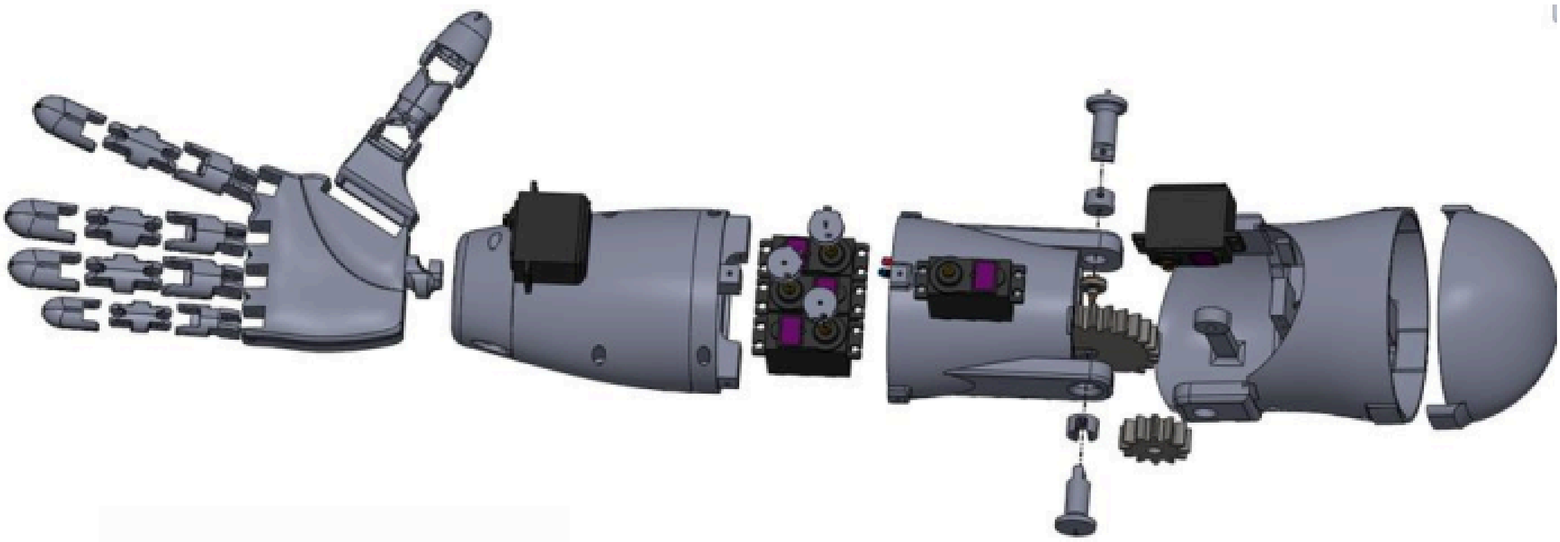

MEDXACT ARM

Study on replacing doctors with robots & Ai

Research is vital for understanding.

BY:

HABIBA HOSSAM – YOUSSEF ABOELAZZ

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01. INTRODUCTION

Robotic-assisted surgery has revolutionized modern medicine by enabling precision, control, and minimally invasive procedures. Despite significant advances in the field, many existing systems, such as the **da Vinci** surgical robot, remain unavailable due to high costs, large size, and complexity. In response to these challenges, our project introduces the **MedXact** robotic arm, a sophisticated, cost-effective, and compact robotic system specifically designed for medical procedures that require precision and flexibility. The **MedXact** robotic arm leverages advances in robotics, computer vision, and wearable technology to redefine surgical practice. At its core, the system consists of a **3D-printed** robotic arm with servo-driven joints, controlled remotely via an **ESP32-based glove.** The glove is equipped with sensors, including distance sensors, **LEDs**, and a **gyroscope**, allowing for intuitive, real-time hand gesture-based control. The integration of the ESP32-CAM module with the system's **computer vision** capabilities will enable it to detect surgical objects and provide the surgeon with a live video feed, enhancing situational awareness.

With the continuous development of life and facilitating all daily operations that we perform for more accuracy and speed with which they are executed, the world has witnessed a great development in surgical operations and all types of precise and non-precise operations over time. Now in the era of **AI and robotics**, the **MedXact** system includes a memory unit to record surgical data. This data can be used for **AI-based learning**, which enables the robotic arm to perform repetitive procedures independently over time, through machine learning, and with a little analysis of the data that the microcontroller infers, it will become more accurate than doctors. By combining affordability, compactness, and automation, **MedXact** aims to make robotic surgery accessible to health facilities that suffer from resource shortages and provide a versatile tool for medical education.

The innovative approach of the **MedXact** robotic arm not only addresses current limitations in robotic surgery but also aligns with the broader goals of modern healthcare to deliver safer, more efficient, and universally accessible solutions. This system represents an important step towards democratizing advanced medical technology while advancing advances in microsurgery, medical training, and many other medical fields.

Executive Summary

The **MedXact** robotic arm is an innovative and cost-effective robotic system designed to revolutionize medical procedures in terms of speed, precision, and efficiency, especially in surgical and ophthalmic procedures that require precision and remote control. This pioneering project aims to address the limitations of current robotic surgical systems, such as high costs, complexity, and inaccessibility, by offering an affordable, compact, and easy-to-use alternative. All of this is part of our design requirements.

The **MedXact** system consists of a 3D-printed robotic arm made of environmentally friendly plastic and reinforced resin that withstands pressure and temperature and is controlled by an ESP32-based glove with integrated sensors, including **light-dependent resistors (LDRs)**, **LEDs**, and a **gyroscope**. These sensors capture hand gestures and movements, enabling intuitive, real-time control of the robotic arm. The arm can be controlled by gestures and hand and finger movements without connecting them to anything via a vision computer, where the movements of the fingers and hand are tracked and the movement data is transmitted via the arm's servers. The arm features servo-driven joints for precise movements and a modular design to adapt to different delicate surgical tasks.

In addition, the system includes an **ESP32-CAM** module with computer vision capabilities, allowing it to detect objects during surgery and provide live video feedback to the surgeon. This ensures increased situational awareness and accuracy. The robotic arm also includes a memory module to record surgical procedures, enabling **AI-based learning** for future autonomous operations after multiple iterations. The arm will be more accurate and faster than a doctor in medical operations.

The MedXact robotic arm offers significant advantages, including:

1. Affordability: Designed with low-cost materials, making robotic surgery accessible to healthcare facilities with limited resources.

2. Compact Design: The lightweight, modular structure allows for easy deployment and operation in a variety of healthcare environments.

3. Advanced Control: The glove-based control system allows surgeons to perform precise procedures remotely, reducing risks in cases of infection or immunocompromised patients.

4. Versatility: It can be used for surgical procedures, medical training, and even AI-based automation of repetitive tasks.

The **MedXact** robotic arm represents a paradigm shift in medical robotics, democratizing access to advanced surgical technology. It has the potential to transform healthcare by reducing costs, enhancing precision, and providing valuable tools for medical education and training. This project is a step forward in bridging the gap between innovation and accessibility in modern medicine.

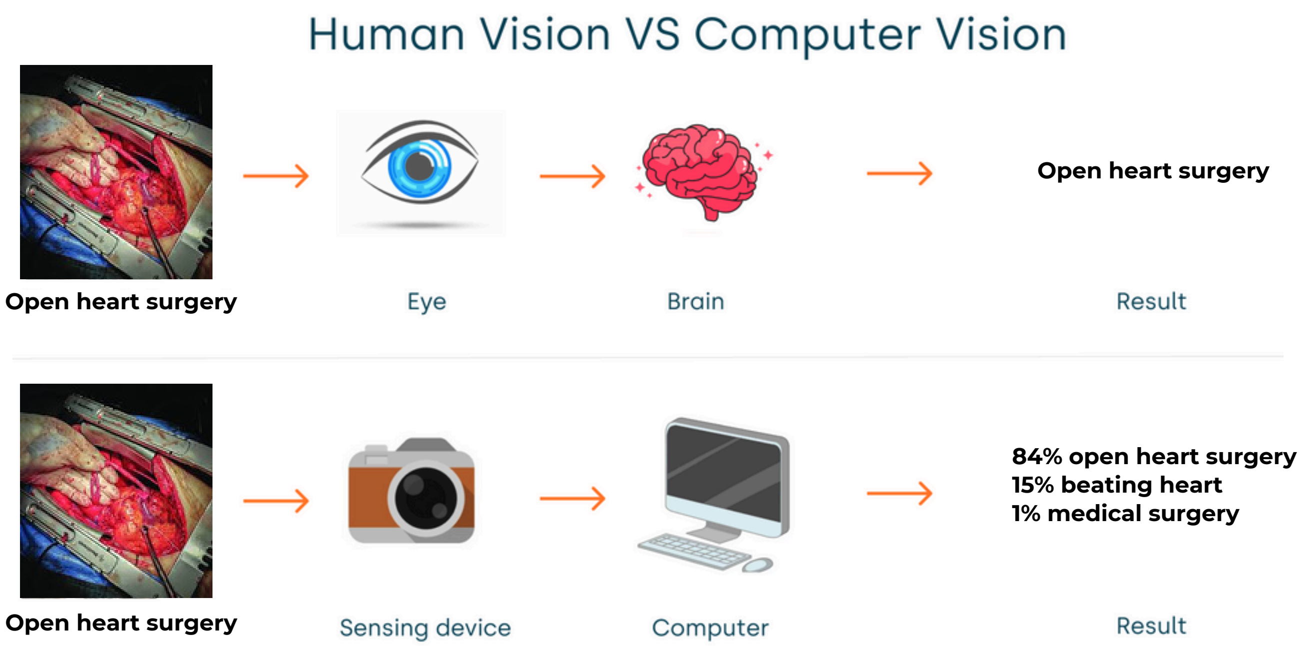


Diagram (1): It shows the difference between human and artificial vision, and explains the accuracy of computer vision.

