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A Neuro-robotic Prosthetic Arm (Ruoko bot)

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Research Paper

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ABSTRACT

This paper focuses on the provision of an affordable and less weight prosthetic arm for the Zimbabwean population. The research concentrated on improving the amputees' living standards by means of providing them with a useful artificial arm which can perform tasks as a normal human arm. The literature review was thoroughly done by investigating the latest prostatic arms available in the market. The V-model or evolutionary prototyping was used in the research project to account for every component of the prosthetic limb. The V-model is a type of software development life cycle (SDLC) paradigm where processes run sequentially in a V-shape. The Ruoko bot is flexible and affordable than the current artificial prosthetic available. The prosthetic limb has an Arduino board which allows the useof an artificial intelligence algorithm to determine which signal of the brain's waves should be translated into bodily motion by an EEG headband.

Keywords

Artificial prosthetic, End effector, IoT technologies, Neuro-robotic prosthetic arm, Ruoko bot, V-model

INTRODUCTION

There are over 57,7million people living with limb amputation over the world and the numbers keeps on growing. The major causes of limb amputation being road injuries, other transportation injuries and mechanical forces (aliberté, Birglen, & Gosselin, 2002). Once someone lose their arm/hand due to unfortunate events they become idle it will be very difficult to find work and also do basic daily chores. Occasionally this inability to be insufficient and self-reliant has resulted in many of the amputees becoming more depressed as compared to the other members of the community with full both hands (Huang., 2007). Prosthetic arms that are available on the market they are expensive to buy because they are not produced locally all of them are being imported from western countries. Most of them with a cost of nearly \$8 000 up to \$100 000 (Byoung Kyu Choi, 2013) this is indeed enough evidence that thereis need for a solution that affordable at them same time efficient solving all the problems of an amputee hence the development of neuro robotic prosthetic arm with end effectors (RUOKO BOT). Brain waves will be used by our prosthetic arm to carry out tasks, and an EEG head cap will capture the brain waves. The Arduino board will then transform the signal sent by the brain into motion using a 3D printed end effector, thanks to the learning, translation, and determination capabilities of an artificial intelligence algorithm. A 3D-printed female socket connector will be used to link our prosthetic arm to the end user. Additionally, if there is a problem interpreting brain waves, speech recognition can assistto operate the arm using the Internet of Things (IoT) when the head cap fails to transmit the signal. Within the Mashonaland West Province, according to recent study we conducted locally at the Chinhoyi General Hospital, approximately (Zulu, 2022).

BACKGROUND

Makonde district is located in the Mashonaland-West region of Zimbabwe, in the town of Chinhoyi. The Makonde district has a population of 153 540 individuals. (Chimedzo, 2022). The Makonde District is home to a diverse population, including amputees. In Mashonaland West, approximately 30% of amputees are concerned about being limited in their talent and possibilities. Before the amputation (Zulu, 2022).A person's physical and emotional health is both negatively impacted by losing an arm. Amputees encounter many difficulties, such as slower walking and balance issues. They also have trouble washing and gardening, and even using common household appliances like televisions and laptops. Low self-esteem brought on by their inability to perform fundamental tasks causes them to feel inferior to themselves, which is another emotional challenge they encounter. In addition, flames have also claimed the lives of people who are blind. This arises from the fact that, in the event of a fire, amputees find it challenging to use fire extinguishers and move slowly when sprinting or fleeing (Newsday, 2020). Most amputees are unemployed which is a huge problem because some of them have families they need to take care and provide for.

PROBLEM STATEMENT

Health has evolved into a crucial requirement for our continued survival, and this includes people who lack all of their upper limbs. Diseases, accidents, or simply being born with incompletely developed limps can all cause these incomplete instances. In Zimbabwe, it has gotten very difficult for those with these unfortunate conditions to purchase prosthetics that help them. The advanced prosthetic hands frequently cost too much to be affordable for a significant part of the amputee consumer base, only the wealthiest amputees can purchase the available prostatic. Frequently, those who cannot afford them are limited to simpler, self-powered choices. A large population will need access to prosthetics, which must be available at a reasonable price.

LITERATURE REVIEW

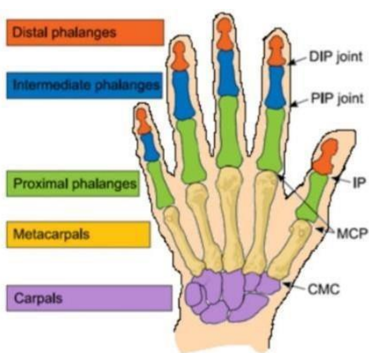
This section looks at various studies and previous work on important concepts that could be used when carrying out projects. Although the literature covers a broad range of these theories, this analysis will focus on four crucial applications that are frequently discussed on a global level in the literature under consideration.

The Human

Hand The human hand comprises of at least 27 bones (depending on the individual) (Europen Commission community research, February 2, 2009), more than 30 individual muscles (L. Segil, 2013) and over 100 named ligaments, nerves and arteries (Tivia., 2022). Prostheses are intended to mimic human bodily processes and restore functionality to people who have lost an extremity. No current prosthetics can match the dexterity, flexibility and fluidity of the human hand (L. Segil, 2013) as shown in **Figure 1**.

