MEDXACT ARM

Study on replacing doctors with robots & Ai

Research is vital for understanding.

BY:
HABIBA HOSSAM – YOUSSEF ABOELAZZ

TABLE OF CONTENTS

INTRODUCTION

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 resulted in more efficiency compared with the open approach as shown in figure (1), 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.

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 as shown in figure (2) , 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.

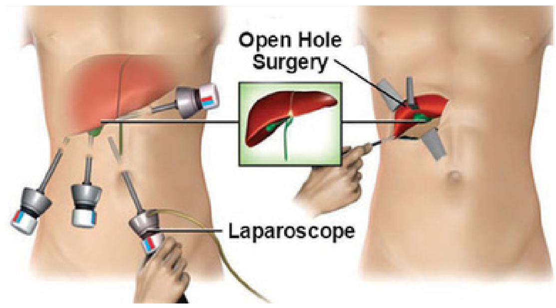


Figure (1)

Figure (2)

PURPOSE

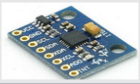
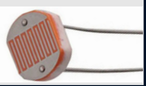
Recent technological advances in surgery have resulted in the development of a range of new techniques that have reduced patient trauma, shortened hospitalization, and improved accuracy and therapeutic outcome , Despite the many appreciated benefits of minimally invasive surgery (MIS) compared to traditional approaches journey began with Lister's groundbreaking research into antiseptic surgery in the 1860s , which significantly reduced surgical infections and established the foundation for modern surgical safety. One of the most groundbreaking advances in surgical history is robotic surgery. Through their exceptional precision, robotic devices reduce the risk of accidental tissue damage. The significant reduction in infection risks is one of the main advantages of robotically assisted surgery. Under the surgeon's supervision, the robot arm can carry out specific surgical tasks on itself to improve the safety of robot-assisted treatment , However, autonomy in a surgical environment is not limited to the performance of a task using preprogrammed movements; it also requires the robot's perception and adaptation to dynamically changing environments with the human always in the control loop, Robotic Systems as Da Vinci system has certain limitations. Many healthcare facilities lack the ability to pay for it due to its high cost, Its size and complexity also limit its use in remote or limited-resource areas. Our Medxact robotic arm technology solves the shortcomings of the Da Vinci system while building on its innovations. Medxact uses inexpensive materials, tiny design, and glove-based inputs to lower the cost and make robotic surgery accessible to more people, these changes facilitate the technology's deployment in a range of healthcare environments, including those with minimal resources, by reducing the amount of training required for operators . Medxact is also used in medical education. More medical students may practice and improve their skills in a simulated setting with low cost, which enable wider use in training situations. Future surgeons will benefit from this accessibility, improving their skills.

METHODOLOGY

Materials

The materials selected for the medical robotic arm are essential to its precision, functionality, and durability. Each component has been selected to meet the specific requirements of a device designed for medical applications, where precision and reliability are of the major importance. The 3D-printed chassis uses lightweight, durable materials to ensure smooth operation while maintaining cost efficiency. The servo motors, essential for precise movement, are paired with high-tensile plastic tendons to mimic natural finger movements, balancing flexibility and strength. The ESP32 serves as the brain of the system, providing robust connectivity and real-time data processing, while the ESP32 camera, mounted on the servo motors, provides the versatile imaging capabilities essential for remote surgical procedures. Each material and component listed in the table has been rigorously evaluated to optimize the arm's performance, from mechanical precision to electronic responsiveness. This thoughtful integration highlights the synergy between materials and design in the development of medical robotics.

Table (1): Shows the list of materials and their details.

Material	Usage	Amount	cost	Description	Image
ESP32 (WROOM 32)	Use it as the main microcntroller to control all parts of the arm and sensor readings.	2	700	A microcontroller with Wi-Fi and Bluetooth used in IoT and automation projects.	
ESP 32 Cam	Used for object detection and to identify injuries.	1	450	A camera module capable of capturing images and streaming video, often used in surveillance.	
Servo Motors (MG996R-180^)	Stores arm movements for replay functionality during training and autonomous operations.	6	1500	Motors that rotate to specific angles, commonly used in robotics and automation.	
Gyroscope Sensor (GY-521)	Detect wrist and arm angles for intuitive motion control.	1	150	A sensor measuring orientation, angular velocity, and acceleration in devices.	
LDR Sensor (Light Dependent Resistor)	Detect finger movements based on light levels.	5	30	A light-sensitive component that changes resistance based on light intensity.	
SD-Card	Stores arm movements for replay functionality during training and autonomous operations.	1	60	A compact storage device for saving data, widely used in electronics and computing.	
Plastic Tubes	Used it in a practical and cheap alternative to the flex sensore.	5	25	Lightweight and durable components used for structural or mechanical applications.	
Servo Gimbal	To make the camera (ESP-CAM) 360 degrees to see all possible angles.	1	30	A device that provides stabilization and smooth movement for cameras or sensors.	
Cost of all materials in the table and other materials			2810 EG		

MECHANCAL DESIGN

The Medxact robotic arm system embodies a combined mechanical design, Our Medxact arm is mainly composed of three primary Components which are the robotic arm, which is a 3D-printed structure , driven by servo motors for controlled movement oursecond main component is the Control Glove, A wearable input device embedded with sensors to capture hand gestures, Thirdly the ESP32 WROOM3 which serves as the central control unit, interfacing between the glove and the robotic arm, while also managing object detection and data storage.

