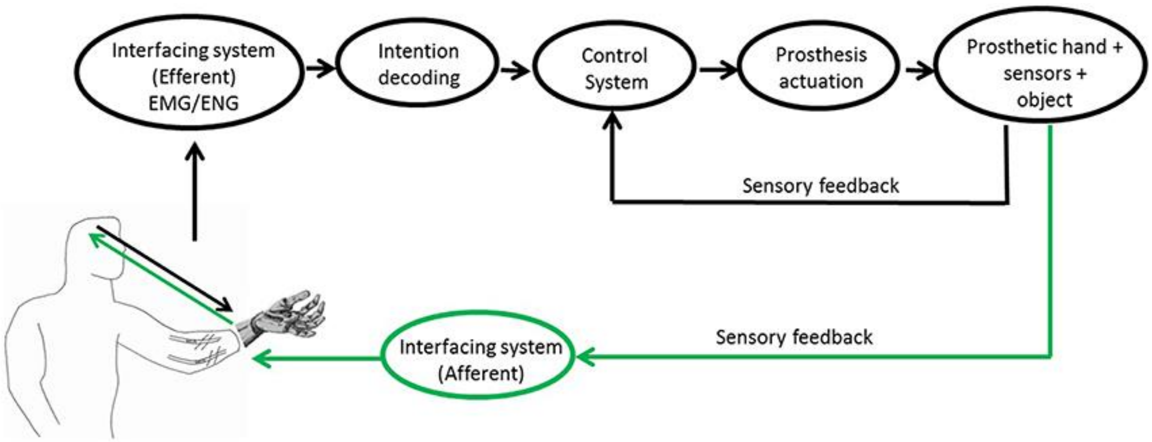
Graduation Project

Bionic Arm Low Level Control System

1.Overview:

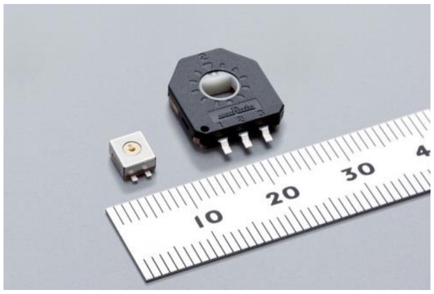
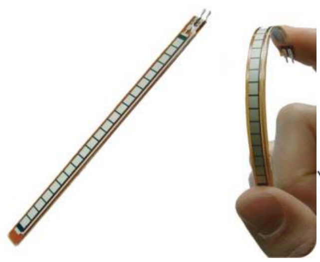
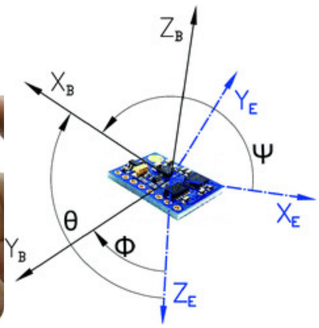
This document presents different researched ideas for controlling the bionic arm and provides a guideline of technical specifications that is recommended to be implemented based on the research outcomes. The document contains different headings that discuss all the elements of the control system as well as a variety of components that can be used in the bionic arm control system.



As seen in the previous figure, the input to the low-level control system (LLCS) comes from the high-level decoding system that takes sensory data describing the human intent. The role of the LLCS is to control the bionic arm actuators to get to the position described by the high-level system as well as make sure that the position is reached in a closed loop feedback control system. The LLCS also reads sensors found on the bionic arm that measure the environmental factors found around the arm and transmits this information on actuators fixed on the human/arm interface to give amputees the feeling of senses such as temperature and touch.