Figure 1

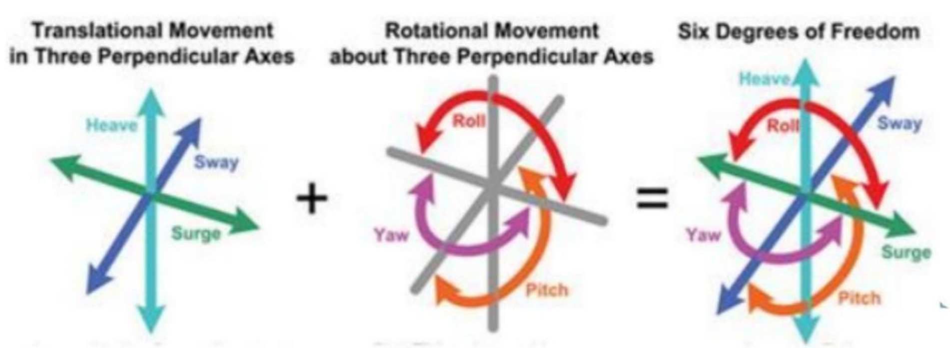
Human Hand (Tivia., 2022)



Before any further discussion, let us briefly explain the meaning of a degree of freedom (DOF) for a reader with a non-engineering background

Figure 2

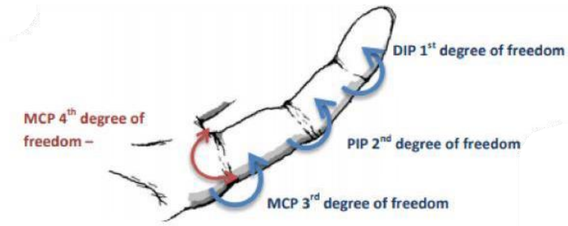
Degree of Movement (tutor2u, 2021)



Consider a location in space based on **Figure 2.** From this point, we can translate (move) along three distinct axes that is, left and right, up and down. We can also rotate around three distinct axes at thesame location. The human neck, for instance, has three degrees of freedom of rotation, allowing us to gaze up, down, and sideways while also tilting our heads. Consequently, a single spot can have up to 6 degrees of freedom in total. (3 translational, 3 rotational) The human finger has four degrees of motionin total. (George ElKoura). Each joint's three rotations—DIP, PIP, and MCP—combine to regulate the flexion and extension of the finger. Abduction and adduction (wiggling) are also possible at the elbow (MCP joint).

Figure 3

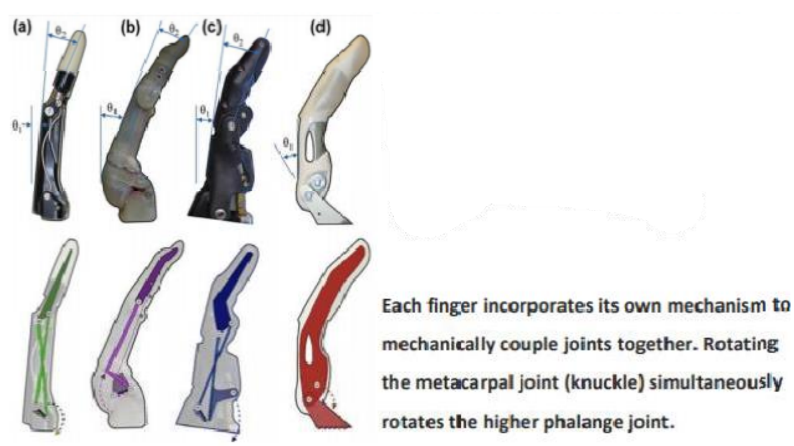
Finger Movement (Nelson, 2013)



In the thumb the lower as shown in **Figure 3,** CMC joint also allows for abduction/adduction – which gives 5 DOFs in the thumb (Matsuoka, 2006). All parts in the human body, including the fingers, are moved by the contraction of muscles and tendons. DIP initially granted independence PIP Second degree of liberty MCP third degree of liberty MCP Abduction/adduction, the fourth degree of freedom,is illustrated by a human finger number of possible outcomes at one location. (Nelson, 2013), 3D Printed Myoelectric Prosthetic Arm. The vast majority of commercial prosthetic fingers are actuated through a joint linkage system powered by DC electric motors (L. Segil, 2013). Kinematic models for various prosthetic fingers are show on **Figure 4**.

Figure 4

Degrees Of Freedom for Fingers (Nelson, 2013)



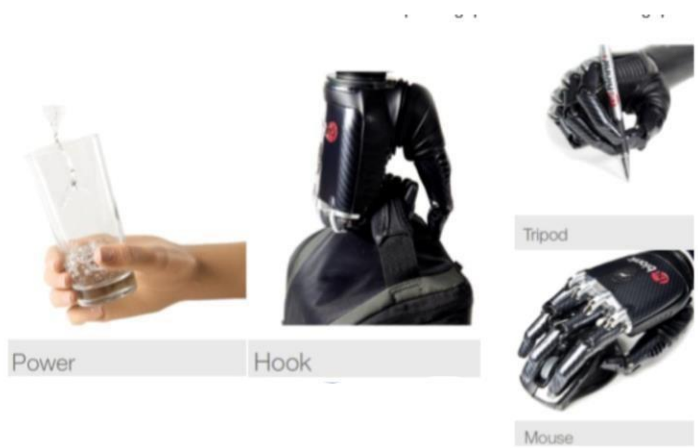
The disadvantage of this construction is that there is no control over individual finger joints. Because all joints in the finger are controlled by a single actuator, the complete finger has only one degree of freedom - these fingers can only open and close in one direction. In fact, a human finger has control over individual joints and can flex in a variety of ways, as in **Figure 5**

Figure 5
Human Palm (Nelson, 2013)

The Be-Bionic 3

The Be-bionic 3 is a world leading commercial myoelectric arm. Like others of its kind, the Be-bionic 3 uses a predefined grip system. A user can select from 14 different grip patterns using muscle activity around their upper forearm (RSL Steeper, 2014). The user can choose a grip pattern and then use muscle activity to trigger the movements associated with that particular grip, rather than having direct control over individual finger movements. On **Figure 6**, four of the Be-bionic 3's fourteen handlesare depicted.