ROBOTIC ARM CONSTRUCTION

For the robotic arm's construction, we used Lightweight and durable materials. Plastic composites and resins were used for 3D-printed components , Resins were used for parts that experience more pressure. These materials were chosen for their cost-effectiveness, strength, and ability to withstand stress during operation. The robotic arm features a modular design with multiple joints to copy human arm movements. Each joint is powered by servo motors, enabling the movement with different angles ,smooth and precise motion as shown in figure(3). The arm movements is based on Drive System Using Tendons and Servo Horns. In addition ,The robotic arm is provided with ESP32-CAM, Its primary role is that it adds vision capabilities to the robotic arm, allowing it to detect objects, recognize injuries, and adjust its operations dynamically , In robotic surgery, vision is crucial for precision. The camera aids in identifying areas of operation or injuries. The camera came along with :

- An OV2640 camera sensor, capable of resolutions up to 2 MP.
- Supports video streaming and still image capture, supporting Formats like JPEG.
- Built on the ESP32-S chip, which includes dual-core processors,Wi-Fi, and bluetooth capabilities.
- Supports multiple GPIO pins for integration with other hardware components.
- Includes an SD card slot, allowing for onboard storage of captured images or videos.
- Wi-Fi and Bluetooth enable remote control, real-time streaming, and wireless integration with other device

Figure (3)

DRIVE SYSTEM MECHANISM

Drive System Using Tendons and Servo Horns : We used tendons shown in figure(4) to transfer motion from servo motors to the arm's joints. they simply copy human muscle behavior which enables precise and natural movements We made sure that they were routed through low-friction channels within the arm to ensure smooth operation. the drive system also uses Servo horns that are mounted directly onto the motors and act as the attachment points for tendons where Rotational motion from the servo horns translates into motion in the tendons, driving the movement of the robotic arm segment, Secondly the Control Interface the (Control Gloves).The Glove based input : The glove contains a Gyroscope Sensor that provides angular motion to adjust servo motor angles in real-time for the 3D arm model,

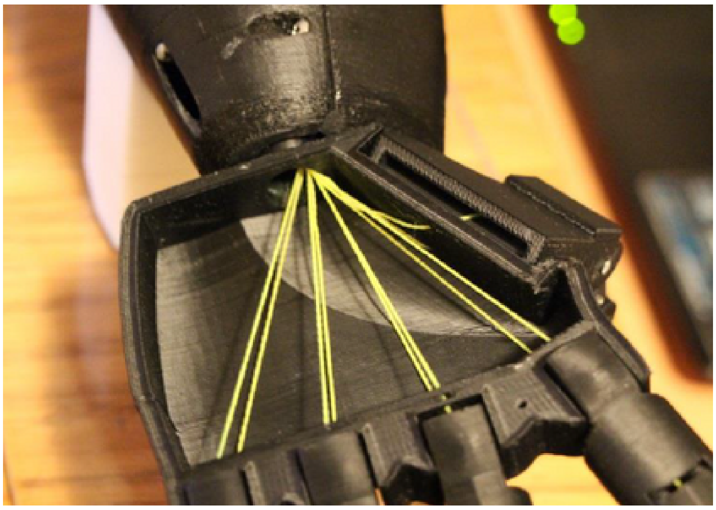


Figure (4)

Light Dependent Resistors (LDRs) are aligned with the fingers. When a finger bends, the light source on the glove is partially or fully blocked, which causes an increase in LDR'S resistance. Conversely, when the finger straightens, the light illuminates the LDR, decreasing its resistance. They translate light-based finger movements into corresponding robotic arm actions that change their resistance based on the intensity of light they receive making them suitable for detecting light and converting it into electrical signals that can be used to trigger actions in a system , They do not require much power, aligning with the energy efficiency goals of the Medxact system .

Microcontroller (esp32-wroom-32) : Serves as the brain of the system, managing the brain of the system managing communication, processing sensor data , It serves as the brain of the system, managing communication, processing sensor data, and controlling actuators.

