IJARIIT
INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 10, Issue 5 - V10I5-1163)
Available online at: https://www.ijariit.com

AI and IoT-Driven Automatic Abdominal Retractor System: Revolutionizing Surgical Techniques

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Abstract

In this paper, an AI and IoT-driven automatic abdominal retractor system designed to enhance surgical precision and efficiency by maintaining consistent retraction forces and intelligently guiding surgical procedures through real-time data from a webcam-based AI tool. Traditional abdominal retractors, manually operated by surgical assistants, often lead to variability in retraction force and increased surgical risks. The proposed system automates this process, ensuring uniform and precise retraction, while also assisting the surgeon in determining the optimal incision points during surgery. The system incorporates a high-definition webcam that continuously monitors the surgical field, utilizing advanced AI-driven image processing to analyze the live video feed. The AI tool identifies key anatomical landmarks and pinpoints the exact location where the surgeon needs to operate, providing real-time feedback and guidance. This allows surgeons to make more accurate decisions, improving both efficiency and patient outcomes. The information is relayed via an IoT-based interface, enabling real-time adjustments and coordination between the retractor's movements and the surgeon's actions. The retractor mechanism operates along three axes—front-back, up-down, and open-close—controlled by a Node MCU IoT device, STM32 microcontroller, and motor driver circuits. The system is powered either by a battery or a standard power supply, ensuring operational flexibility in various clinical settings. Additionally, the IoT connectivity enables remote monitoring and control, allowing for adjustments in real-time as needed. This innovative approach has the potential to revolutionize surgical procedures by integrating automation and AI, ultimately improving the accuracy, safety, and outcomes of surgeries.

Keywords— *Automatic abdominal retractor, AI-driven surgery, IoT-based surgical tools, STM32 controller, Node MCU, Motor driver circuit, Real-time retraction, Surgical automation, Webcam-based AI, Remote surgical monitoring.*

I. INTRODUCTION

The concept outlines the design, development, and validation of an innovative automatic abdominal retractor system that aims to enhance surgical efficiency and improve patient outcomes through the integration of IoT and AI.

This system introduces an automatic retraction system that adapts to real-time surgical needs and requirements. Unlike traditional abdominal retractors, which depend on manual manipulation by surgical assistants, this innovative approach aims to streamline the retraction process. This section will outline the chosen topic for the final year project, focusing on addressing current challenges and motivations in surgical practice. It encompasses problem definition, objectives, and the rationale behind designing this system, along with the methodology that will be developed to meet these needs. The project concept is built upon a clear problem definition, specific objectives, justifications for the system's design, and a methodology aimed at addressing the identified needs. The system will leverage AI-based technology to monitor and operate the retractors during surgery through an IoT cloud platform. When surgeons are prepared to begin the procedure, the system will activate through AI, utilizing the IoT cloud and a controller to manage the open-close mechanism of the retractors.