Figure 6
Be-Bionic Arm (RSL Steeper, 2014)



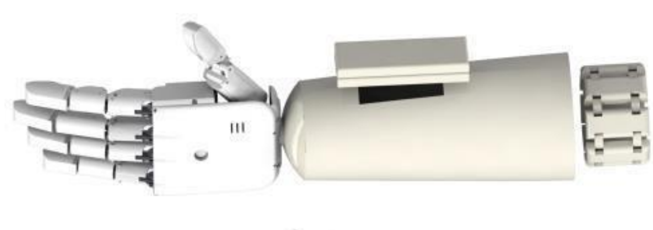
A predefined grip system has the drawback of preventing the user from precisely controlling finger positions to grip a particular object or finish a job. Instead, a user must select and implement the grip pattern that best fits the task at hand. Furthermore, the user must cycle through a number of grip patterns before they get to their desired choice. For instance, several grip changes might be necessary to open a bag, pick up a heavy item, put it inside, and then close the bag. This means that seemingly easy tasks like this might actually require a lot of time to complete, which can be tiresome and frustrating. 40 percent of human hand use is possibly accounted for by the thumb (Belter, 2013) . The design of the thumb, which is more intricate than the other digits, is essential in all prosthetic hands. The thumb on the Be-bionic 3 can be adjusted to be either opposed or non-opposed; the differences between these configurations are shown in **Figure 7**.

Figure 7:
Be-bionic Thumbs (RSL Steeper, 2014)

With all that being said, prosthetic devices are intended to provide more than functional practicality. For many amputees, the loss of an extremity is also accompanied by a significant decrease in confidence and self-esteem (Bebionic, 2010). Electromyography (EMG) electrodes positioned on the user's skin surface are used to operate the Be-bionic 3.

Myelectric Controlled Prosthetic

Figure 8
Myoelectric (oymotion, 2015)



Myoelectric Controlled Prosthetic **is** developed OYMotion Technologies which is a start-up company in the biomedical engineering sector based In Shanghai, China. OYMotion are providing an array of smart medical devices suited both for private and hospital usage. Their product selection ranges from smart knee- and elbow orthoses to physical muscle rehabilitation solutions (oymotion, 2015) . Prosthetic hands, however, are their primary offering. The hardware components needed to fit a smart prosthetic hand have been developed in recent years as shown in **Figure 8**. Therefore, until the spring of 2018, the mechanical development of these devices has been put on pause. They use EMG technology called myoelectric, which collects electromyography (EMG) signals produced by myoelectric prostheses electrodes (known as myoelectrodes) are "dry" metal electrodes housed in a plastic case are contraction of muscles close to a residual limb for an amputee. OYMotion is currently developing concepts for a smart bionic hand capable of collecting and analyzing gesture data to give the user a highly flexible device. Electrodes placed on the skin's surface or inserted into the body are used to analyze these impulses. The internal actuators are controlled by myoelectric devices as shown in **Figure 9**, it enables a more precise control as compared to mechanical ones. Electromyography, or EMG, is specified as an electrophysiological technique (Göker, 2014) used for the purpose of detecting and analyzing anyelectric activity generated within the skeletal muscles within the human limbs.

Figure 9

Myoelectric Devices (armband, 2013)

The Neuralink (Elon Musk)

Neuralink is a company co-founded by Elon Musk in 2016, with the technology "which enable someone with paralysis to use a smartphone with their mind faster than someone using thumbs". The Silicon Valley Company, which has already successfully implanted artificial intelligence microchips in the brains of a macaque monkey named Pager and a pig named Gertrude (the Guardian, 2022). In order to implant a chip with electrodes into someone's brain inside their skull, Neuralink created and is still developing a two-piece device with the assistance of neurosurgeons who insert micron-scale threads intoregions of the brain that regulate movement. Many electrodes are present in each thread, which links to an implant known as the "Link." This allowed Neuralink to translate brain waves into a robotic arm that replicates the utility of human hands (applications, 2020).

Figure 10

Brain Waves Implant (wired, 2022)

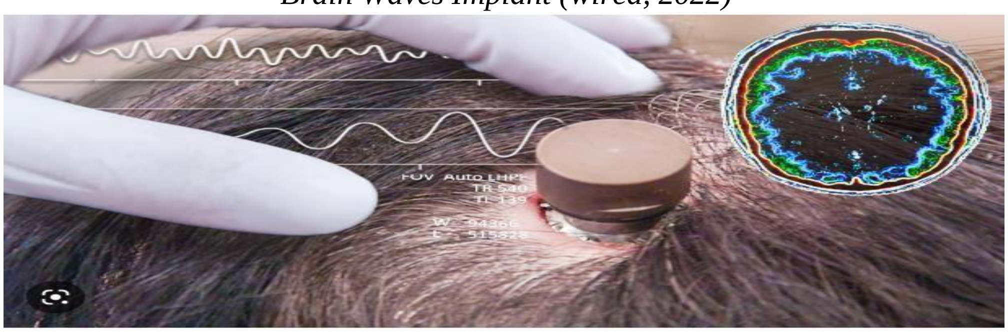
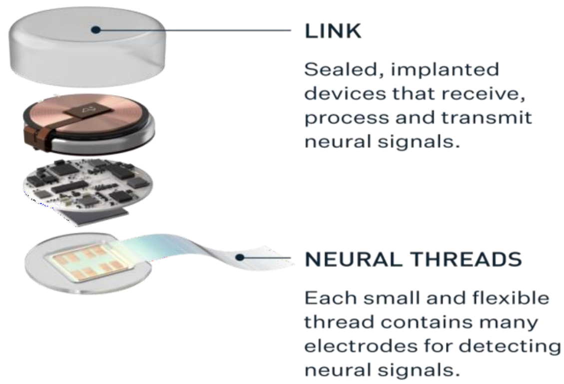


Figure 11

Brain Wave Device (Shankland, 2021)