Overview

The **MedXact** robotic arm is a cutting-edge medical innovation designed to advance the field of robotic-assisted surgery and medical training. Based on the principles of accessibility, precision, and affordability, this project leverages emerging technologies such as robotics, computer vision, and artificial intelligence to create a versatile and cost-effective solution for healthcare.

Key Components

The **MedXact** robotic arm system consists of three core components:

1. Robotic arm: A 3D printed structure powered by servo motors, providing precise control for delicate surgical procedures. Its modular design allows for flexibility in a variety of medical procedures.

2. Controller glove: A wearable device equipped with advanced sensors such as optical sensors, LEDs, and a gyroscope, allowing surgeons to intuitively control the robotic arm through hand gestures.

3. ESP32-CAM and AI: A computer vision-powered camera that provides live video feedback and detects objects in the surgical environment. It supports data recording for AI-based learning, allowing the arm to perform autonomous operations over time.

Key Features

- **Remote Control:** The robotic arm can be controlled wirelessly using a glove, ensuring safe operation in situations that require minimal direct human interaction.
- **AI Learning:** By analyzing recorded actions, the system can learn and perform repetitive tasks autonomously, enhancing efficiency and reducing surgical fatigue.
- **Affordability and Accessibility:** The **MedXact** robotic arm is designed using low-cost materials and components, making it suitable for use in resource-constrained healthcare settings.
- **Versatility:** The system is adaptable to a variety of medical applications, including microsurgery, infection-risk procedures, and educational training for future surgeons.

Objectives

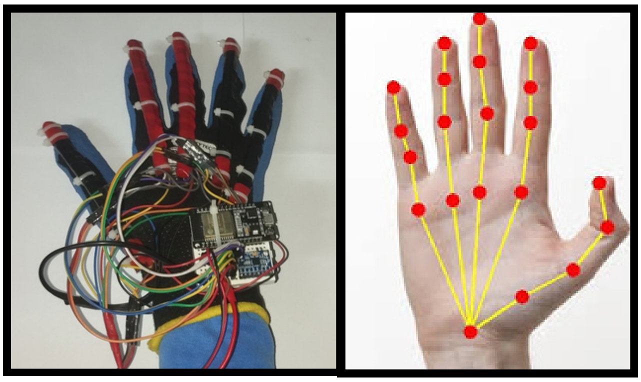
The MedXact robotic arm aims to overcome the challenges of current robotic surgical systems, such as:

- High costs, making them inaccessible to many healthcare facilities.
- Large size and complex settings, limiting their use in small or rural hospitals.
- Limited adaptability to diverse medical needs.

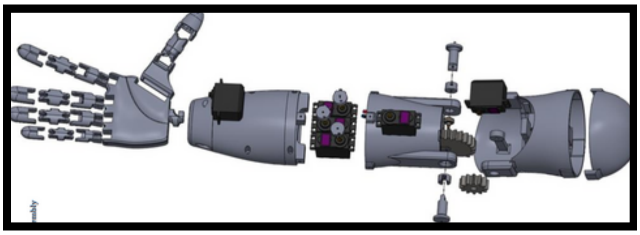
Vision

The **MedXact** robotic arm envisions a future where advanced robotic technology is no longer the privilege of a few elite facilities but a standard tool available to all. It aims to improve surgical outcomes, train the next generation of surgeons, and ultimately save lives through innovation and accessibility.

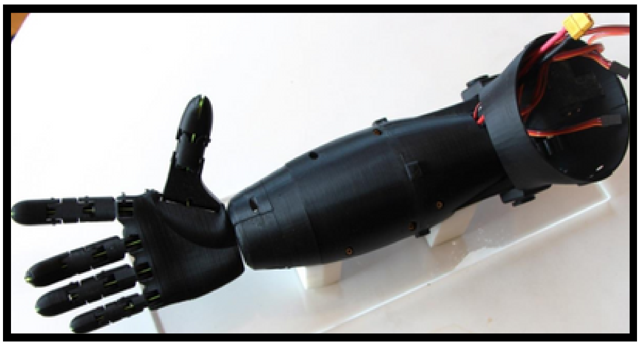
This project bridges the gap between advanced medical robotics and real-world operation, making it a pioneering contribution to modern healthcare.



Figure(1): It shows the methods of controlling the arm, where in the first case the control is through the glove and in the second case by tracking the hand and fingers via computer vision.



Figure(2): 3D design of the arm and servo motors in standard sizes.



Figure(3): The arm after printing is in accordance with the design requirements.

02. METHODOLOGY

Categorization

The MedXact Robotic Arm can be categorized based on its features, applications, and technological innovations. Below are the key categories under which this project can be classified:

1. Field of Application

· **Medical Robotics:** Aimed at enhancing surgical precision and enabling complex medical procedures.

· **Healthcare Technology:** Focused on providing affordable solutions for resource-constrained healthcare environments.

· **Medical Education and Training:** Used in training surgeons by simulating real-life surgical scenarios.

2. Technology Domain

· **Robotics:** The robotic arm is equipped with servo motors and a 3D-printed structure to ensure precise movements and adaptability.

· **Wearable Technology:** The glove controller integrates sensors (LDRs, LEDs, gyroscope) for intuitive and responsive operation.

· **Computer Vision and AI:** The ESP32-CAM allows real-time video feedback and object detection, while AI enhances learning and autonomous operations.

· **IoT and Wireless Communication:** Utilizes Wi-Fi and Bluetooth for seamless communication between the control glove and robotic arm.

3. Functionality

· **Precision Surgery:** Assists in highly delicate operations requiring exact movements.

· **Remote Operation:** Enables surgeons to operate from a distance, reducing infection risks in sensitive environments.

· **Autonomous Capabilities:** Incorporates AI-driven functionalities for repetitive and learned surgical tasks.

4. Innovative Aspects

· **Cost-Effective Design:** Employs affordable materials and components to make robotic surgery accessible.

· **Compact and Modular:** Designed to overcome size and complexity challenges of traditional robotic surgery systems.

· **Learning and Recording:** Features data storage for AI training, enabling continuous system improvement.

5. Problem-Solving Approach

· **Addressing Limitations of Existing Systems:** Tackles issues such as high cost, size, and operational complexity found in systems like the Da Vinci Surgical System.

· **Accessibility and Deployment:** Focuses on low-cost, portable design for use in diverse and underserved healthcare settings.

6. Classification as an Automated Mechanical Unit (AMU)

· **Automation:** Performs surgical tasks with high precision and minimal human intervention.

· **Mechanical Engineering:** Incorporates servo motors and actuators for controlled movements.

· **Sensor Integration:** Employs advanced sensors for environmental feedback and gesture recognition.

By categorizing the **MedXact** Robotic Arm under these domains, the project demonstrates its versatility, innovative nature, and significant contribution to advancing medical technology.

Classification

The MedXact Robotic Arm project falls into multiple classifications based on its purpose, technology, and application areas:

1. Based on Purpose
· **Medical Technology:** Designed sp1ecifically for assisting in medical procedures such as surgeries, eye operations, and healthcare applications.
· **Assistive Robotics:** Enhances the precision and capability of human surgeons, reducing error and improving outcomes.
2. Based on Technology
· **Robotics:** Incorporates mechanical arms and servo motors for precise movements.
· **IoT and Wireless Communication:** Utilizes ESP32 for wireless control via Wi-Fi and Bluetooth.
· **Computer Vision:** Includes a camera module for real-time object detection and situational awareness.
· **3D Printing:** Uses 3D-printed components for lightweight and customizable parts.
· **Embedded Systems:** Relies on ESP32 microcontroller for data processing and system integration.
· **Artificial Intelligence (Optional):** Allows for autonomous operation after AI training using recorded surgeries.
3. Based on Application
· **Healthcare:** Assists in surgeries, particularly in regions with limited resources.
· **Medical Education:** Serves as a training tool for students and professionals to practice surgical techniques.
· **Remote Surgery:** Facilitates operations in distant or isolated locations, reducing infection risks and improving accessibility.
· **Research and Development:** Provides a platform for testing and innovating new surgical techniques and tools.
4. Based on Functionality
· **Automated Mechanical Units (AMU):** Follows a structured phase design for automation, integrating sensors, actuators, and control systems.
· **Wearable Technology:** Uses a glove with sensors and gyroscopes to interpret user gestures.
· **Surveillance and Monitoring:** Equipped with an ESP32 Cam for live feedback and data recording.