2.Actuator Feedback Sensors:

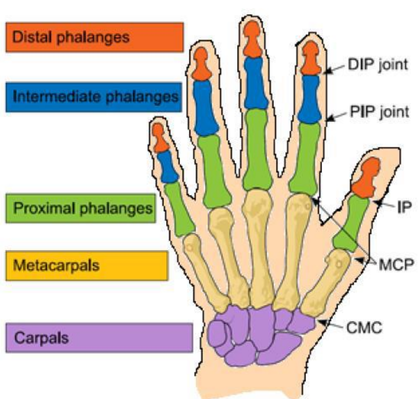
These sensors are used to ensure the position of the different joints found in the bionic arm. although some actuators contain internal feedback mechanisms such as servos, using feedback sensors found on the joint mechanisms provides extra confidence in the predicted position of the arm joints because it takes in consideration any mechanical flaws or slips that might occur between the motor and the joint mechanism. Different sensors can be used simultaneously in a sensor fusion operation to accurately determine joint positions. **Compact size rotary potentiometers** are mainly used as a structural part of the joint mechanism directly connected to the rotating part of the joint to measure its angle. **Flex sensors** can be placed on top of the arm fingers to measure the angle produced by the whole finger. **Inertial Measurement Unit** can be placed in the hand structure to determine the orientation of the hand as a whole and giving feedback of the hand position used to control the motor moving the joint connecting the hand to the arm.

Although feedback sensors are redundant in the bionic arm system because many commercial systems are implemented using the human senses such as vision as a feedback mechanism controlling the arm, adding these complementary sensors makes it easy to control the arm and provides an integrated solution that works in multiple situations without the dependency on human sense for feedback. The system operates by taking only desired set position as human input and does all other steps needed to ensure the arm fulfills this set point.

Other feedback mechanisms that can be used include non-electrical systems such as pneumatic systems with pressure valves and regulators. Although this system of pneumatic actuators is favored for its strength and flexibility, it violates our general specifications of “natural looking arm with human like range of motion”.

3.Arm Actuators:

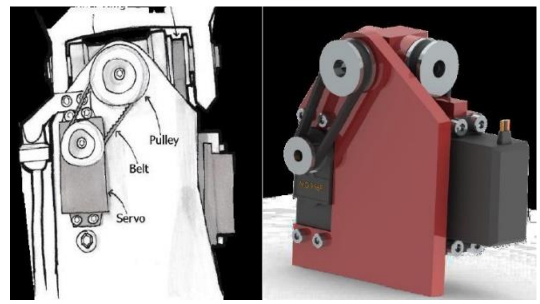


The human finger in total has 4 degrees of freedom. Three of these are the rotations of each joint (DIP, PIP, MCP) which combine to control flexion and extension of the finger. The knuckle (MCP joint) also allows for abduction/adduction. In the thumb the lower CMC joint also allows for abduction/adduction – which gives 5 DOFs in the thumb.

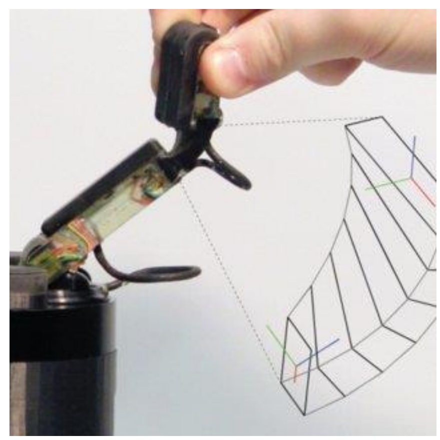
Different actuation methods are present with various types. As stated earlier, pneumatic actuators are out of the project scope because of the extra requirements and dimensions of compressors and valves. So, this section will focus on electrical actuators like DC motors and other mechanical power transmission methods with different control mechanisms.

Instead of using open loop DC motors, we can directly use off the shelf Servo motors and modify them if needed to suit the mechanical design specifications. Extracting the servo motor inner potentiometer and planting it on the mechanical joint will enable continuous rotation and will let us measure the position of joints instead of the motor shaft. Initial assumptions including torque needs will not exceed the specifications of the Metal Gear Servo Motor 15Kg.cm. If extra torque is needed, reduction mechanisms can be introduced in the design.