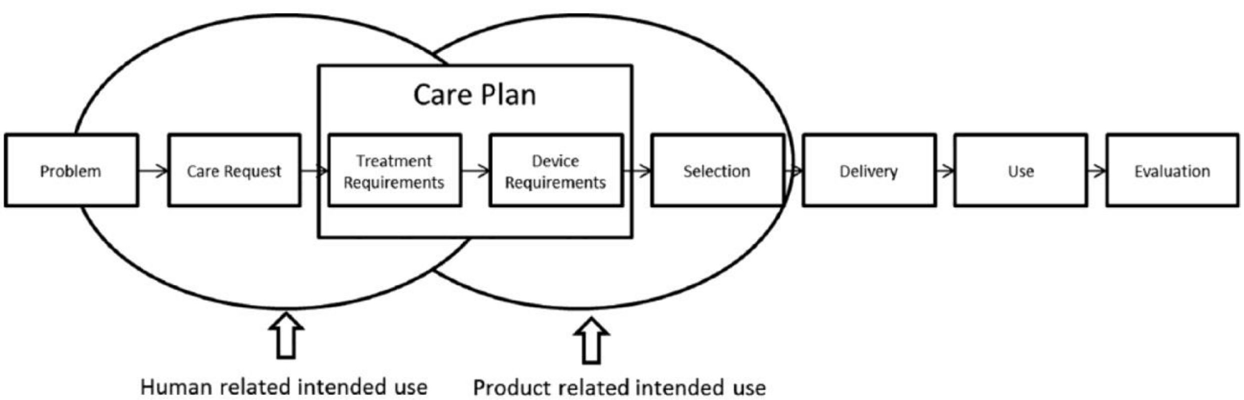


The Link's neural threads are so delicate and flexible, as shown in **Figure 10 and 11**, that a human hand cannot implant them. Instead, they are developing a robotic device that can insert these threads precisely where the neurosurgeon desires them to be in a safe and effective manner. People continue to be wary of becoming test subjects for this on-going technology because it is still in development and not yet accessible to the general public.

CONCEPTUAL FRAMEWORK

Figure 12

Prosthesis Prescription Protocol of the Arm (PPP-Arm): (Wijdenes et al., 2018)



The process is designed to organize, support, and assess the recommendation for an adapted device or prosthesis as shown in **Figure 12**. The protocol produced a standard prescription policy that was applicable across the country. The PPP-Arm protocol has a number of benefits that were discovered while the project was being carried out:

- Complete and well-organized
- User-friendly, applied nationally
- Digital reporting,
- Workplace-independent login options for every team member
- Patients acquire deeper understanding of their own prostatic experience process;

- A prescription report is made for the insurance company
- The protocol helps create a national database for research.

The time commitment required to learn how to operate the prostatic arm and put the conceptual framework's highlighted protocol into practice was the biggest drawback identified. A questionnaire completed by the participating teams was used to assess the effectiveness of the PPP-Arm procedure, which resulted in the creation of a prostatic arm. The following were the key conclusions:

- The few can afford the PPP-Arm protocol.
- The prosthetic applications' quality has increased: PPP-Arm offers a more organized report that contains all the data required for the insurance provider to evaluate the application.
- The PPP-Arm protocol has resulted in a number of good improvements, including improved utilization, more structure and comprehensiveness in the prescriptions, increased treatment homogeneity across the nation, and the establishment of a trial period for temporary prostheses.

By implementing a PPP-Arm protocol, there has been a national uniform and structured method to advise and evaluate the prescription of upper limb prostheses and the development of it. Rehabilitation teams for upper limb prosthesis users work more uniformly using a national prescription protocol. A national project coordinator and knowledge brokers in each team are prerequisites for successful protocol development and implementation. All stakeholders involved in protocol development and implementation include: rehabilitation teams, orthopedic workshops, patient organizations, and insurance companies.

METHODOLOGY

In this section we lay out and describe the study plan, research methodology, and research limitations in this part. A mixed method approach was used in the study, which is based on logical principles that contribute to the thesis's ultimate objective. It is both quantitative and qualitative in nature.

Interviews

This technique involves the interviewer asking the interviewee questions to gather data (Zulu, 2022). In order to gather data in Makonde District, the researchers utilized four distinct forms of interviews: structured interviews, semi-structured interviews, unstructured interviews, and focus groups; however, the one we employed is described below. In this section, the interviewee arranges the inquiries chronologically (MBA Knowledge Base, 2021) The Chinhoyi Provincial Hospital was approached by the researchers to conduct a structured interview to learn more about the problems limb amputees face. The importance of the query was indicated by a higher number. Weights were assigned to the queries. By employing this strategy, the researchers were able to glean information from the interviews about the issues encountered by limb amputees and gain insight into potential solutions. But it was not an adaptable strategy to use. When the researchers were unable to alter the queries to better suit the interviewees' moods, they ran into problems. Structured interviews were carried out, there aren't many set questions during an interview, but the interviewer is free to alter terminology and phrasing (Doyle, 2020) .At Makonde District, the researchers performed a less formal interview. The citizens of Makonde District were asked questions by the researchers about the difficulties that the amputees experience and suggestions that might be helpful to them. Depending on the responses from the respondents and factors like age and gender, the researchers were able to modify their questions. With this approach, the researchers were able to be more adaptable by modifying the language of the questions to match the respondents' current circumstances. Semi-structured data analysis takes time since it involves more qualitative data.

With this non-directive data collection technique, respondents answer questions that are related to the study's topic in any sequence (Tegan , 2021) to learn more about the severity of the problems amputees in that area faced, the researcher conducted unstructured interviews with health professionals in the Makonde district. The best study technique was chosen because the health professionals demonstrated their industry knowledge and were willing to share all of their experience with the researchers. On the other hand, the lack of formality in this study methodology makes it less reliable. Additionally, this was more appropriate for qualitative data, making it less suitable for determining the breadth and severity of the issues amputees' experience.

Focus group

Using this qualitative research technique, a limited number of demographically chosen individuals are interviewed on the research issue (Tegan, 2021) .Four amputees from the Makonde district were chosen by the researchers, and they conducted interviews with them to learn more about the problems they face and the best ways they see to address them. The interviewers spoke with individuals who care for amputees at old people's homes in Makonde about the subject at hand. The researchers were able to learn a lot from the participants' body language and the experts' responses, which was really beneficial. Data analysis, however, was seriously hampered by the possibility of body imbalance.