5. Based on Market Focus

· **Cost-Effective Solutions:** Provides a low-cost alternative to expensive robotic systems like the Da Vinci surgical system.

· Scalable Technology: Adaptable to different medical needs, from minor surgeries to complex procedures.

Problem Management

Problem Identification

Plastic Durability Issues

One of the key challenges encountered in the development of the Medxact robotic arm was the durability of plastic components, especially in parts subjected to high pressure. The original plastic materials used in the 3D-printed arm were prone to cracking and deforming under stress, leading to potential failure in critical areas of the arm's movement and control. The root cause of the issue lay in the mechanical stresses experienced by certain components, such as the joints and motor mounts. These parts makes it hard for the arm's movements and the forces applied during operation. The plastic used in these areas was not strong enough to withstand the pressure, which resulted in damage over time.

Solutions Implemented

To address this, we made the decision to replace plastic with resin in the parts most exposed to high pressure. Resin, particularly when used for 3D printing, offers greater strength and durability compared to standard plastics. We carefully selected resins that could handle the stresses of the robotic arm's operations without compromising flexibility and performance.

The new resin components were designed with enhanced structural integrity in mind, ensuring they could withstand the mechanical demands without cracking or deforming. This allowed the arm to maintain consistent functionality and improved the overall lifespan of the system.

This process highlighted the importance of material selection in the design of robotic systems. The switch to resin in critical parts not only solved the immediate problem but also enhanced the overall durability of the Medxact robotic arm. Going forward, the project will continue to explore the use of more advanced materials to further increase the efficiency and longevity of the system.

User interaction and comfort

Ensuring that the glove was comfortable and responsive while accurately detecting subtle hand gestures proved difficult. The glove needed to strike a balance between sensitivity and comfort, as it had to fit a wide range of hand sizes and still perform effectively without causing strain.

Solution implemented

We redesigned the glove's structure for better shape, using flexible, lightweight materials that allowed for ease of movement without

Compromising sensor functionality. The glove's design was also adjusted to ensure it fit various hand sizes comfortably while maintaining the precision needed for controlling the robotic arm.

High Cost of Flex Sensors

Initially, we planned to use flex sensors in the glove for detecting finger movements. However, we encountered a significant challenge with the cost of these sensors. Flex sensors, particularly high-quality ones with good accuracy and durability, are relatively expensive, making it difficult to stay within budget while ensuring the system could scale effectively. The high cost of flex sensors posed a financial barrier, especially when considering the need for multiple sensors for precise movement tracking.

Solution implemented

To overcome this cost challenge, we decided to replace the flex sensors with Light Dependent Resistors (LDRs). LDRs are significantly cheaper and, when integrated into a suitable setup, can provide accurate detection of finger movements based on the varying light levels caused by hand gestures. We designed a system where changes in light intensity, corresponding to finger movement, were detected by the LDRs. By using a combination of LDRs and adjusting the design of the glove, we were able to replicate the functionality of flex sensors at a fraction of the cost, without compromising on performance or accuracy.

03. ANALYSIS

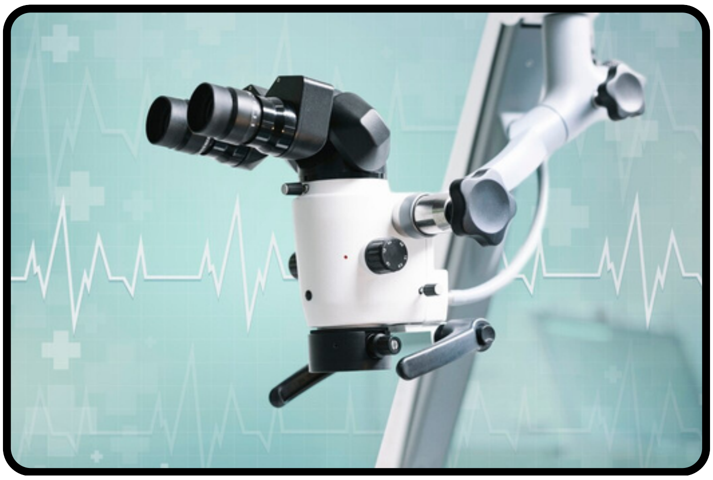
Features and Capabilities

Autonomous Operation with Pre-recorded Movements

The system captures inputs from the glove's sensors and records these movements onto an SD card. These recorded sequences can then be replayed to perform repetitive or pre-defined tasks autonomously. Where these Applications include Surgical simulations where specific movements need to be replicated. Surgical operation with high accuracy

Real-time Injury Detection

With the ESP32 CAM, the system provides real-time image recognition capabilities. with AI models trained on injury datasets allow the robotic arm to identify wounds, cuts, or abnormalities during operations. It has several features where it provides visual feedback to users, can alert operators of detected issues, ensuring quick responses. This feature improves safety and reduces errors .



Figure(5) Real time detection

Visual feedback

The system provides haptic or visual feedback to the user, enhancing interaction. Vibration feedback in the glove for specific tasks or alerts.
Real-time notifications on a connected display for better situational awareness.

Figure(6) Vibrational Feedback

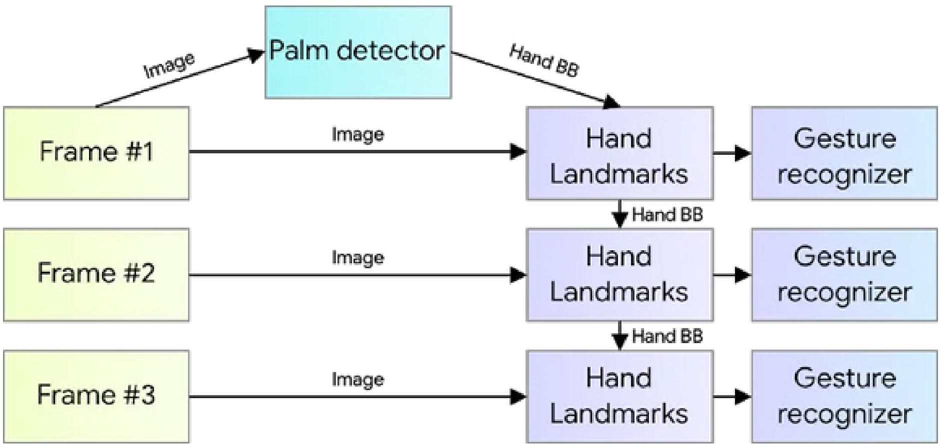
Communication

Communication via ESP to ESP

The Medxact Arm employs an ESP-to-ESP communication protocol, supporting up to 244 channels for seamless interaction. It is simply a system where The glove's sensors transmit data wirelessly to the robotic arm via an ESP32 module. The channels ensure smooth, interference-free communication, allowing multiple commands to be processed simultaneously.

Hand Gesture Control

The Medxact Arm utilizes advanced computer vision techniques, leveraging Mediapipe and OpenCV for hand gesture recognition. These tools enable real-time tracking of hand positions and movements with high accuracy, allowing intuitive and natural control of the robotic arm. No need for physical sensors or direct contact with the glove, Flexibility in gesture definition and recognition for diverse operations. Enhanced responsiveness and precision in controlling the robotic arm's movements **as shown in Fig(7) and Fig(8).**



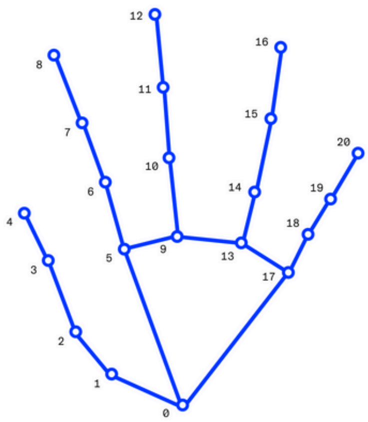
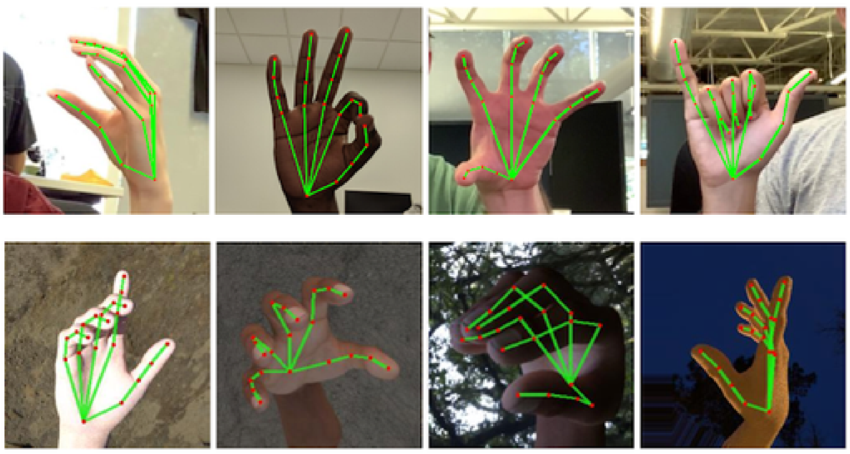
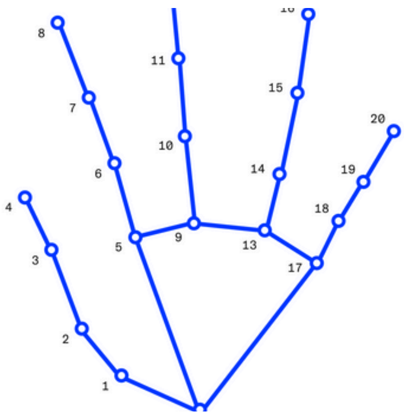


Diagram (2) Hand Gesture mechanism



Figure(7) Hand Tracking movements



Fig(8)

Communication via glove controlled system

The glove control system **as shown in Fig(9)** is the core interface of the Medxact Arm, designed to translate hand movements into precise robotic arm actions. This system ensure intuitive and reliable control for a variety of healthcare applications. The key components of this system are Gyroscope Sensor which detects the orientation and angular motion of the hand, Provides precise angle adjustments to the robotic arm's servo motors , Ensures smooth, accurate movement, especially in tasks requiring advanced skills. Light Dependent Resistor (LDR) is designed to monitor finger movements based on light levels. where it works by the bending of fingers which changes the amount of light reaching the sensor, which is interpreted as a command for specific robotic arm actions. This way of communication simplifies the mechanism for tracking finger movements.