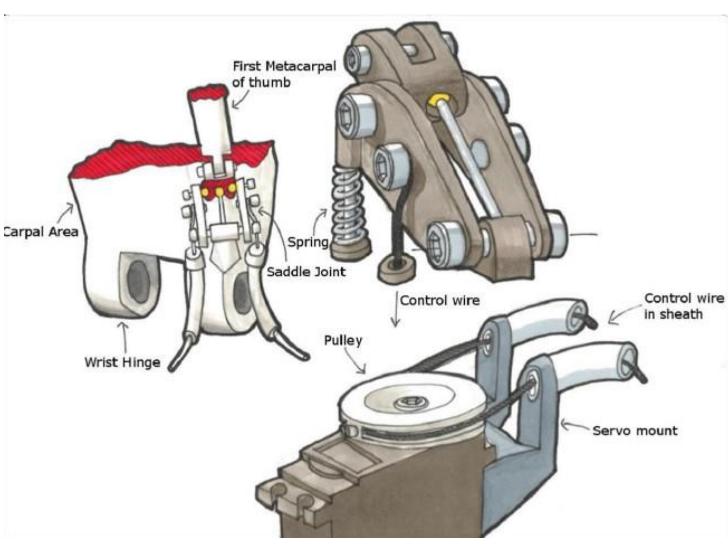
Metal Gear Servo Motor (15 kg.cm)
LE 285.00

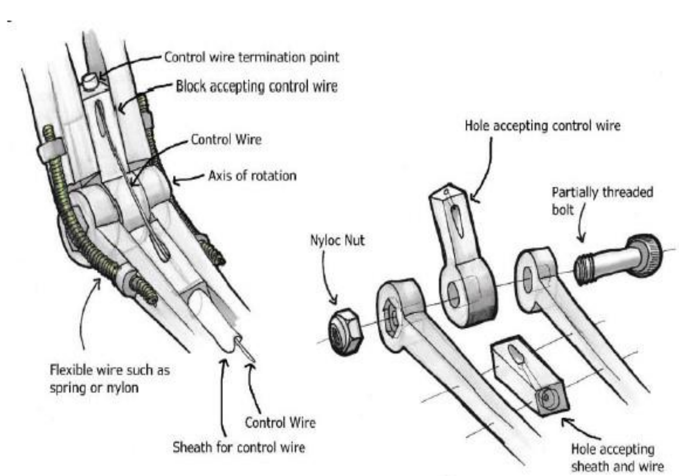


Active Software Compliance introduces virtual springs in the actuation system as it moves the motors based on the dynamic load acting on the motor based on the closed loop feedback sensor readings. This compliance allows for natural movement of the hand fingers and protects the mechanical design from failure if opposing force exceeded a certain threshold. Compliance can also be achieved by adding springs in the design that stores excess energy in the form of spring deformation. Both forms of compliance can be present simultaneously but will cause interference among each other if not calibrated effectively.

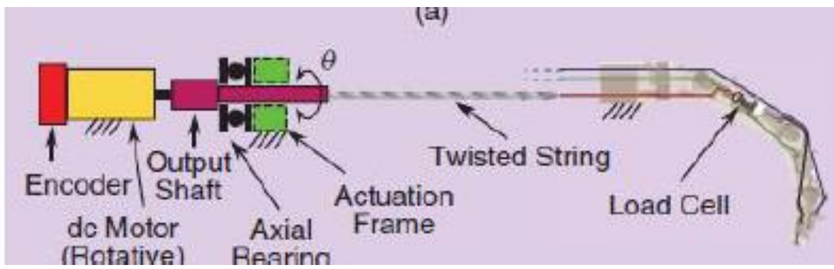


Different actuation mechanisms can be implemented, and each has its own set of advantages and drawbacks. **Pully-String** mechanism uses strings that pass through the finger hinges and closes the finger with all hinges simultaneously, decreasing three degrees of freedom into one. It is known for its compact design and simple operation with some designs having a spring that extends the finger when the string tension is released.