Data analysis

This technique is applied to data modeling to support decision-making (Calzon , 2021) . Data pertinent to the study's topic will be analyzed by the researchers using content analysis. A technique called content analysis is used to examine qualitative and numerical data from interviews that are presented as written or recorded text (Luo, 2021) .For data analysis, the researchers employed Python. This application made it possible for academics to visualize and analyze data using pandas, NumPy, and matlib with only a few lines of code. When compared to other data analysis methods, content analysis is very flexible, very dependable, and the availability of the interviewer has no bearing on the analysis's findings as shown on Figure 14 (Luo, 2021).However, content analysis only describes data and cannot be used in situations where a more in-depth investigation of the data is needed (tutor2u, 2021).

Quantitative methods

In order to create a solid and trustworthy end product for our project, this procedure was employed to compile pertinent hardware components from several suppliers.

Experiments

A field experiment is a research method where the independent variable is manipulated, and the dependent variable is measured in a real-world setting (StudySmarter, 2023).In our study a field experiments conducted for our study in order to find the best results and components for our project so many .This experiment was done to in order to determine the type of component and the prices and how to get them because some of the we not locally available like the EEG sensor so for that we compared price and shipment time below is the list of variable that were used for our field experiment .

Here is a list of the hardware components that were studied and tested in this study.

- Server motors
- 3D printing Filament
- EEG hand caps
- Microcontroller bands

- Steeper motor
- Temperature sensor
- Humidity and temperature sensor

To discover the best hardware component, various online stores, including eBay, Alibaba, Amazon, and AliExpress, were investigated. Online research was also done in addition to physical shopping. When choosing which EEG sensor to use, this field experiment was helpful. There are many sensors available, including the Muse and BCI EEG sensors, but we ultimately chose the TGAM EEG sensor because it was sold on AliExpress and had a minimum shipping period of & days, which is appropriate for our project milestone. We chose the SG90 servo motor because it was the finest hardware option for finger control, was locally accessible, affordable, and readily available. The Arduino Uno microcontroller was inexpensive and widely accessible locally for higher motors and temperature sensors.

Surveys

To see how amputees are cared for, the team conducting this quantitative research went to Chinhoyi Provincial Hospital. This research was able to interview two amputees about their replacements in this situation. The Chinhoyi physician Dr. Zulu recommended a passive prosthetic arm, and the replacement was purchased from Otto Bock Triple Bands (Pvt), a local base business in Borrowdale, Harare. We conducted interviews with two candidates who were of opposite sexes to learn how they are adjusting to living after amputation. The candidates shared their experiences with the researchers.

Conceptual framework for

SOFTWARE DEVELOPMENT METHODOLOGY

In this research, the V model was used to create the prosthetic arm algorithm and extreme programming techniques. The V model or evolutionary prototyping was used in our IOT-based project to account for every component of the prosthetic limb. The V-model is a type of SDLC paradigm where processes run sequentially in a V-shape. It is also referred to as the Verification and Validation paradigm. It is based on the correlation between a testing phase and each related development stage (JavaTpoint, javatpoint, 2021). Each step's development was closely related to the testing stage. Only after the prior phase has been completed, i.e., there is a testing activity corresponding to each development activity, does the next phase begin. A methodical and visual depiction of the software development process is offered by the V-Model, which is a software development life cycle (SDLC) model. It is based on the concept of a "V" shape, with the two legs of the "V" standing for the steps in the software development process, from collecting and analyzing requirements to designing, implementing, testing, and maintaining the software.

Justification of using the V model

It is a methodical approach to building the best possible hardware and software base systems. This development methodology was chosen in order to gain a clear grasp of the project's scope without having to use our software and hardware directly. Along with working independently more often than they would under the agile methodology, team members also prefer to work on a systematic approach and visual representation of the software development process. Business requirement analysis: This is the first stage in which the needs of the amputee are understood in terms of product requirements. To fully comprehend the expectations and precise needs of the amputee, this phase includes extensive dialogue. This research revealed that amputees require lightweight, functional arms in order to perform their tasks. System Design: System engineers use the user requirements document to analyze and understand the business of the proposed system at this stage.

SYSTEM ANALYSIS

Detailed information on the system and its users is provided in this section. Then it shows the functional and non-functional needs that were gathered by employing various techniques like interviewing, surveys, and brainstorming. Following the selection of the most crucial requirements, requirement analysis was implemented utilizing a variety of methods, including class diagrams, sequence diagrams, and activity diagrams.

Requirement analysis

System requirements analysis is the process by which researchers gain a thorough understanding of the system as defined in the system aim and objectives (Martin, 2021)The researchers will outline the functional, non-functional, software, and hardware requirements of the RUOKO BOT in this section.

Functional requirements

These are the fundamental features that the end user requests and expects the system to provide (chitrasingla2001, 2020). The functional specifications for the RUOKO BOT acquired in the prior session are listed below.

- The system shall read thoughts
- The system shall detect temperature
- The system shall process the thoughts.
- The system shall detect the hand movements
- The system shall notify the user

Non- functional requirements

The researchers' nonfunctional system criteria are as follows:

- Portability- The system must be extremely portable, with the user wearing the prosthetic limb all day.
- Maintainability- The system must be highly maintainable and readily adaptable to environmental changes.
- Usability- The prosthetic limb should be simple to use and not burden the user.
- Performance-The system must recognize brain waves and communicate with the prosthetic arm as imagined.
- Scalability- The system must be able to integrate new components and functions.

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- Performance-The system must recognize brain waves and communicate with the prosthetic arm as imagined.
- Scalability- The system must be able to integrate new components and functions.

SYSTEM REQUIREMENTS

System requirements for the system fall into three groups, namely:

Interface Requirements

Members will be able to use the interface with ease.

- The device should be comfortable to wear
- The device should fit the user with easy.