Figure (9) Glove controlled

Robotic-assisted surgery represents one of the most significant advancements in surgical technology. Surgery was transformed with the arrival of robotic devices like the da Vinci Surgery System in the early 2000s, which offered improved control, flexibility, and precision during operations. In delicate surgeries, robotic arms under the direction of highly skilled surgeons provide more accurate cuts and movements, lowering the possibility of human error. For a number of populations, surgeons have used robotic-assisted surgery; however, the surgical community has accepted this technology far too slowly. It is mostly because to its fundamental high cost and technical limitations. Indeed, robotic surgery has advanced significantly during the last 20 years . A large number of surgical procedures were performed with the assistance of robots , even with comparative success rates to standard laparoscopy. As a newly developing field, it still has many challenges and obstacles. This work is centered on the current status and progression of robotic surgery as well as the future perspectives in this field , Despite studies showing that the conventional laparoscopic approach as **shown in figure (10)** resulted in more efficiency compared with the open approach, the robot surgery, instead, has revolutionized the concept of MIS (minimally invasive surgery). The use of robot assistance has helped to realize the full potential of MIS with improved consistency, safety and accuracy. Da Vinci Surgical System, which was introduced in the early 2000s. This system

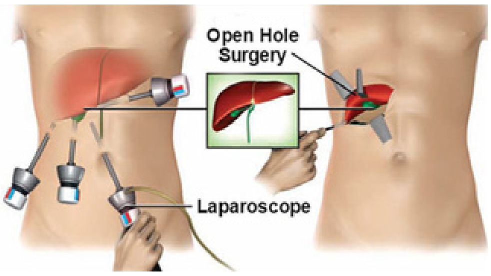


FIGURE (10)

transformed minimally invasive procedures by enabling surgeons to perform highly precise operations using robotic arms. It offers features like 3D high-definition visualization, instruments with a greater range of motion than the human hand, and ergonomic controls. These innovations have led to benefits such as reduced blood loss, smaller incisions, and faster recovery times for patients.

The development of articulated, precision tools to enhance the surgeon's dexterity has evolved in parallel with advances in imaging and human-robot interaction. since then , Surgeons worldwide have embraced the rise of this new robotic surgery. The robotic platform provides many advancements, solving many tricky problems encountered during standard laparoscopy. the field of surgery is under constant evolution. Surgeons continue to explore new approaches to improve outcomes for patients by making procedures safer and more effective , historical timeline and advancements in surgical techniques, starting from traditional open surgeries in the 1860s to more modern, minimally invasive and robotic surgeries. It shows the progression of technology and methods, highlighting the major breakthroughs in surgical innovation. One of the most well-known advancements in robotic surgery is the Da Vinci Surgical System, which was introduced in the early 2000s. This system transformed minimally invasive procedures by enabling surgeons to perform highly precise operations using robotic arms. It offers features like 3D high-definition visualization, instruments with a greater range of motion than the human hand, and ergonomic controls. These innovations have led to benefits such as reduced blood loss, smaller incisions, and faster recovery times for patients , which led to the decision to develop Medxact as a cost-effective alternative. We wanted to create a system that would provide affordable rehabilitation and assistance, improving the accessibility of robotic therapy to a wider audience.

Glove-Controlled Systems and Sensor Technologies:

Much of the research around glove-controlled robotic systems focuses on the use of flex sensors and other specialized components that detect hand movements. While effective, flex sensors can be quite costly, which made them unsuitable for a project with budgetary constraints. Our research into sensor technologies led us to Light Dependent Resistors (LDRs), which, although not as common in medical applications, offered an affordable and highly effective alternative. By integrating LDRs into our system, we were able to accurately detect changes in hand position and movement while keeping the costs manageable.

3D Printing in Medical Devices:

The use of 3D printing in medical device design has opened up new possibilities for creating customized, lightweight, and cost-effective solutions. Our background research on 3D printing technologies revealed that this method would allow us to produce highly personalized parts for the robotic arm, reducing manufacturing costs and lead times. We leveraged 3D printing to design parts that were both durable and lightweight, which is critical for a device that needs to be both functional and comfortable for long-term use in medical environments. This research also provided insights into the best materials to use for different parts of the robotic arm, ensuring that each component met our performance requirement

Remote Surgery

Medxact Arm enables surgeons to perform operations in geographically distant locations, leveraging its wireless capabilities and real-time communication. This is particularly beneficial in areas with limited access to advanced medical facilities, where this is important to expand access to specialized medical care in underserved and rural areas. In addition reduces the need for patient relocation to advanced medical centers.

High-Precision Operation

The robotic arm is engineered for tasks requiring high accuracy, such as microsurgery or repairing delicate tissues. Which reduces the error in complex surgical procedures. and Improves patient outcomes by ensuring consistent, high-quality execution.

Medical Training

The system offers an interactive and realistic platform for medical trainees to practice procedures without risking patient safety. Several features support training which are Pre-recorded movement playback for repetitive task practice, Gesture control with Mediapipe and OpenCV provides an intuitive learning experience and Object detection allows trainees to identify and handle instruments effectively.

Addressing Surgeon Shortage

Medxact Arm offers a scalable solution to address the global shortage of skilled surgeons, especially in developing regions. **as shown in Fig(11)**

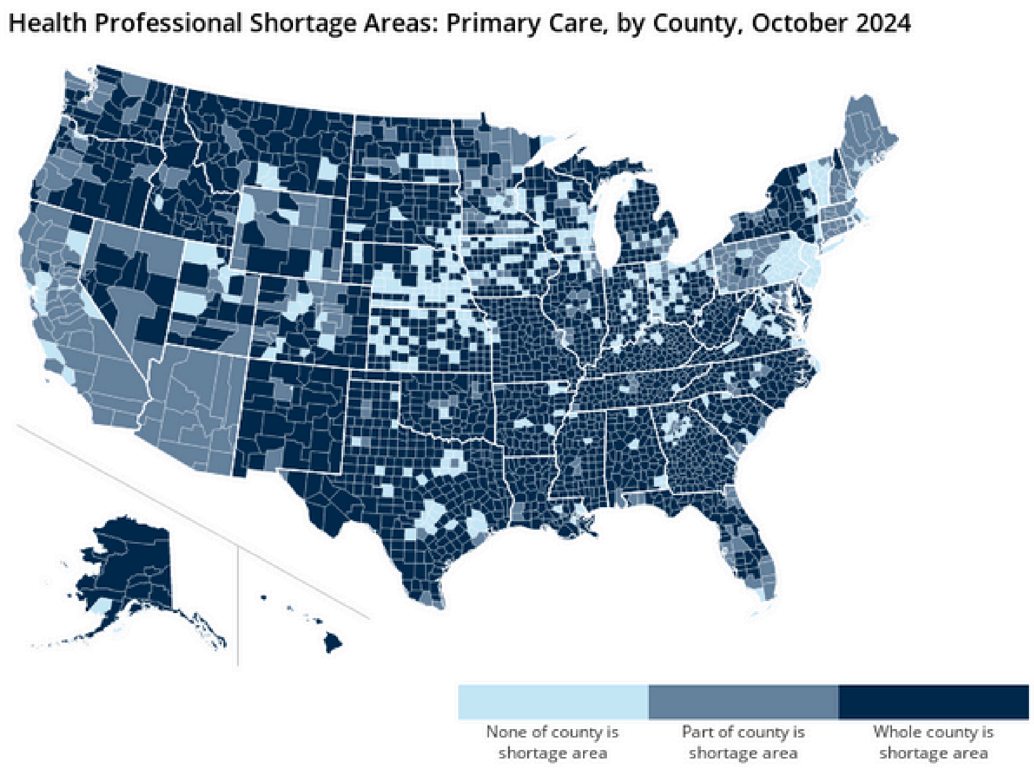


Figure (11) Glove controlled

04. DESIGN PROCESS

3D Printing and prototyping

The design process of the Medxact Arm combines engineering principles, advanced technology integration, and user-centered design to create a reliable and innovative robotic system. The process can be broken down into the following detailed stages:
With the design and components finalized, the prototyping and 3D printing stage commenced. models of the robotic arm using CAD tools such as SolidWorks . The design underwent multiple iterations to optimize for strength and flexibility. Once finalized, the components were 3D-printed using durable materials like Plastic and Resins. A modular approach was adopted, enabling easy upgrades and repairs **as shown in fig(12) and fig(13)**