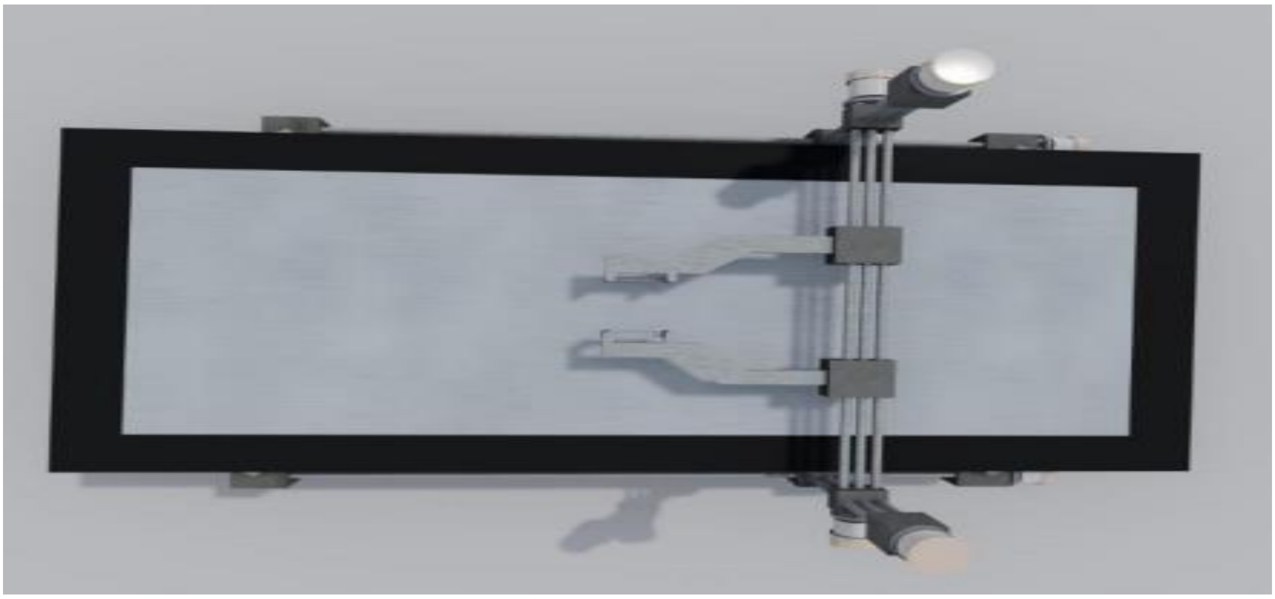

Fig. 1. Concept Diagram of AI and IoT-Driven Automatic Abdominal Retractor

The proposed system aims to address these challenges through automation, providing precise control and consistent retraction force throughout the surgical procedure. It will utilize an AI-based application to manage the retraction operations via an IoT device (Node MCU). This will enable the machine to move front-to-back with its horizontal component, vertical movement with the vertical limb, and open and close the retractors using the secondary horizontal surface of the machine. All operations will be controlled by an STM32 controller and a motor driver circuit. The entire system will be monitored through a webcam and an IoT application, with the microcontroller responsible for managing and operating the motor. An AI and IoT-based application will be developed to operate the system according to the surgeon's requirements during surgery.

The increasing demand for precision, efficiency, and safety in surgical procedures has driven innovations in medical technology. Traditional abdominal retractors rely heavily on manual control, which introduces variability in retraction force and potentially leads to inconsistent surgical outcomes. Surgical assistants manually manipulate these retractors, often resulting in fatigue, varying degrees of retraction, and additional pressure on the surgeon. To address these issues, we propose the design, development, and validation of an innovative **AI and IoT-driven automatic abdominal retractor system**. This system not only automates the retraction process but also provides real-time feedback, enabling surgeons to focus on more critical aspects of the procedure.

The concept integrates **Artificial Intelligence (AI)** for dynamic control and **Internet of Things (IoT)** technology for remote monitoring and control, with the aim of optimizing retraction in real-time based on surgical needs. This advanced system ensures consistent retraction force, improves surgical workflow, and reduces human error. The project addresses key challenges in current surgical practices and provides a robust solution designed for modern operating rooms.

II. ABDOMINAL AI RETRACTOR

Problem statement:

To design and develop automatic abdominal retractors for surgery utilizing an AI, IoT, and embedded controller-based system.

Surgical procedures, especially those involving the abdominal cavity, necessitate the use of retractors to hold back tissues, thereby enhancing visibility and access to the surgical site for surgeons. Traditional manual retractors often require an assistant to maintain their position, which can lead to issues such as hand fatigue, inconsistent pressure, and limited precision. Furthermore, manual retraction may contribute to prolonged surgery times and increased strain on medical personnel. The main challenge in abdominal surgeries is the need for consistent, precise, and fatigue-free tissue retraction. Current manual retraction methods can be inefficient and may not adapt dynamically to the needs of the surgery, potentially affecting surgical outcomes and increasing the risk of complications. There is a need for a more efficient, automated solution that can provide stable retraction with minimal human intervention.

Improving retraction methods during surgery can significantly enhance surgical precision, reduce operation time, and minimize strain on medical personnel. An AI & IoT based automatic abdominal retractor can offer consistent retraction, adapt to the changing dynamics of the surgery in real-time, and potentially improve patient outcomes. This innovation is particularly important in complex or lengthy surgical procedures where precision and efficiency are crucial.

Importance of Problem Statement

Focus: Clearly defines the issue of inefficient manual retraction and the need for an automated solution.

Guidance: Provides a clear direction for the project, outlining the integration of AI and IoT technologies.

Justification: Highlights the significance of improving surgical precision and efficiency, justifying the need for the project.

Evaluation: Establishes benchmarks for success, including retraction consistency, real-time adaptability, and overall improvement in surgical outcomes.

Objective:

1. Designing a retractor mechanism that can be controlled automatically with help of application.
2. Integrating AI to adjust retraction pressure and positioning dynamically based on real-time feedback.
3. Utilizing IoT to monitor and control the retractor remotely, ensuring precise and consistent retraction.
4. Testing and validating the design through simulations and practical trials to ensure its effectiveness and safety.
5. Evaluating the performance of the automatic retractor in comparison to traditional manual methods in terms of precision, efficiency, and user satisfaction.

Fig. 2. Retractor model for proposed system

III. LITERATURE REVIEW

The research article titled "Etiologic of Infection, Femoral Nerve and Splenic Injury by Abdominal Retractor" investigates the factors contributing to infections in surgical wounds, femoral nerve injuries, and splenic injuries during abdominal surgeries.