Hardware Requirements

- RAM 4GB (Minimum)
- HDD 50 GB Hard Disk Space (Minimum)

BUSINESS MODELLING PROCESS

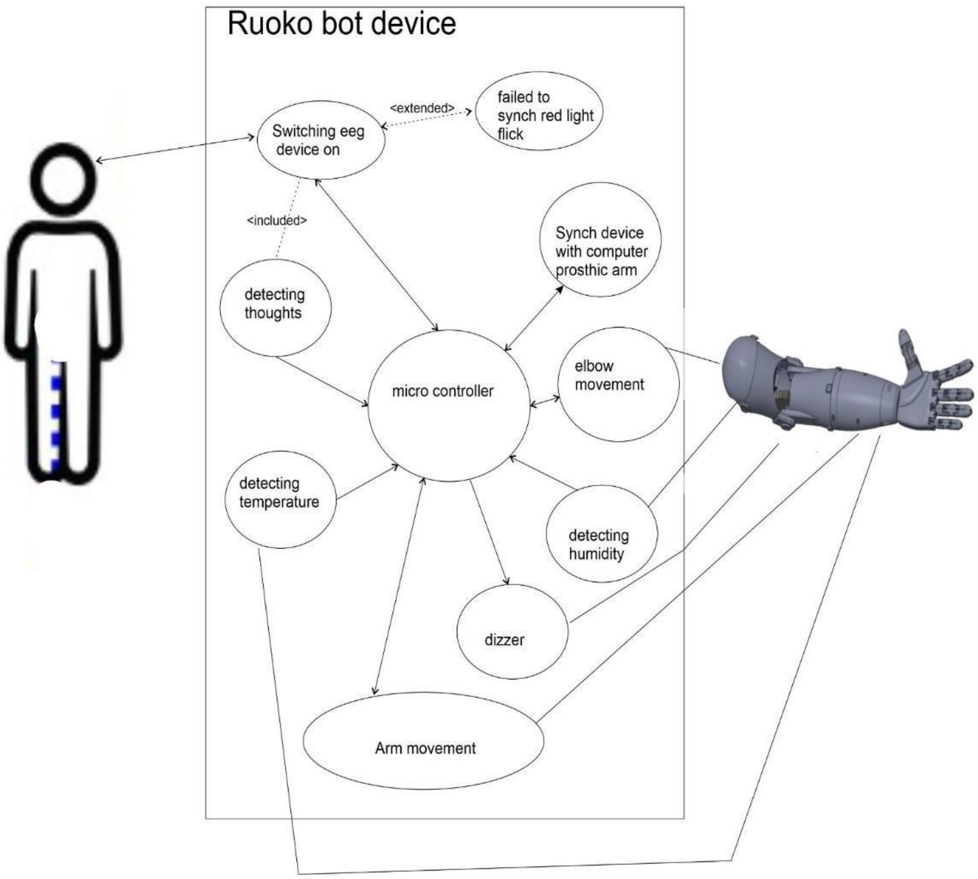
This is a graphical method of illustrating how business processes are related and interconnected through the use of flowcharts and activity diagrams. (Swain, 2021)Business process modeling depicts the events and activities that take place in the business. Services can carry out business activities, so business process modeling depicts the representation of business operations in a graphical and quantitative format. Use case model was used by the experts in business process modeling.

Use case model

These are UML diagrams that show various actors and how they interact with the system. A role is represented by an actor, a use case by an activity within the system, a system by an overall collection of roles, and packages are used to group roles together (Mattar, (2013)). The only actor identified by the researchers was the amputees. The researchers created the following use case diagram for the RUOKO BOT (Neuro robotic prosthetic arm with an end effector) as shown in **Figure 13**:

Figure 13

Use case

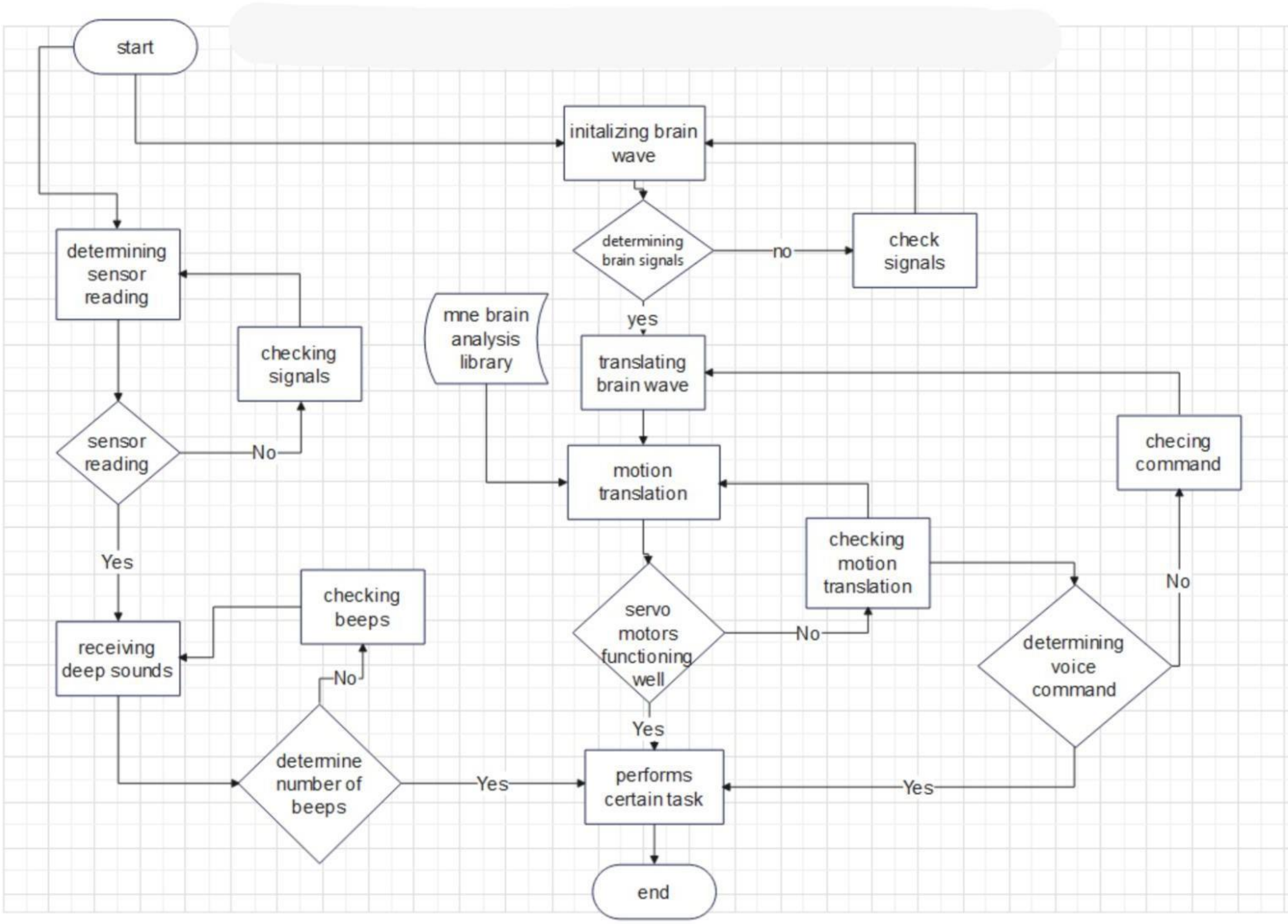


General subsystem flowchart

This is the flowchart integration of the previous subsystems. The general system flowchart includes modules and functionalities for thoughts, temperature, and hand movement. The system will first determine whether or not the EEG headset has translated the thoughts into brainwaves. An artificial intelligence algorithm will learn, translate, and determine which signal is sent by the brain before translating it into motion via a 3D printed end effector. A 3D printed female socket connector will connect our prosthetic arm to the end user. A 5 servo motor will control the fingers, while a 1 servo motor will control the elbow. In addition, if the head cap fails to transmit the signal, speech recognition can help control the arm using the Internet of Things (IoT) if there is a problem interpreting brain waves as shown on **Figure 14.**

Figure 14

System Flowchart

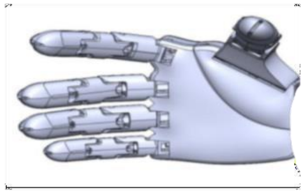


DESIGNING OF MECHANICAL & INDUSTRIAL COMPONENTS

Although mechanical design makes use of CAD tools, it adheres to all the standard guidelines to provide a fully compatible result. When working on an Internet of Things project, Tinker CAD was chosen as a versatile and dependable alternative as shown in **Figure 15**.

Figure 15

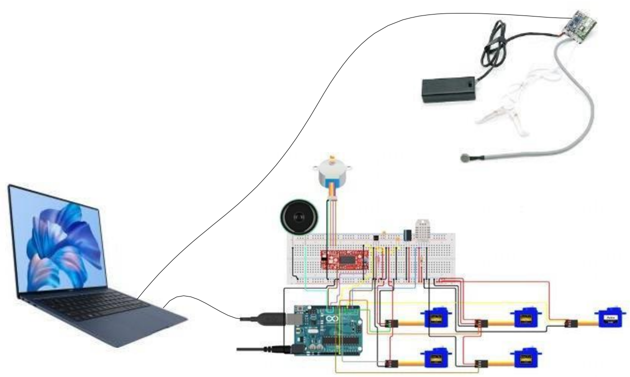
Ruoko Bot End Product

Design	End product
 this was designed using tinker Cad which is an online computed added design software	

SIMULATION DESIGNING OF COMPONENTS

We used computer-based simulation modeling for the system design to understand its behavior and predict the effect of changes. Protius Simulation was used since it is a powerful method for analyzing, designing, and operating the **Figure 16** shows a simple simulation of servo motor and a temperature sensor.

Figure 16
Protius Simulation



Architecture Design: The first step in choosing an architecture is to ensure that you are aware of everything that is involved, including the list of modules, a short description of each module's functionality, their interface relationships, dependencies, database tables, architecture diagrams, and technical information. A certain step includes the integration testing model. **Module Design:** Thesystem is divided into manageable modules during the module design process. Low-Level Design, which is the specification of the components' intricate design. **Coding process:** The coding process is initiated after designing. As a result, this research revealed that Python, Arduino, and some coding standards will be used to develop it. The final build is enhanced for improved performance prior to checking it into the repository, and the code undergoes numerous code reviews to verify its performance.

RUOKO BOT COMPUTER TESTING

The core i3 Sony laptop computer shown below was used by the researcher to filter the EEG data and then to interface with the microprocessor to operate the Ruoko bot prosthetic limb.

Integration testing

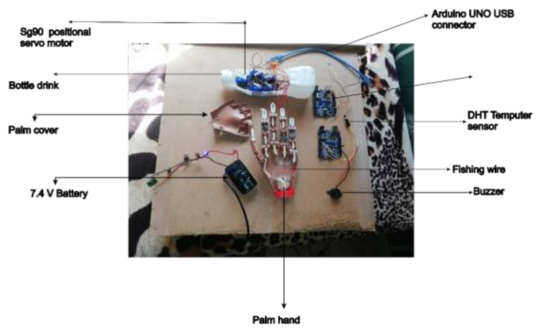
Integration testing is combining all unit tests and debugging them as one unit in order to ensure compatibility (Randall & CTAL, 2020). Integration testing is done to find any issues that could arise from integrating all the parts, to check the system's functionality interoperability, and to guarantee stability (Choudary, 2020). The researchers examined the hardware's compatibility with the simulation's components.

Hardware integration test

By performing each of the unit hardware tests listed in the earlier test cases as a single unit, the researchers were able to confirm that the Ruoko Bot was operating as intended. The DHT temperature sensor, DHT11, Bluetooth module, buzzer, and Arduino board will turn on as soon as the Arduino IDEis turned on, as shown below: The image shown in **Figure 17** shows each hardware component both before and after component integration.