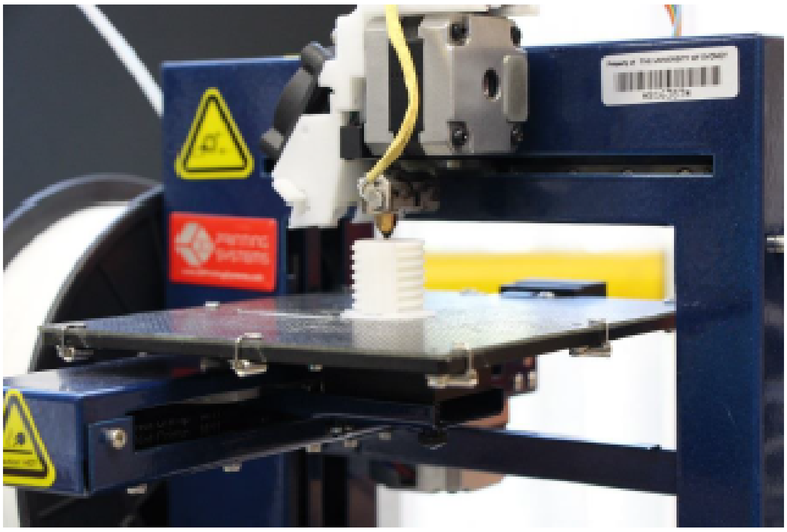


Figure (12) 3D printing

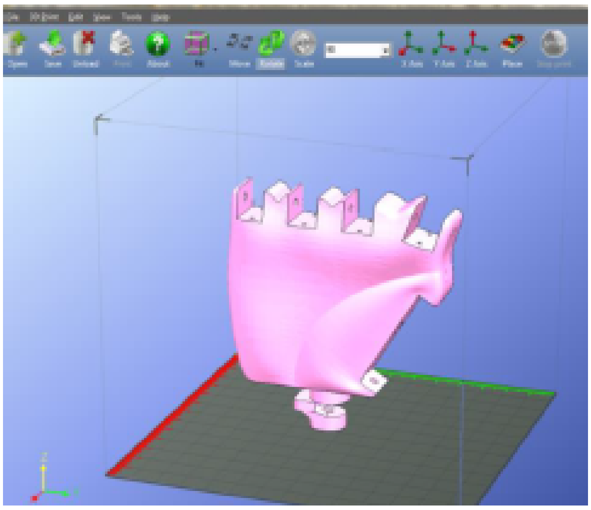


Figure (13) 3D modelling

Prototyping (Robotic Arm Construction)

The robotic arm was built to mimic human arm movements as shown in Fig() and Fig() after 3D Printed parts were collected together, integrating multiple degrees of freedom. Contained several components .
Servo Motors (e.g., MG996R):
Controlled each joint (base, shoulder, elbow, wrist) for precise movements.
Calibrated to align with the glove's input.

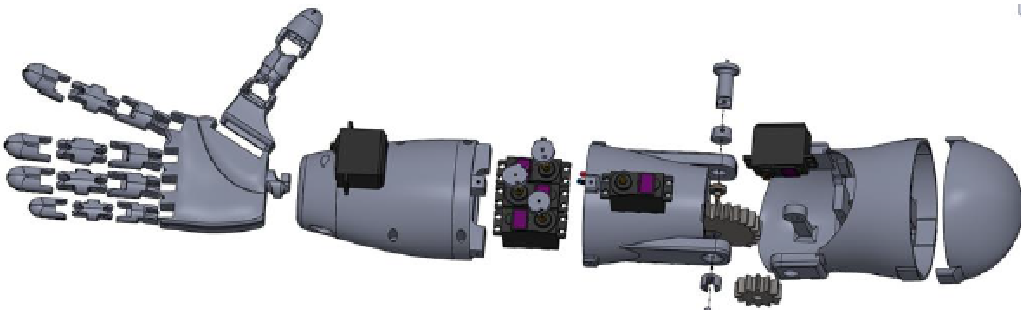


Figure (14) 3D Printed Parts

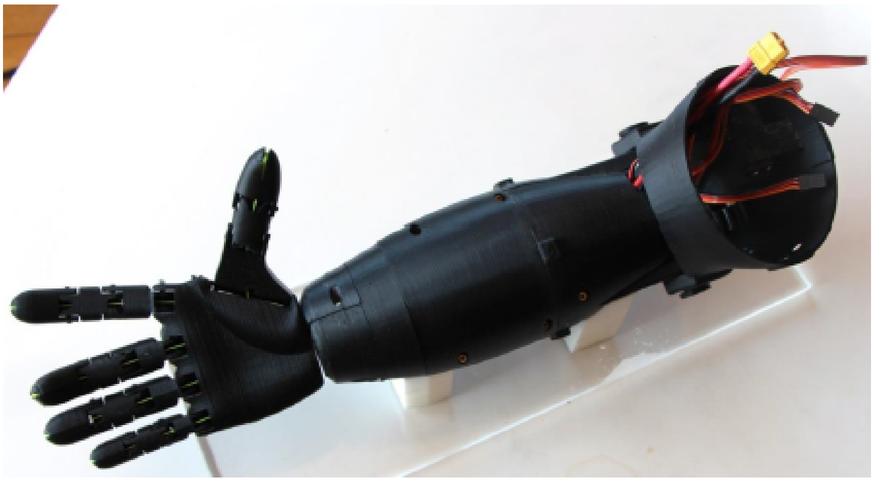


Figure (15) 3D Printed Parts after being collected together

Servo motors are an essential component of the Medxact Arm, enabling precise control of joint and fingers movements with a specific ratio **as shown in Fig(16)**. Their ability to achieve accurate positioning, speed control, and torque makes them ideal for applications requiring reliability, such as healthcare robotics , Servo motors are installed at key joints, including the base, shoulder, elbow, and wrist.

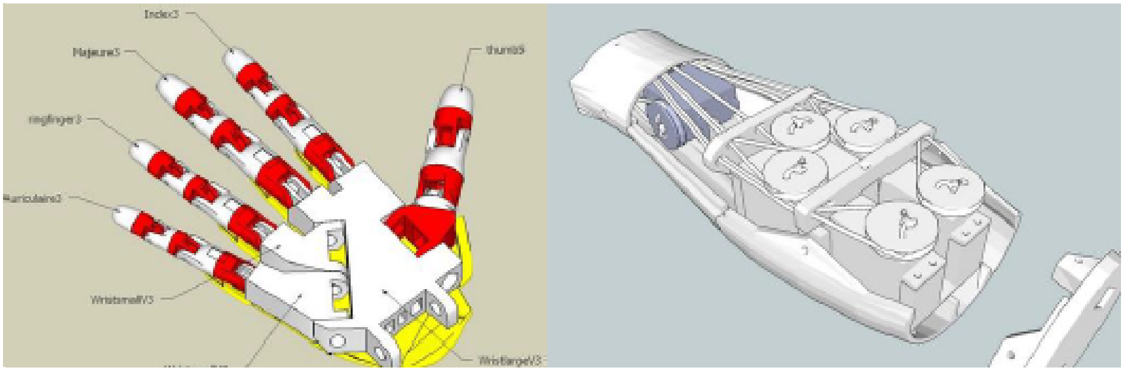


Figure (16) Servos ratios to fingers

They enable rotational and linear movements, providing the arm with multiple degrees of freedom (DOFs).

Degree Of Freedom : The concept of "degree of freedom" (DOF) defines the range and complexity of movements a robotic system can perform. In the Medxact Arm, the use of 3D prototyping allowed for precise control and customization of the arm's degrees of freedom, resulting in a highly functional and helps in healthcare applications. A degree of freedom refers to a robot's ability to move in a particular direction or rotate around an axis as shown in **Fig(17)**. For example:

Translational Movement: Forward, backward, left, right, up, or down.

Rotational Movement: Pitch, yaw, and roll.

Creating six degrees of freedom for more flexible and precised moves.