Functions of microcontroller in Medxact:

- LDR Sensors: The ESP32 reads analog signals from Light Dependent Resistors (LDRs) embedded in the glove. These signals represent finger movements and light intensity variations.
- Gyroscope Sensor: The ESP32 processes data from a gyroscope to determine glove orientation and hand movement angle
- Wi-Fi and Bluetooth capabilities support wireless operation, crucial for applications requiring flexibility and mobility.
- Resistance changes from LDRs are mapped to servo angles.
- The ESP32 generates precise Pulse Width Modulation (PWM) signals to drive servo motors in the robotic arm. This ensures smooth and accurate movements.

The Automated Mechanical Unit (AMU) and phase design

Designed for precision medical applications, the Medxact robotic arm is designed with affordability, accuracy and simplicity in mind. The robotic system combines 3D printed components, servo motors and a sensor-integrated control glove, connected through the ESP32 for seamless operation. The compact and lightweight design of the AMU ensures ease of use in surgical environments. The 7 servo motors are connected to the analog pins in the ESP-32 and all the positive wires are connected to the 5V and the GND to GND and also to the LEDs as shown in Figure (5). The same thing in the ESP in the glove, we used a 10K resistor in the LDR and it was also connected to the analog pins as shown in the following figure(6).

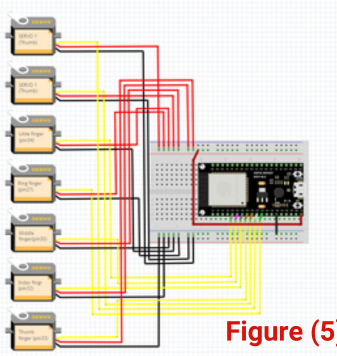


Figure (5)

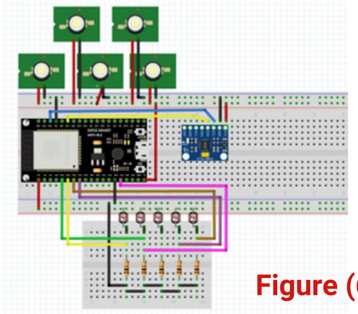


Figure (6)

AMU Components and Features

Robotic Arm: 3D printed structure with servo motors for precise joint movement, and all its parts are designed in 3D as shown in the design in the following figure(7).
Control Glove: Built-in sensors (LDR, gyroscope, LEDs) to capture and translate hand gestures into commands.
ESP32 WROOM32: Acts as a central processing unit, facilitating communication between the glove and the arm while enabling Wi-Fi/Bluetooth connectivity.

Design and Operation Stage

Input Reading: The glove captures the surgeon's gestures through the built-in sensors. **Signal Processing:** The ESP32 interprets the input signals and determines the direction of movement of the robotic arm. **Motion Execution:** The servo motors precisely control the movements of the arm and hand based on the processed signals.

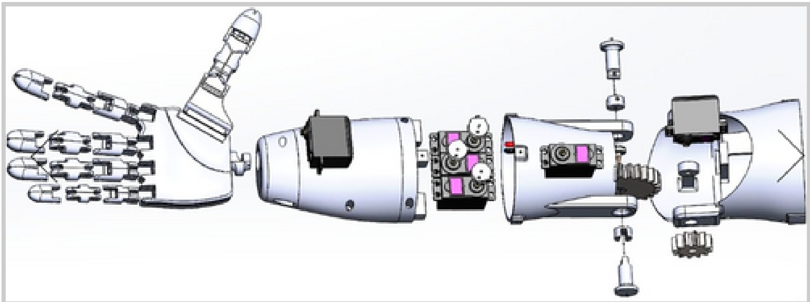


Figure (7)