Figure 17

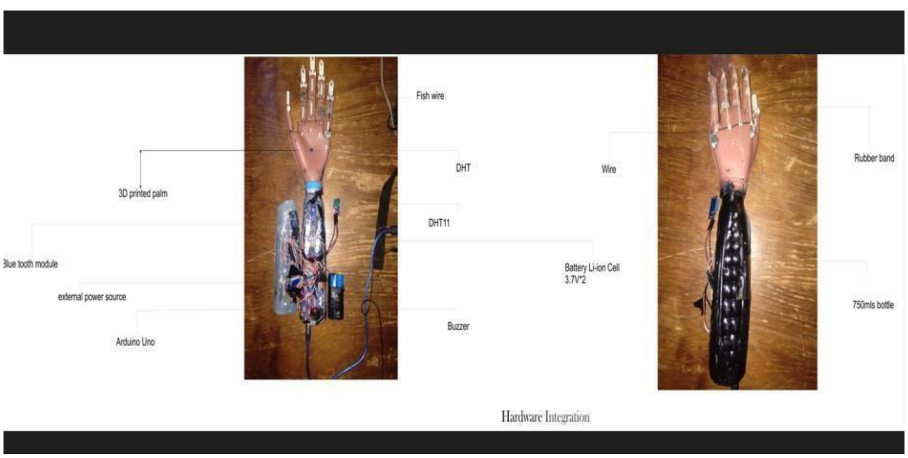
Hardware Integration Test



The image in **Figure 18** shows what our prototype will look like once all of the parts have been put together.

Figure 18

Hardware integration test results



EEG headset Testing

A thorough analysis of the data was done once it was collected and saved in csv format. The results of the research are as follows. Beta waves are related with active mental processes, such as thinking and problem-solving, as well as movement, and have a frequency range of 5 to 30 Hz. According to research, beta waves are involved in planning and carrying out movements because they are more active in the seconds before a movement in the motor cortex and other brain regions. Theta waves are electricaloscillations that occur in the brain between 4 and 7 Hz. Although they are frequently connected to sleepiness, daydreaming, and extreme relaxation, they also play a significant part in a number of processes.

Classification algorithms used

This step involved training a classifier or recognition algorithm utilizing the retrieved features and the outputs that matched as input data. A pre-selected optimization strategy is used to train the classifier to recognize patterns in the data, learn from them, and respond to inputs. After a fruitful training session, the classifier's dependability is evaluated. Different classifications were tested in order to determine which the best was, and classifiers were trained and put through rigorous testing in order to provide precise classification models that help to confirm the results. Three classifiers were explored in order to choose the best one for building the Ruoko bot hand: artificial neural networks (ANN), convolution neural networks (CNN), and decision trees (DT) techniques.

Real-time implementation

To evaluate the Ruoko bot arm design and the EEG signal control with the neural network enabled, different types of tests were performed. After the training phase, it will be possible to judge whether the user can accurately control the Ruoko bot, according to the testing situations. The prosthetic hand movements were streamlined to enable the user to simulate a variety of tasks, such as turning the motors to a holding position for objects, grabbing, and drinking. Simulators were used in single-action testing to carry out one action at a time while recording the motor movements. Making a fist, spreading the fingers, and closing are among the single actions as shown in **Figure 19**.

Figure 19

Real Time testing of the whole system

EVALUATION AND CONTRIBUTION ON THE RESEARCH

This study concentrate on providing an affordable price and less weight prosthetic arms in Zimbabwe. This is because the current Idle Arm in this country is heavy and cannot perform tasks. Also, the research concentrate on improving the amputees' living standards by means of providing them with a useful artificial arm which can perform tasks as a normal human arm. For many people, an artificial limb can improve mobility and the ability to manage daily activities, as well as provide the means to stay independent. To invite the idea of robotics in Zimbabwe. You can experience the advantage of a comfortable fit when the prosthetic is designed and fitted appropriately and this will be different from the idle arm designed before in Zimbabwe. In terms of functionality, the prosthetic arm offers a variety of functional abilities, including the ability to precisely grasp, grip, lift, and manipulate objects. It should ideally support a variety of grip styles and force feedback settings to accommodate various tasks. A prosthetic arm has usable controls that are simple to use and understand. The user's capacity for adapting to the arm's control system and learning curve were taken into account. Ruoko bot was built with user comfort in mind and is comfortable and fit. Weight, size, adaptability, and padding have all been taken into account. To reduce discomfort or skin irritation during continuous use, the arm was fitted snugly and comfortably. Durability and dependability, materials utilized, manufacturing quality, and any known flaws or concerns were taken into account. A durable prosthetic arm (Ruoko bot) can survive normal wear and tear and be protected from damage caused by impacts, dampness, or temperature changes. The power source, battery life, and charging system of the arm were evaluated, and the findings were impressive. The ability to utilize a battery for prolonged periods of time without regular recharging or battery replacement. Cost, functionality, and overall user value were all considered in a fair proportion.

CONCLUSION

The right to health care is guaranteed by the Zimbabwean Constitution, but its execution has proven difficult, especially in developing countries like Zimbabwe. Despite this, we do acknowledge that by providing public institutions with static artificial prosthetic arms, the Zimbabwean government has made smart investments in the health sector. Despite all the success made, the Zimbabwean government still has a long way to go before it meets the global standards for sustainability, economic growth, and health care. Its facilities cannot support its expansion. Communities experience issues because of expensive artificial prosthetic limbs. Most medical treatments are expensive which has a lot to do with amputees which is the main reason why the affordable Ruoko Bot was created. Ruoko Bot uses an EEG headcap, voice recognition, humidity sensor, and a temperature sensor to propose solutions to the issues raised by the linked work listed during the literature study. The design and development of the neural robotic prosthetic arm with an end effector (RUOKO BOT) were covered using the V Model methodological approach and UML diagrams. As a result, the researcher was able to accomplish the project's second and third goals. System validation and system testing were done. According to the testing conducted, the RUOKO BOT, an end effector-equipped neural robotic prosthetic arm, achieved its goals and satisfied user needs. Ruoko Bot has the potential to greatly raise the standard of living for people who have lost their upper extremities. This technology makes use of cutting-edge technologies like machine learning algorithms and brain-computer interfaces like EEG headgear to provide intuitive control and organic movement. However, there are still issues that need to be resolved, such as enhancing the devices' robustness and dependability, bringing down the cost and complexity of the technology, and making sure that patients get the right assistance and training. Overall, the creation of Ruoko Bot represents a promising area of research that could change the prosthetics industry and enhance the lives of millions of people living with amputations in the region of Africa.

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