Another method in which a DC motor is used to twist two tendons together is known as **twisted string**. This shortens the length of the tendons which generates tension and closes the fingers. The big advantage of this method lies in the fact that there is a direct transformation of rotational motion in the motors to linear motion in the tendons – no intermediate pulley system is required to move the fingers. Another advantage is that large forces can be exerted by the fingers. Essentially, the tendon pair can continue to be twisted, increasing the force exerted by the finger – until of course there is a mechanical failure somewhere. However, this can be a slow way of actuating fingers since many rotations are required to fully close a finger. As previously discussed, the actuators used in this system are standard servo motors. These motors can be controlled to rotate to angular positions up to ± 90 degrees from rest. Since the artificial tendons move relatively little to open and close each finger, the angular precision of each servo somewhat affects how precisely the fingers can be controlled.



4.Arm Feeling Sensors:

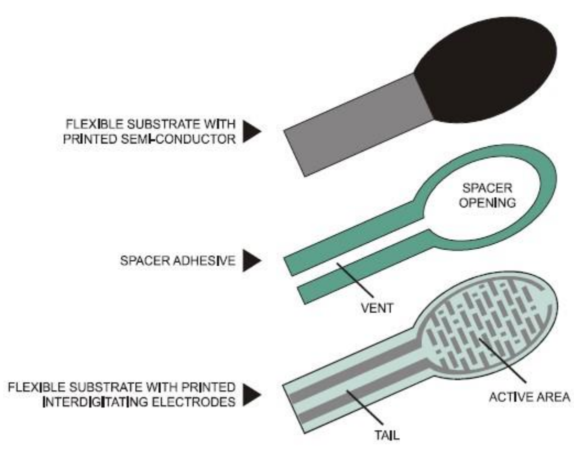


Figure 1: FSR Construction

Most commercial bionic arms have one-way channel of interaction between the user and the arm. the amputee orders the arm to do a specific task, and the arm performs this task with no feedback or "feeling" between the human and the arm. This missing piece of interaction can be fulfilled by adding another set of sensors that measure the surrounding environment of the arm. the human sense of touch can be emulated by having **force sensing resistors (FSR)** on the bionic arm that sense the pressure acting on the object/sensor. The microcontroller then enables an actuator fixed on the amputee's limb that stimulates the sensation of holding force based on the pressure applied on the FSR sensor.

Different methods are present to transmit the arm state to the user. Some methods are invasive that include neurological surgeries to remap nerves and are out of the scope of this project. Other methods are noninvasive but substitute the physical phenomenon measured with another one. For instance, having a vibrator motor placed on the limb with increasing vibration as FSR force readings increase is a **substitution feedback mechanism**. **Modality matched mechanism** imitates the same physical phenomenon as measured by the sensor. For instance, having a mechano-tactile bladder that presses on the amputee's limb as the FSR force readings increase transmits the force readings as force on the human limb.

The simplest and easiest way to obtain a force measurement, without adding mechanical sensor, is to measure the motor current. It is directly proportional to the applied load. As finger force increases, the current draw increases. For controlling the five servomotors, the micro controller read all the analog inputs coming from **acs712 current sensors**. It then compares these readings with stored value for each motor for each grip pattern. If some obstacle stops the finger, motor current increases. Consequently, microcontroller change motor angle backward until current reaches its normal values. However, the current sensors have some drawbacks, as they require some tuning and adjustment to become useful. They, also, shortly draw a large amount of current when the motor start to move even if the finger is still under no load condition. Moreover, the motor must be geared down to provide enough torque; this will lead to inaccurate measures for the small loads.