The study, conducted by Ángel Raúl Soriano Sánchez and colleagues, reviews medical literature from 2000 to 2013 and focuses on the design and structure of semi-automatic retractors used in abdominal surgical procedures. The results suggest that these retractors are associated with the ethology of infections and injuries studied. The article emphasizes the importance of anatomically designed retractors to minimize detritus lodging, which can lead to complications [1]. The study by Park et al. in 2007 introduces a novel approach to laparoscopic surgery with trocar-less instrumentation, utilizing a magnetic anchoring and guidance system (MAGS). The objective was to address limitations of conventional laparoscopy, such as the need for multiple trocars and restricted working envelopes. The study conducted porcine laparoscopic nephrectomies, showcasing the feasibility of trocar-less laparoscopy with only two trocars. While the study establishes proof of concept, challenges such as coupling strength and magnet interference need further exploration for broader clinical application. The proposed technology has the potential to reduce trocar-related morbidity and enhance surgical flexibility. Research Paper analysis of abdominal retractors For Surgery. Trocar-less laparoscopy using magnetically anchored instruments is feasible and may expand intracorporeal instrument manipulation substantially beyond current-day capability. The ability to reduce the number of trocars necessary for laparoscopic surgery has the potential to revolutionize surgical practice [2]. In laparoscopic surgery, surgeons can use only rod-shaped instruments that can be inserted through a trocar and therefore high technique is required. To overcome this problem, much work has been done to develop multi-degree of-freedom forceps. However, they are still inadequate to grasp, manipulate or push aside large internal organs, like a spleen, pancreas, and liver. This paper proposes mechanical hands with detachable fingers that can be assembled in the abdominal cavity, each of whose parts can be inserted through a trocar. Two types of such three-fingered hands are developed. The three fingers of one are dependently driven and those of the other are independently driven. For each hand, we show fixing and power transmission mechanisms. Power of each hand is transmitted from operator's hand to its fingers by connecting wires with a ball and socket. Experimental results verify that both hands can grasp large and oily objects like internal organs. One goal of this study is to develop simple hands that can be used as a retractor. The other goal is to develop skillful hands that can replace surgeons' hands in hand assisted laparoscopic surgery which is still invasive by making a 7-8cm incision to insert a human hand into the abdominal cavity[3].

Surgical management of an adrenal gland tumor that had extended into the thoracic portion of the caudal vena cava in a dog JAVMA[4]. This case report describes the successful surgical management of a complex adrenal gland tumor in a 14-year-old Border Collie with extensive extension into the thoracic portion of the caudal vena cava.

The dog presented with collapse, tachycardia, and hypotension, revealing a pheochromocytoma on biochemical testing and CT scans. A combined median sternotomy and midline celiotomy approach was employed, involving temporary occlusion of various vascular structures. The surgical team performed a venotomy to extract the tumor thrombus, necessitating a 25-minute period of vascular occlusion. Despite the challenges and potential complications associated with the procedure, the dog recovered well postoperatively, and histologic examination confirmed the tumor as a pheochromocytoma. This case highlights the successful application of a comprehensive surgical approach for managing an adrenal tumor with extensive intravascular extension in a canine patient[4]. Research Paper analysis of abdominal retractors For Surgery.

Lateral Surgical Approach to Lumbar Intervertebral Discs in an Ovine Model Volume 2012, Article ID 873726/ The Ritchie Centre, Monash Institute of Medical Research (MIMR), Monash University Clayton Victoria Australia the Alfred Hospital Prahran Victoria Australia [5]The research article presents a novel minimally invasive surgical technique for a far-lateral approach to the lumbar spine in sheep, which is commonly used as a large animal model for preclinical spine surgery studies. The traditional anterior or anterolateral approaches to access lumbar intervertebral discs in sheep involve larger incisions and abdominal retraction, posing potential risks. The newly proposed lateral approach allows for smaller incisions, excellent visualization of intervertebral discs, and minimal abdominal retraction, resulting in a well-tolerated procedure with minimal morbidity in the animals. This minimally-invasive lateral approach to the anterior sheep lumbar spine affords easy access to the intervertebral discs from L1 to L6 and can be performed safely without significant morbidity to the animals. The procedure allows for excellent visualization and surgical access to the intervertebral discs. This surgical approach, which is easily learnt, provides an alternative to anterior or anterolateral approaches, which require larger incisions and greater abdominal retraction[4-5]. In the 2001 study titled "Colloids Versus Crystalloids and Tissue Oxygen Tension in Patients Undergoing Major Abdominal Surgery" by Lang et al., 42 patients undergoing major abdominal surgery were randomly assigned to receive either 6% hydroxyethyl starch (HES) or lactated Ringer's solution (RL) for intravascular volume replacement. The fluids were administered perioperatively, maintaining central venous pressure. Continuous monitoring of tissue oxygen tension (ptio2) in the left deltoid muscle revealed that ptio2 significantly increased in the HES group (up to 59% at T4), while decreasing in the RL group (up to 223% at T4). Despite similar systemic hemodynamic and oxygenation, the study concluded that HES 130/0.4 improved tissue oxygenation during and after major surgery compared to crystalloid- based strategies, suggesting enhanced micro perfusion and reduced endothelial swelling as potential factors. Limitations and the evolving landscape of medical knowledge since 2001 should be considered when interpreting these findings [6].