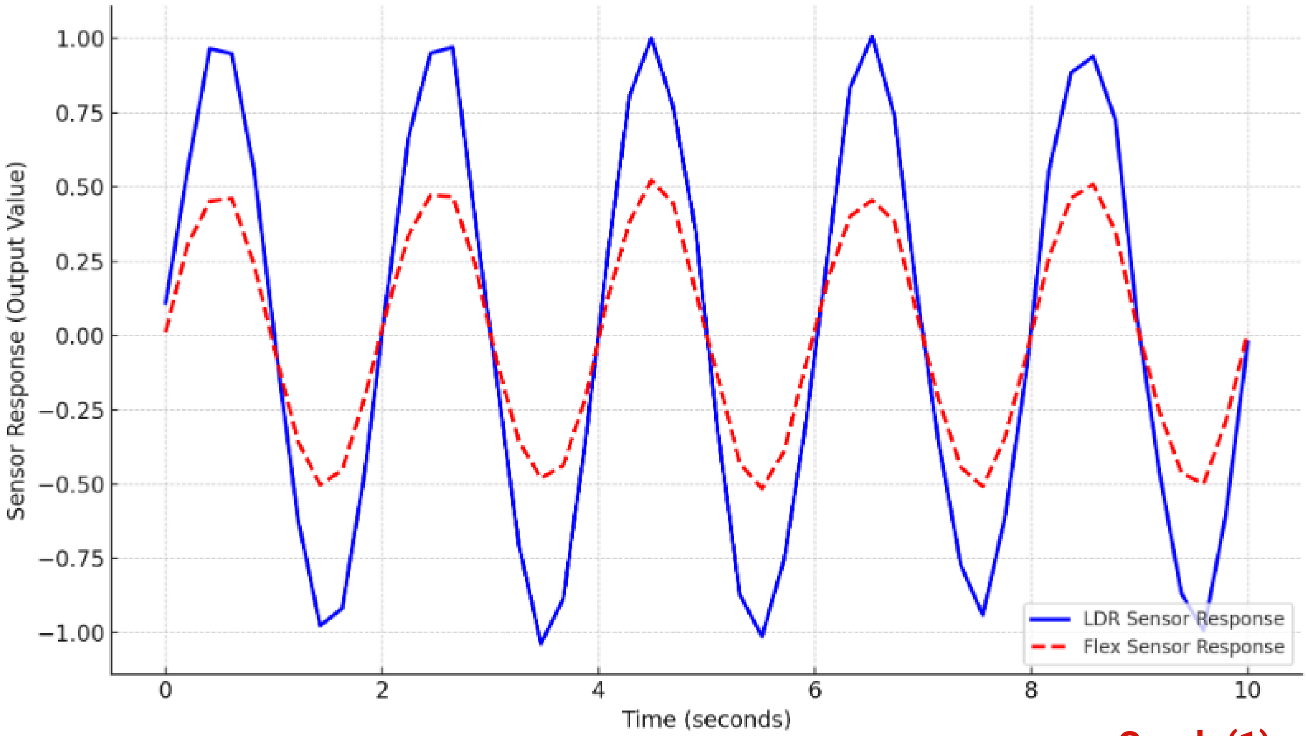
Camera Feedback: The ESP32 camera transmits real-time footage to assist in surgical operations, via Wi-Fi or connecting to the ESP's own channels. Memory Recording: The operations are stored for future AI learning, and then executed without any human intervention.

Cyclic process

 # Input by control glove: The surgeon's hand gestures are translated into successive commands that are processed by artificial intelligence.
 # Movement execution: The robotic arm performs precise actions, such as grasping or surgical cuts, and all of these precise movements have been tested as shown in the picture.
 # Feedback: The ESP32 camera provides live video with high quality and frequency, ensuring the accuracy of surgical operations.
 # Learning and improvement: The stored data allows the artificial intelligence to repeat procedures independently, by analyzing the images and videos saved with the movements it has performed, knowing the type of medical operation it is performing.

DATA DISCUSSION AND ANALYSIS

During the development and testing phases of the Medxact robotic arm, several parameters were recorded to ensure better functionality and accuracy , We tested several parts , these included The Light Dependent Resistor (LDR) was tested for its reaction speed and accuracy. It was found that the LDR provided faster detection in light-intensity-based movements than traditional flex sensors do. response Time of Sensors , The LDR proved to be a highly responsive sensor for detecting finger movement, outperforming traditional flex sensors in both speed and reliability as shown in graph(1) which Shows sharp peaks and dips, indicating high sensitivity to finger movements . the robotic hand was able to imitate the hand movements of the controller fairly well without any significant delay. The ability to grip objects was limited to the weight and surface hardness of the objects. From the results it was observed that the robotic hand could grip objects weighing up to (XXX) grams , which involves the bending of fingers to close the hand around an object. As the fingers bend, the movement or change in angle needs to be captured accurately to translate into robotic arm movement as shown in Figures (8, 9, 10, 11).



Graph (1)

Figure (8)

Figure (9)

Figure (10)

Figure (11)

Degree Of Freedom (DOF)

Looking at the above **figure (12)**, imagine a point in space. From this point we can translate (move) along 3 different axes, i.e. we can move **forward/backward, up/down and left and right.** At the same point we can also rotate around **3 different axes.** The human neck for example has 3 degrees of rotational freedom – we can look left/right, up/down and tilt our head sideways. So in total a single point can have a maximum of 6 degrees of freedom (3 translational, 3 rotational). The human finger in total has 4 degrees of freedom [7]. Three of these are the rotations of each joint **(DIP, PIP, MCP)** which combine to control flexion and extension of the finger as **shown in figure(13).** The knuckle **(MCP joint)** also allows for abduction/adduction **(wiggling the finger from side to side).** In the thumb the lower CMC joint also allows for abduction/adduction – which gives **5 DOFs** in the thumb [8]. Fingers, and all joints in the human body are actuated (moved) via contraction of muscles and tendons. **Figure (14)** illustrates the Degrees of Freedom **(DOF)** in a robotic arm and hand system. Each joint **(shoulder, elbow, wrist, and fingers)** is equipped with specific **DOF**, enabling flexible and human-like movements. The movement information flow of the hand and arm is directly converted into the control instruction flow of the robotic hand-arm. Moreover, the robotic arm is teleoperated by the arm and hand, the robotic hand is teleoperated by the fingers. The seven postures of the arm and hand is used that included 1DOF of the body rotation, **2DOF** of the shoulder, **1 DOF** of the elbow joint, and **2DOF** of the wrist. Figure (15) explains the mechanical principles of forces and moments acting on the system, Where MEDXACT arm translates forces applied at the glove (user input) into controlled torques at the finger joints, ensuring accurate and efficient robotic finger movement. **Torque(M)=Force(F)×Perpendicular Distance(d).** **M1=F1 · d1**: The resulting moment (torque) at the first joint , where F1 is the input force applied by the user's finger via the glove , d1 is the lever arm distance from the tip of the finger , The perpendicular distance from the axis of rotation (pivot point)
M2=F2 · d2: The torque transferred to the joint mechanism.
M3 is the torque acting on a gear system (or a pulley).