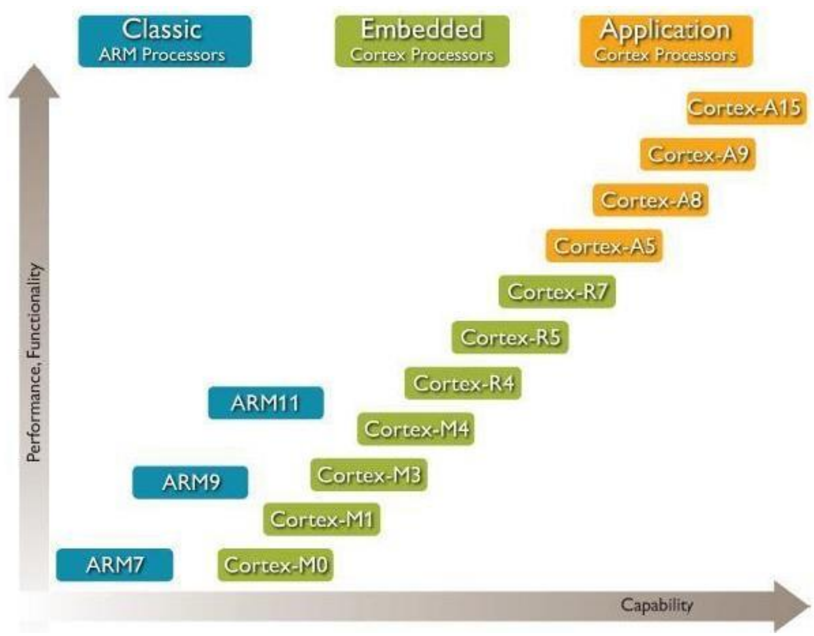
To make the prosthesis as much as possible like a real human hand, the smart bionic is equipped with temperature feedback system. This enables the user to feel the temperature of what she holds with her bionic hand. Amlx90614 infrared thermometer is then used for its capability of measuring temperature from a portion of the thermal radiation emitted by the object being measured without the need of physical contact with the object. These measurements are then converted to the user via a thermoelectric cooler known as Peltier. It consists of two ceramic plates with a series of P and N type semiconductor material between them. The module conveys heat from one side to the other, with consumption of electrical energy, relaying on the direction of the current.

Furthermore, a vibrator motor is integrated into the prosthesis itself that will vibrate whenever the fingers are moving or when the user changes the grip pattern, to make the user able to know that the signal coming from her muscles when flexing them is read and analyzed by the microcontroller. Tactile sensory feedback is an essential element of life. Another way for the user to interface with the smart bionic sensors is by a Bluetooth program on an android device connected with the hand by Hc-05 Bluetooth module. It uses serial communication to communicate with the microcontroller and the

Android program. Moreover, it makes the user able to get a live feedback from her smart bionic throw her mobile phone or tablet like the temperature of what she touches as well as the battery percentage. To design the Android program, the MIT App Inventor 2 is used to develop the layout and the user interfaces as well as the program blocks.

5.Microcontrollers:

The brain of the bionic arm! it is the main element responsible for translating the input desired point coming from the high level control into a set of commands that moves the actuators to achieve the desired point while constantly measuring feedback values for monitoring disturbances. Microcontrollers are generally chosen based on the number of used I/O pins and the features present in the device. Some microcontrollers have more interrupts than others while others are faster and can handle faster clocks. All these factors affect the overall responsiveness and capabilities of the bionic arm. Different alternatives are present to operate the bionic arm. **8bit Microcontrollers** like **AVR** or **PIC** are a viable cheap option that can get the job done. Another alternative that is more prominent in the industrial embedded market is the **32bit Microcontroller ARM.** ARM is known for its low power consumption paired with high speeds and availability in the market. Also, it can be used to run the high-level control deep learning algorithm on the same board as the LLCS. Other options include microprocessors like **raspberry pie** that run on Linux. All the previous devices can be used based on the needed I/O pins needed to operate all the arm components. To have an initial assumption, if an ARM microcontroller will be used, the capabilities needed will be in the range from Cortex M3 to Cortex R7 (Medium Line Processors).



References are found in the following drive:

https://drive.google.com/drive/folders/1SN5lKe9-eHq0HgJhlP8tYHDnbAOe1ulo?usp=sharing