

Table 3: Test of moving the arm in a cutting motion over a pre-determined length

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	**Problem Research**	**70 days**	**Thu 9/9/10**	**Wed 12/15/10**		
2	Identify Problem	10 days	Thu 9/9/10	Wed 9/22/10		Team
3	Contact Sponsor	10 days	Thu 9/9/10	Wed 9/22/10		Don
4	Research similar studies	10 days	Thu 9/9/10	Wed 9/22/10		Kevin,Jake
5	Assess Needs	5 days	Thu 9/23/10	Wed 9/29/10	2,4,3	Team
6	Identify Objectives	5 days	Thu 9/30/10	Wed 10/6/10	2,5	Team
7	Obtain EMG	14 wks	Thu 9/9/10	Wed 12/15/10		Jake
8	Obtain robotic arm	14 wks	Thu 9/9/10	Wed 12/15/10		Don
9	Obtain electronics	14 wks	Thu 9/9/10	Wed 12/15/10		Kevin
10	**Concept Devlopment**	**80 days**	**Thu 10/7/10**	**Wed 1/26/11**		
11	Become Trained in Software	4 wks	Thu 10/7/10	Wed 11/3/10	5,6	Team
12	Familarize with EMG	30 days	Thu 12/16/10	Wed 1/26/11	7	Team
13	Establish process using software	3 mons	Thu 11/4/10	Wed 1/26/11	11	Kevin,Team
14	**Product Development**	**20 days**	**Wed 1/12/11**	**Tue 2/8/11**		
15	Link Robotic Arm Electronics to software	4 wks	Wed 1/12/11	Tue 2/8/11	9	Jake,Kevin
16	Install electronics in arm	3 wks	Wed 1/12/11	Tue 2/1/11	8,9	Jake,Don
17	Link EMG with software	4 wks	Wed 1/12/11	Tue 2/8/11		Kevin,Don
18	**Product Testing**	**15 days**	**Wed 2/9/11**	**Tue 3/1/11**	**14**	
19	Perform predetermined tasks	3 wks	Wed 2/9/11	Tue 3/1/11		Team
20	**Product Analysis**	**15 days**	**Wed 3/2/11**	**Tue 3/22/11**	**18**	
21	Functionality of Arm	1 wk	Wed 3/2/11	Tue 3/8/11		Jake
22	Testing Accuracy	2 wks	Wed 3/2/11	Tue 3/15/11		Kevin
23	Testing Precision	2 wks	Wed 3/2/11	Tue 3/15/11		Don
24	Degree of Accomplishment	1 wk	Wed 3/16/11	Tue 3/22/11	22,23	Team
25	**Final Protcol**	**20 days**	**Wed 3/23/11**	**Tue 4/19/11**	**20**	
26	Final adjustments	1 wk	Wed 3/23/11	Tue 3/29/11		Team
27	Presentation to sponsor	1 wk	Wed 3/30/11	Tue 4/5/11	26	Team
28	Analysis of sponsor feedback	1 wk	Wed 4/6/11	Tue 4/12/11	27	Team
29	Incorporate sponsor feedback	1 wk	Wed 4/13/11	Tue 4/19/11	28	Team



Timeline 1: Timeline of the work distribution

Nostradamus Technologies
Don Groves: Project Leader

ESTIMATE SHEET

JOB NAME	Robotic Arm Controlled Surgery
LOCATION	University of South Carolina
JOB DESCRIPTION	
CONTRACTOR	
ESTIMATOR	Jake Tomlinson
CHECKED BY	Don Groves
ESTIMATE #	1
DATE	11/28/10
BID DATE	

NOTES

DESCRIPTION	QUANTITY	RATE	MATERIAL	LABOR	SUBCONTRACT	TOTAL
ALDS Robotic Arm	1	485.00				485.00
Wrist Rotation Device	1	41.74				41.74
Base Rotation Kit	1	32.35				32.35
Force Sensing Resistor	1	5.00				5.00
Wireless Mini Camera	1	50.00				50.00
Miscellaneous Materials/ Supplies		200.00				200.00
Publication Costs	1	50.00				50.00
Indirect Cost		100.00				100.00
		TOTAL				964.00

Figure 5: Budget list for our group