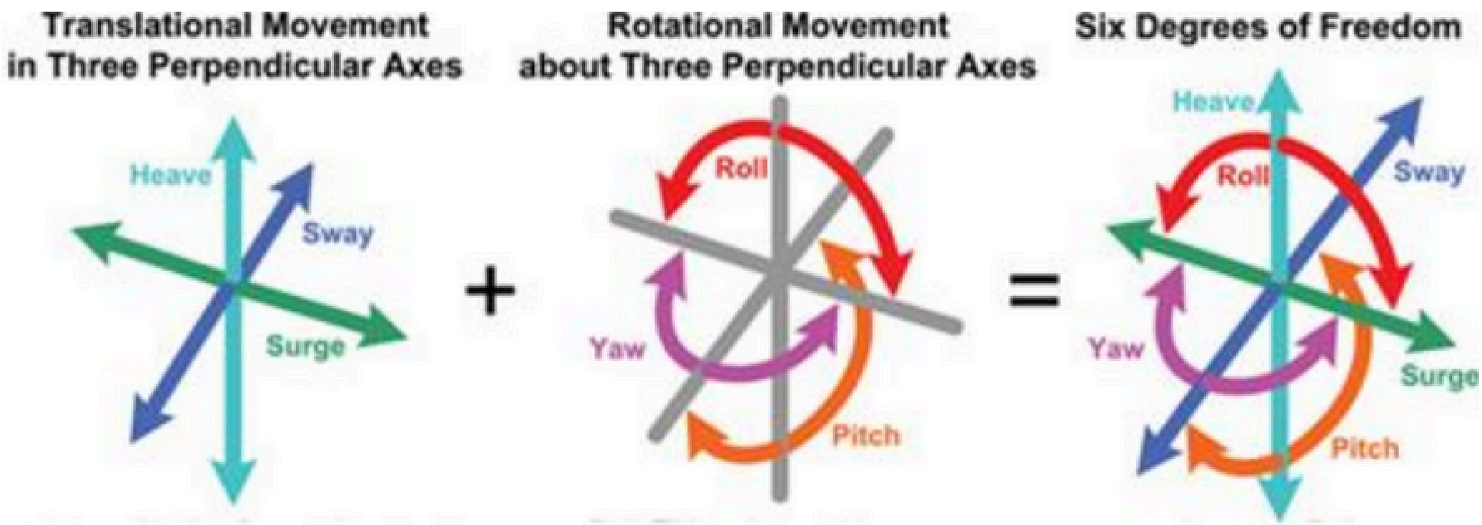


Figure (12)

Degree Of Freedom (DOF)