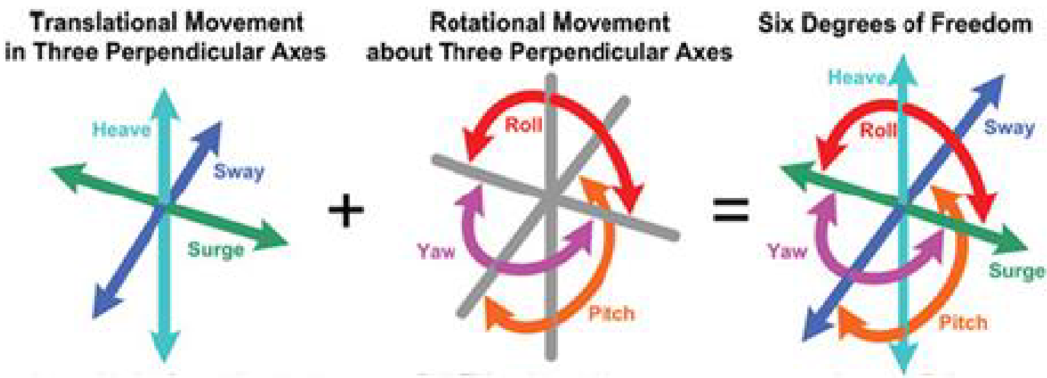


Figure (17) The Six Dofs

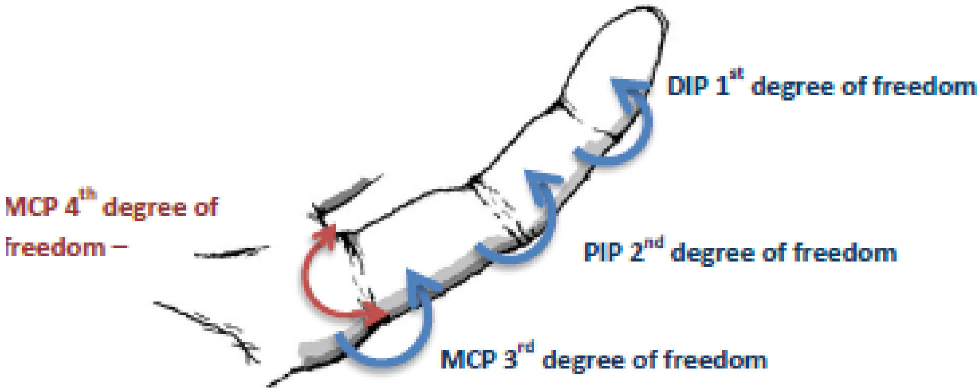


Figure (18) Finger's DOF

Robotic arms, such as the Medxact Arm, often replicate human arm movements, requiring multiple DOFs to mimic actions like bending, rotating, or grasping. The higher the DOF, the more complex and precise the arm's movements can be.

Role of 3D Prototyping in DOF Development

Customizing Joint Design

the Medxact Arm's joints were designed to provide maximum flexibility. Servo motors were strategically placed to allow rotational movements at key points **as shown in Fig(18)**, such as the shoulder, elbow, and wrist, mimicking human arm motion.

Drive System

The drive system of the Medxact Arm is the mechanism responsible for converting the control signals from sensors and microcontrollers into precise physical movements. This system forms the core of the robotic arm's functionality, enabling it to execute complex operations with accuracy and efficiency. The tendons wrap around custom 3D printed servo horns creating a closed loop shown below. As the servo motor rotates one way it pulls on the tendon and closes the finger. To open the finger the motor is rotated in the opposite direction. **Fig(19)** shows the artificial tendon drive for the index finger. As it is connected to the movement of servo motor , it opens and closes based on its angle movement

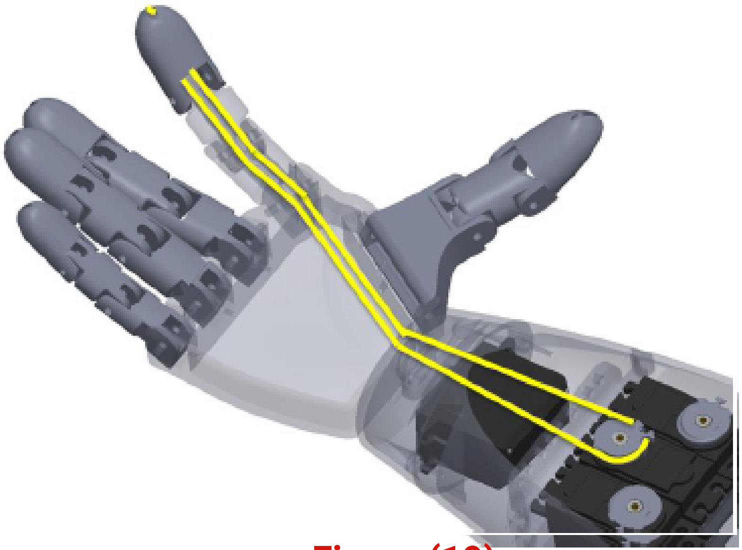


Figure (19)

Prototyping (Glove System Development)

The glove was equipped with sensors and controls to enable precise motion tracking and gesture recognition.

Gyroscope Sensor : Captures hand orientation and angular movement, Sends data to the robotic arm to adjust joint angles.

Light Dependent Resistor (LDR): The Light Dependent Resistor (LDR) plays a critical role in the Medxact Arm as a sensor for detecting finger movements. By using changes in light intensity to determine positional variations, the LDR provides a cost-effective and efficient way to interpret input from the glove, which directly controls the robotic arm. This feature adds precision and adaptability to the system, making it suitable for healthcare and medical applications. it detects finger bending based on light levels , Changes the servo motor angle to reflect finger movements. LDR sensors are embedded in the glove, typically positioned to sense light variations caused by finger movements.

Functionality:

Each finger is associated with an LDR and a light source.

As a finger bends **as shown in Fig(20)** and as it is straightforward **as shown in Fig(21)** , the amount of light falling on the LDR changes due to obstruction or redirection.

The LDR detects these variations in light intensity and alters its resistance accordingly.

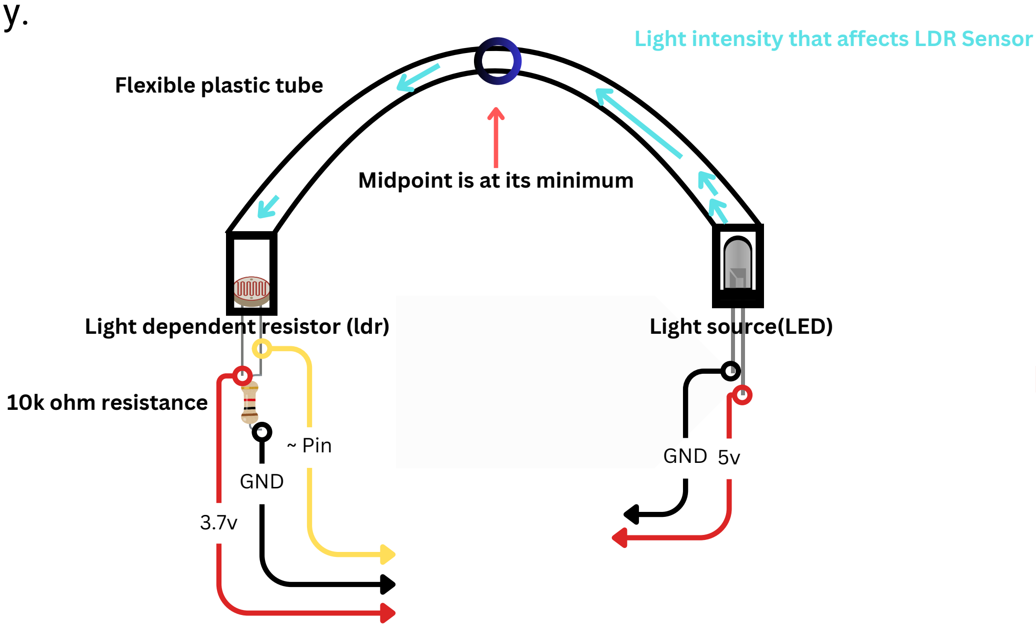


Figure (20)

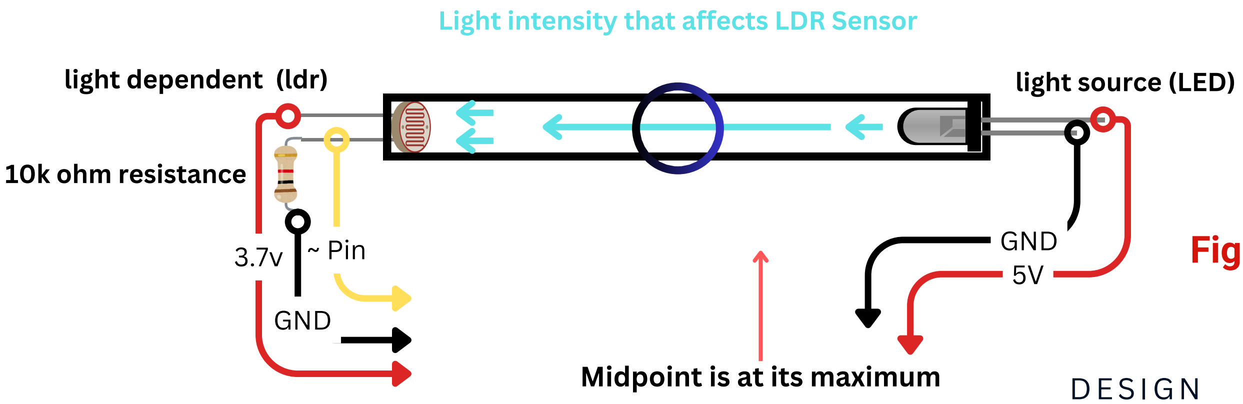


Figure (21)

ESP32 CAM:

It brings visual intelligence to the robotic arm, allowing for real-time object detection and image recognition **as shown in Fig(22)** It provides high-Quality Imaging , equipped with a camera capable of capturing detailed images, the ESP32 CAM can analyze visual data with precision. ensuring clarity in critical tasks like identifying injuries or inspecting objects.