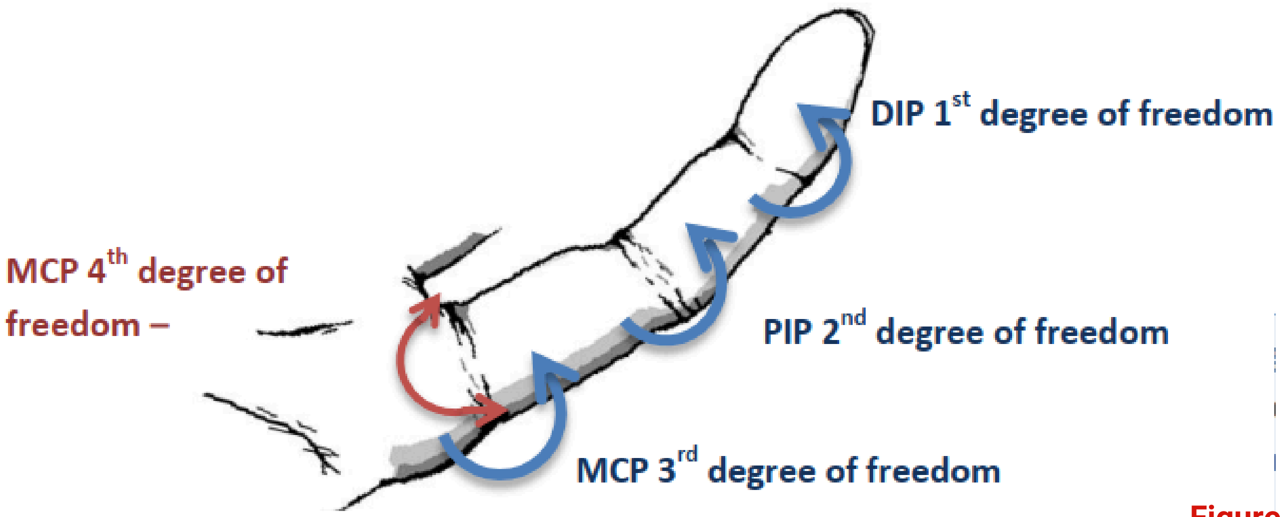


Figure (13)

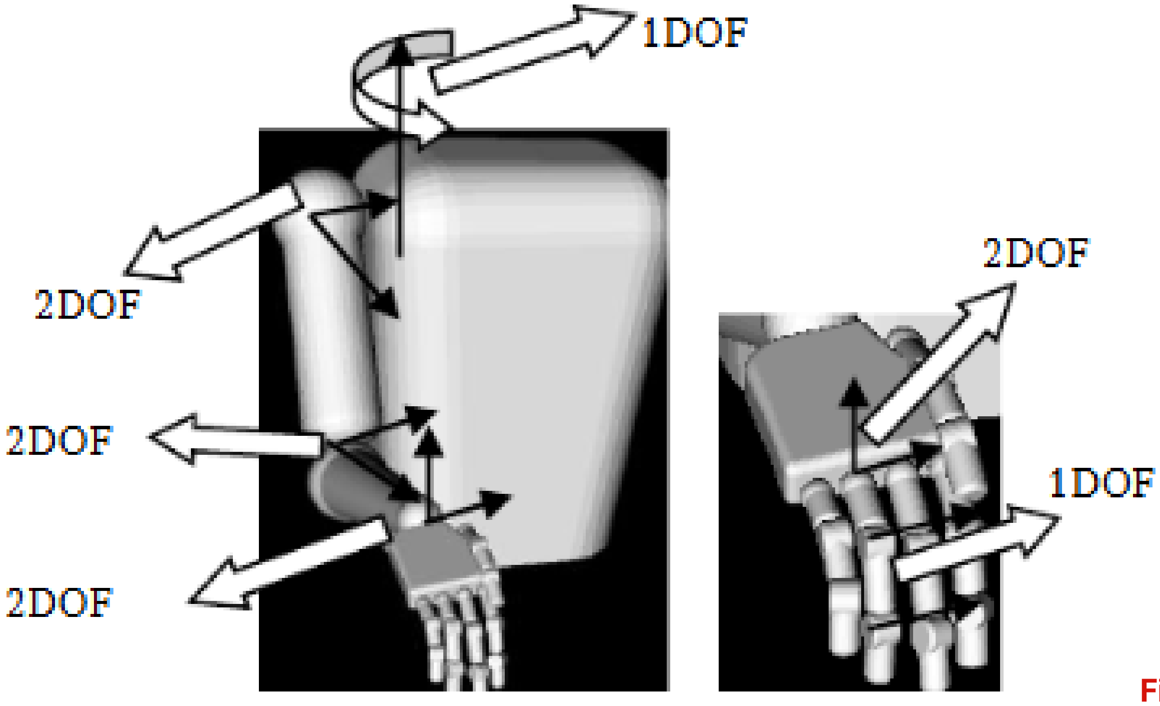


Figure (14)