Wireless Connectivity:

Operates over Wi-Fi or Bluetooth, enabling seamless integration with the glove control system and other components.

Figure (22) Object detection algorithm

SD Card

During glove-controlled sessions, data from sensors (e.g., gyroscope, LDR) is processed and saved as a sequence of movements. Each sequence includes timestamps, angles, and sensor values to ensure accurate reproduction

Playback Mechanism:

When autonomous operation is required, the saved sequences are retrieved from the SD card and executed by the robotic arm.

The ESP32 reads the data in real-time and commands the servo motors accordingly **as shown in Diagram(3)**

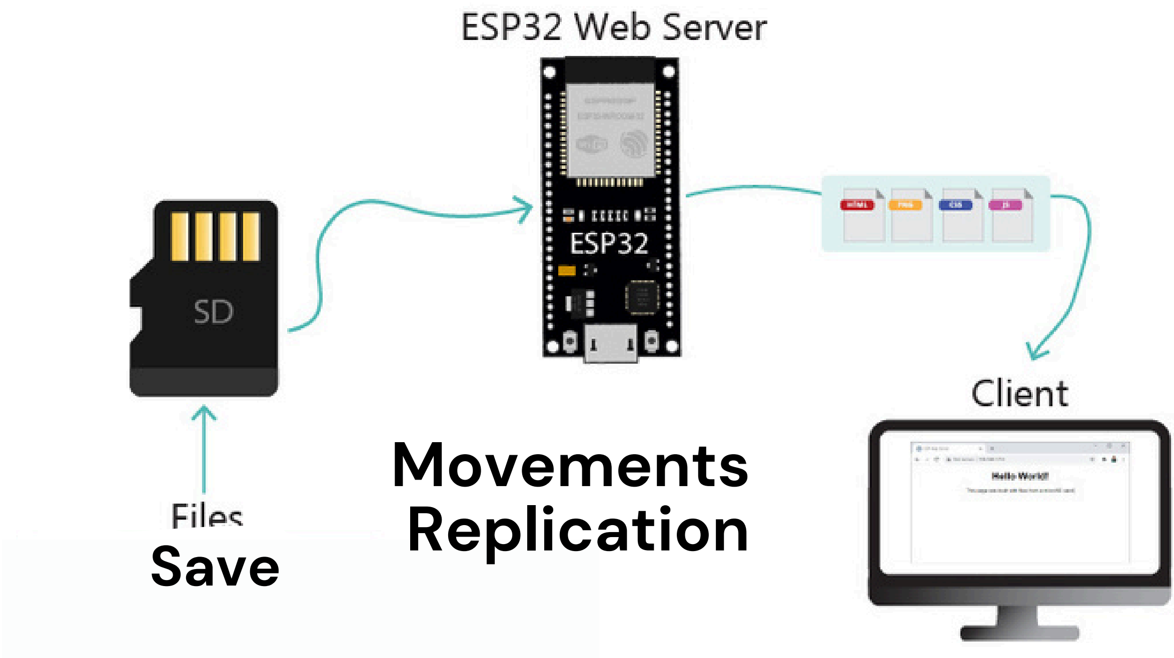


Diagram (3) Movements Replication

Testing and Optimization

Testing is a critical phase in the development of the Medxact Arm, ensuring that the system functions reliably and meets the required performance standards for healthcare and other applications and user interaction to validate the system's efficiency, safety, and usability.

Testing Hand Gripping in Medxact Arm

The hand-gripping functionality in the Medxact Arm is one of its most critical features, reflecting its ability to perform precise and controlled tasks. This capability was subjected to several testing to ensure it met the requirements of healthcare applications, such as surgery and training. The system is physically capable of several various grip pattern arrangements **shown in Fig(23).**

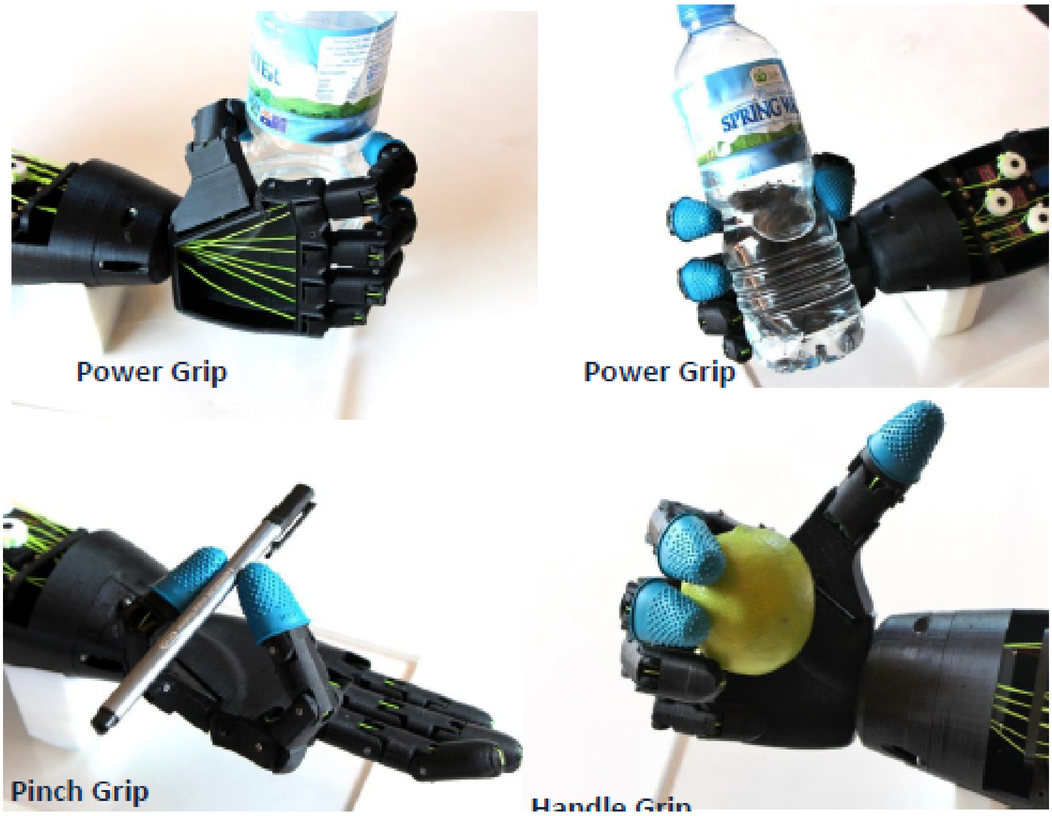


Figure (23) Hand Gripping

By Applying the hand gripping test we ensured several parameters which are
Precision and Accuracy: the robotic arm replicates the user's hand movements precisely, enabling firm and controlled gripping.
Force Control: Test the arm's ability to apply the appropriate amount of force for various objects, from fragile items like medical instruments to sturdier materials.
Adaptability: Validate the system's ability to adjust grip strength and finger movements in response to different sizes, shapes, and weights of objects.

Testing Object Detection

A dataset of medical and non-medical objects was used to train the machine learning models, ensuring a wide range of recognizable items.
Images with varying angles, distances, and lighting conditions were included
The ESP32 CAM was tested by presenting it with objects from the dataset and measuring recognition accuracy. Lighting Variability:
Initial tests showed reduced accuracy in low or uneven lighting.

False Positives:

The system occasionally misidentified objects with similar shapes or colors. Retraining the model with a more diverse dataset significantly reduced these errors.

Results and Outcomes

High Accuracy: The object detection system achieved over 90% accuracy across various testing scenarios, with consistent performance in identifying tools and injuries.
Real-Time Operation: The system demonstrated a detection and response time of less than 1 second, enabling real-time interaction with the environment.
Enhanced Adaptability:
The system effectively recognized and distinguished objects of different shapes, sizes, and textures.

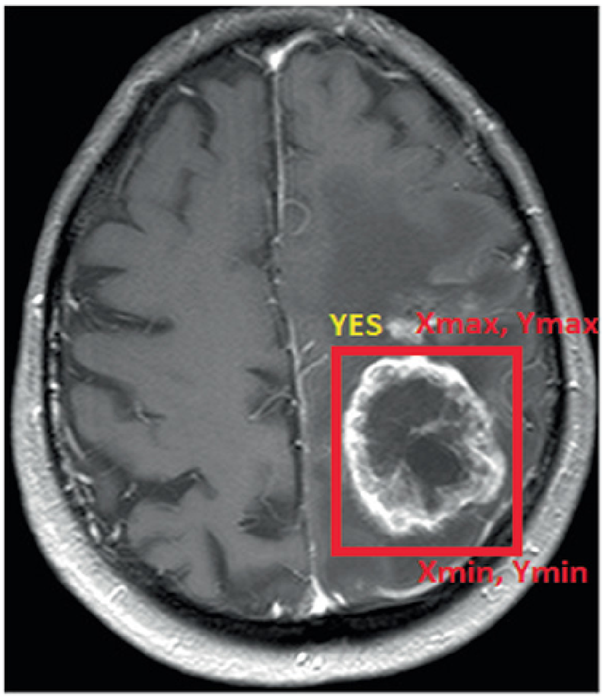


Figure (24)

05. FUTURE ENHANCEMENTS

Integration with AI for Advanced Analysis

The Medxact robotic arm aims for a more advanced era in robotic-assisted surgery. Since every project may not be 100% effective, there is bound to be a small percentage of error, which is why we have provided a recommendation that includes future plans for this system so that we can talk about the problems we ha ve encountered and their solutions as well. Some of the recommendations are:

Accurate learning with artificial intelligence: Training the robotic arm using advanced artificial intelligence algorithms to perform complex surgeries independently and developing machine learning technology for the arm.