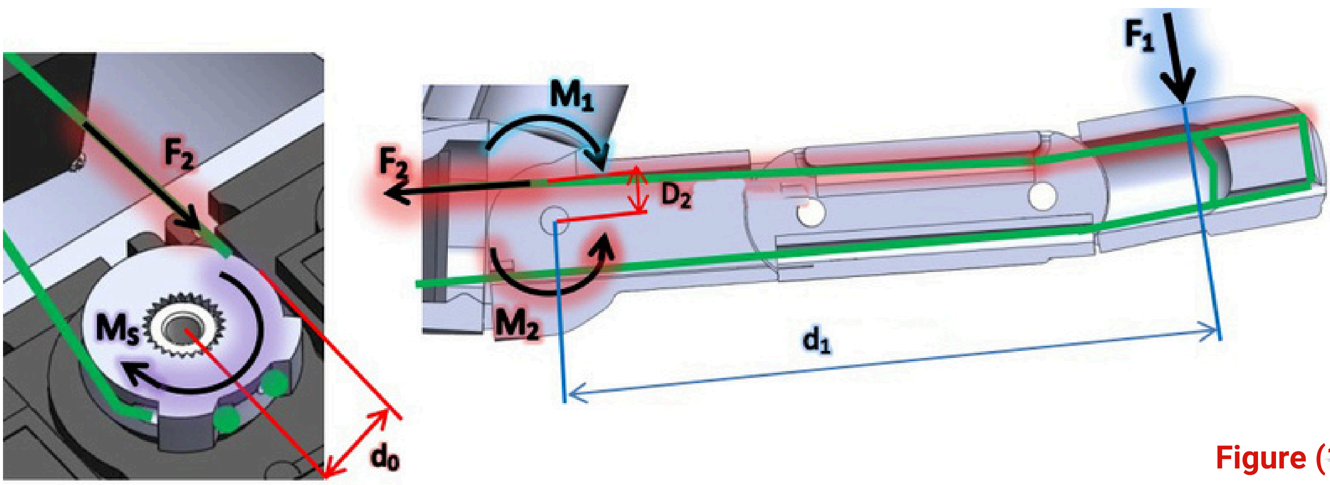


Figure (15)

Servo Quality Analisis

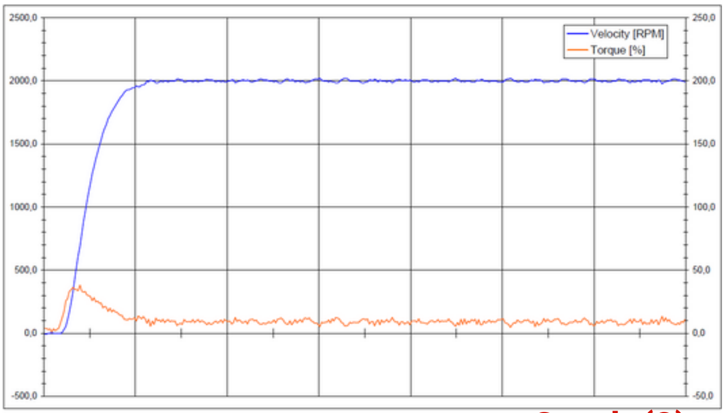
This MG996R high torque digital servo features metal gears, producing an extra high torque of 13kgf in a small package. Essentially an upgraded version of the popular MG995 servo, the MG996R features improved shock resistance and a redesigned PCB and IC control system, making it more accurate. This standard high torque servo can rotate almost 180 degrees (90 degrees in each direction).

Table (2): Shows how servo motor behaves under different conditions.

Test Condition	Speed Variation (%)	Torque Variation (%)
Unloaded Motor	-1.2%	8.8%
TBS 300 µm (Total Ball Shear)	-2.5%	16.4%
TBS 500 µm	-3.2%	22.9%
DS 6 mm	-4.3%	80.6%

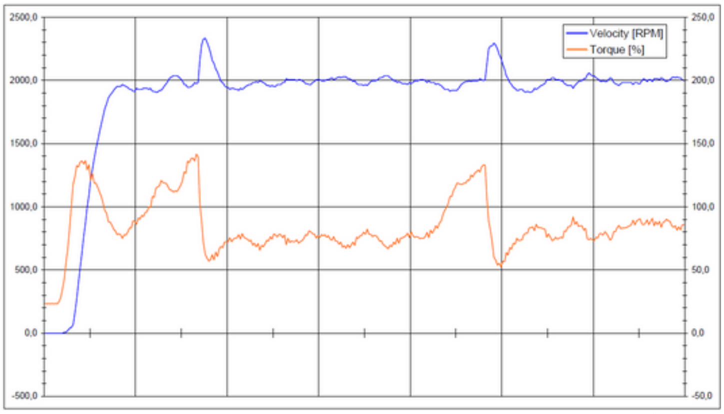
Servo Quality Analisis

- Full Speed Variation: -1.2% to 1.1%.
- Torque Variation: ±8.8%.
- Graph Characteristics: Displays low torque variations with consistent velocity, as the motor operates without load. The torque curve is relatively stable as there is no external force pr resistance acting on it.



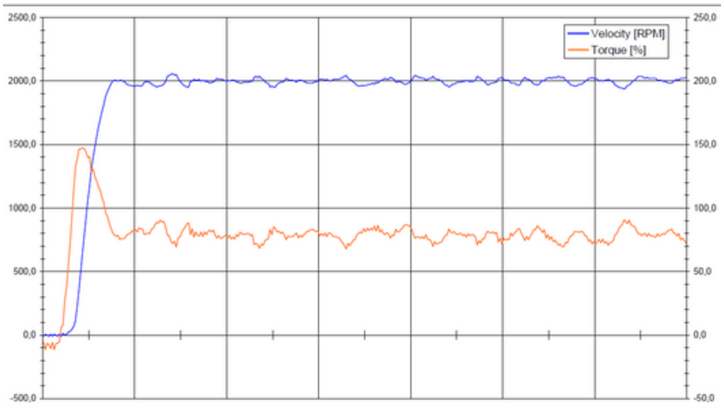
Graph (2)

- Full Speed Variation: -2.4% to 2.2%.
- Torque Variation: ±16.4%.
- Graph Characteristics : The ball shear test adds a moderate load, resulting in noticeable torque demand changes while maintaining velocity.