Figure (25)

Technical improvements

Improving sensor technology: In the future of the Medxact robotic arm, we aim to improve sensors such as optical sensors as they provide high-resolution detection of motion and position, allowing for very precise operation during difficult tasks which is useful in delicate surgeries, such as neurology, and pressure sensors. In addition, upgrading to higher resolution cameras and using multiple cameras with better stability to obtain clearer and more precise images during operations.

Improving materials: Replacing plastic components with solid and biocompatible materials such as carbon fiber and light weight materials or aluminum and titanium for durability and real-life medical applications.

Real-time wireless operation: Improve glove-arm communication through network boosters to reduce latency in remotely controlled procedures, resulting in rapid haptic feedback: By integrating force sensors to provide haptic feedback, surgeons can "feel" what the robotic hand is touching as if it were in the operating room when used in training junior doctors.

Multi-arm integration: Add multiple simultaneous arms to assist in more advanced surgeries, simulating an entire surgical team **as shown in Fig(26).**

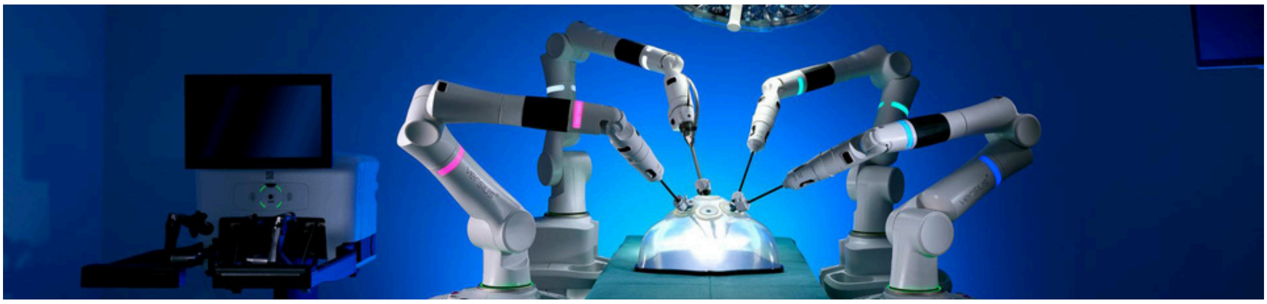


Figure (26)

Energy efficiency: Low-power motors and servo systems will be developed to ensure long-term operation without overheating due to the presence of coolers.

Sterilization-friendly design: Make the structure resistant to the high-temperature sterilization processes required in operating rooms.

Regulatory approval: Obtain certifications such as FDA or CE to make our robotic arm suitable for use in real-world hospitals.

Broader Applications Beyond Healthcare

By expanding its applications beyond healthcare, Medxact can become a versatile and impactful tool across various industries. These enhancements not only highlight the system's adaptability but also underscore its potential to address challenges in fields as diverse as manufacturing, disaster response, agriculture, education, and beyond. Such versatility ensures that the Medxact Arm remains at the forefront of robotic innovation, benefiting humanity in numerous ways, Expand applications to other sectors, such as manufacturing and aerospace, for delicate assembly tasks.

06. CONCLUSION

Summary of achievements

In conclusion, the Medxact robotic arm system represents a transformative step in healthcare robotics, born from a vision .By blending innovation and simplicity, we've developed a system that is both technologically advanced and user-friendly. The use of lightweight yet durable materials like Plastic and resins ensures structural integrity without compromising on cost-effectiveness ,Builds on the improvements of previous systems, such the Da Vinci surgical system, Combining glove-controlled input, a compact design, and reasonably priced materials like plastic and resins, Using components like the ESP32 WROOM32 microcontroller and ESP32 CAM module ensures precise control, efficient data processing. ,The tendon-based drive system, combined with servo horns, provided smooth and reliable movements. This design mimics human biomechanics, making the Medxact arm suitable for object manipulation

MedXact System fulfilled many achievements

- Advanced Control Systems integrated multiple control methods, including:
- Hand Gesture Control: Enhanced with OpenCV and Mediapipe for real-time precision.
- Glove Control: Features sensors like gyroscope and LDR for accurate movement detection.
- Real-Time Object Detection: Leveraged the ESP32 CAM for injury detection and object recognition, enabling automated and precise responses during operations.
- Autonomous Operation:
- Incorporated an SD card module to record and replay arm movements, allowing for pre-programmed and autonomous task execution.
- Haptic Feedback Integration: Added vibration feedback to enhance user awareness and precision during delicate tasks.
- Sustainability and Accessibility:
- Focused on using eco-friendly materials and affordable components, making advanced robotic technology accessible globally.
- Healthcare Impact:
- Addressed critical challenges such as infection control, remote surgeries, and the global shortage of skilled surgeons.
- Scalability and Customization

Vision for Medxact

This project bridges the gap between the newest technology and real-world applications by introducing a drive system powered by tendons and servo horns to provide realistic movements for surgical procedures.

. Additionally, research indicates the strategic employment of flex and LDR sensors improves reliability and precision in dynamic surgical circumstances. Additionally, **MedXact**'s influence goes beyond surgery to medical education, giving aspiring surgeons practical experience in a safe setting.

MedXact is a solution rather than simply an instrument because of its focus on adaptation and accessibility. It makes innovative surgical technology affordable populations with limited resources. This project improves the expectations for healthcare robots thanks for its innovative engineering, precise methodology, and focus to reliability.

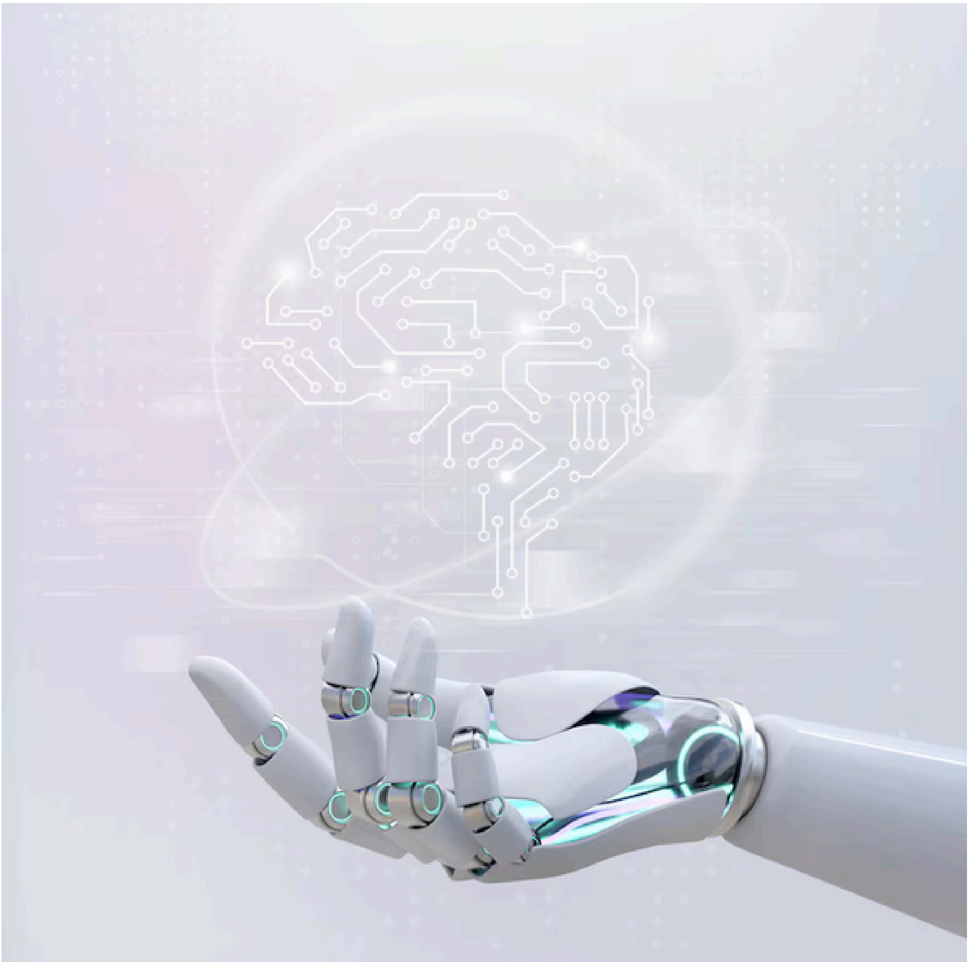


Figure (27)

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