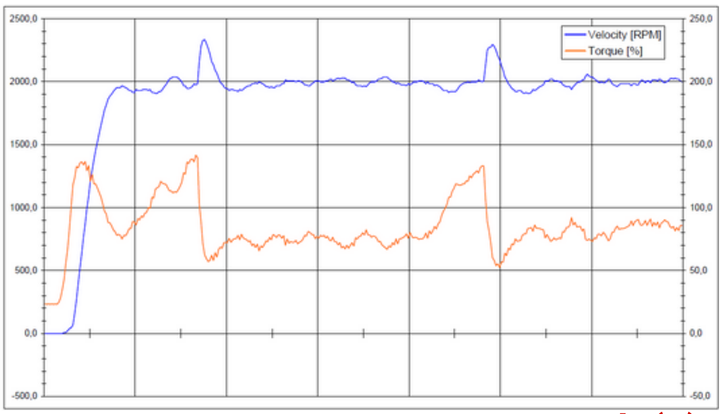
Graph (3)

- Full Speed Variation: -3.1% to 2.2%.
- Torque Variation: ±22.9%.
- Graph Characteristics: Larger balls increase the load, resulting in higher torque variation. Velocity fluctuation is more pronounced compared to the 300μm test, demonstrating the motor's performance under higher stress.



Graph (4)

- Full Speed Variation: -4.6% to 14.8%.
- Torque Variation: ±80.6%.
- Graph Characteristics: This test introduces the highest load, leading to significant torque variation and reduced velocity stability. The graph shows the motor's capacity to handle extreme loads, emphasizing its operational limits.



Graph (5)

CONCLUSION

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.
- Real-time feedback for training and surgical applications.
- 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.

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.

RECOMMENDATION

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 have encountered and their solutions as well. Some of the recommendations are:

- 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.
- 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.
- 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.
- Energy efficiency: Low-power motors and servo systems will be developed to ensure long-term operation without overheating due to the presence of coolers.
- Scalability for industries: Expand applications to other sectors, such as manufacturing and aerospace, for delicate assembly tasks.
- 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.

LITERATURE CITED

Website

Peters, B. S., Armijo, P. R., Krause, C., Choudhury, S. A., & Oleynikov, D. (2018). Review of emerging surgical robotic technology. Surgical Endoscopy, 32(4), 1636—1655. https://doi.org/10.1007/s00464-018-6079-2

Automate. (2024, December 20). Servo motors explained and why they're useful in robotics. Retrieved , from https://www.automate.org/motion-control/blogs/servo-motors-explained-and-why-they-re-useful-in-robotics

Conference Paper

Klazura, G., Graf, A., Sims, T., Rojnica, M., Koo, N., & Lobe, T. E. (2022). Assessment of the da Vinci single-port robotic platform on cholecystectomy in adolescents. Journal of Laparoendoscopic & Advanced Surgical Techniques, 32(4), 438–441. https://doi.org/10.1089/lap.2021.0674

Nasrudin, N., Ilis, N. M., Juin, T. P., Chun, T. T. K., Zhe, L. W., & Rokhani, F. Z. (2011). Analysis of the light dependent resistor configuration for line tracking robot application. In 2011 IEEE 7th International Colloquium on Signal Processing and its Applications (pp. 500–502). IEEE. https://doi.org/10.1109/CSPA.2011.5759930

Report

Association of Surgeons in Training, & The Royal College of Surgeons of England. (2022, August). Future of surgery: Technology enhanced surgical training: Report of the FOS:TEST commission,thttps://doi.org/10.1308/FOS2.2022

Article

International Federation of Robotics. (2023, June 22). Robotics contributing to human well-being. Retrieved from https://ifr.org/case-studies/robotics-contributing-to-human-well-being

Rivero-Moreno, Y., Echevarria ., C., Pianetti, L., Cordova-Guilarte, J., Navarro-Gonzalez, J., Dorado-Avila, G., Osorio-Romero, L., Chavez-Campos, C. (2023). Robotic surgery: A comprehensive review of the literature and current trends. Cureus, 15(7), e42370. https://doi.org/10.7759/cureus.42370

FOR FURTHER INFORMATIONS

Youssef Aboelezz :
Youssef.1723063@stemismailia.moe.edu.eg

Habiba Hossam :
Habiba.1723515@stemismailia.moe.edu.eg