IV. METHODOLOGY

The main task of the system is to make the retractor system to develop & validate retractor system or machine to enhance surgical efficiency and improve patient outcomes through the integration of IoT and AI. fig.1- represents a system architecture (block diagram) for an AI & IoT-based automatic abdominal retractor for surgery.

In this system STM32 microcontroller acts as the central processing unit. It'll connect the node MCU ESP 8266 and Camera module CAM32 as input devices to the microcontroller. Motor driver L293D & L298 as an output device. When surgical working will take place, AI based application send the command signal to node MCU ESP 8266 through IOT cloud about the operation of machine-like movement of retractor & holder to either UP, DOWN, FORWARD, REVERSE, LEFT & RIGHT respectively. These signals provided serial to STM32 by ESP 8266 & according to the received signal STM32 microcontroller will drive the motors through motor driver L293D for forward, reverse, left & right & L298 for UP -DOWN movement. The CAM32 module will help to monitor the operation of machine at the time of retractor process as well as completion of surgical process. Following blocks will proposed for working module.

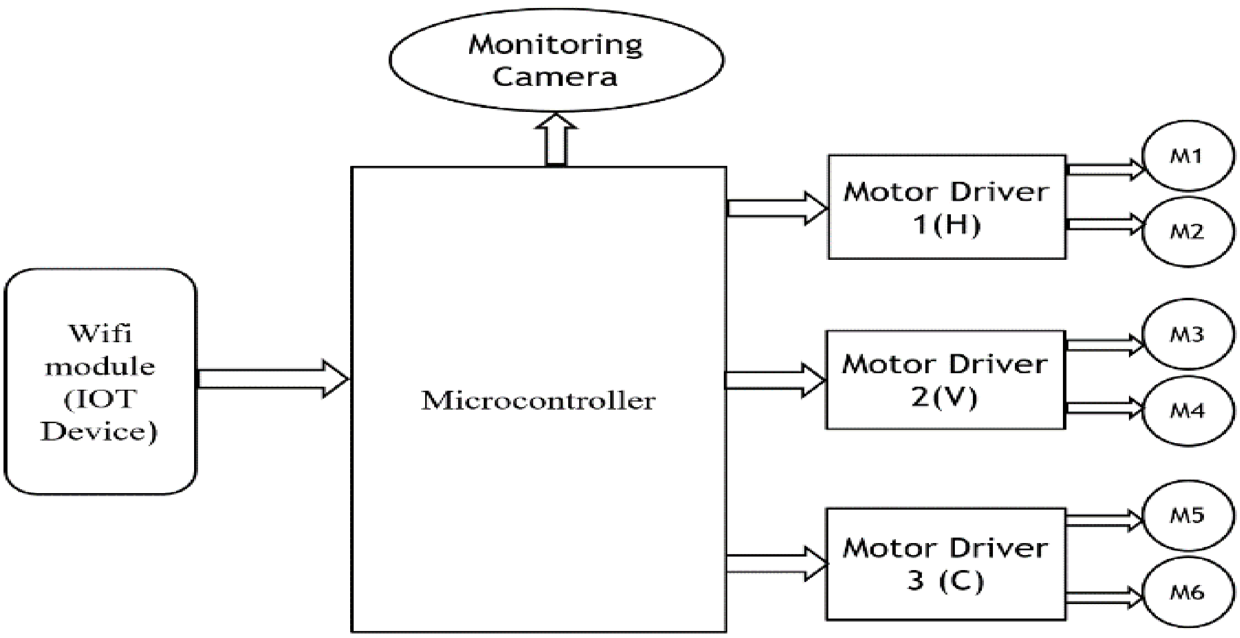

Fig. 3. Block Diagram of AI and IoT-Driven Automatic Abdominal Retractor

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Arm Cortex STM32: The STM32 family of 32-bit microcontrollers based on the Arm Cortex-M processor is designed to offer new degrees of freedom to MCU users. It offers products combining very high performance, real-time capabilities, digital signal processing, low-power / low-voltage operation, and connectivity, while maintaining full integration and ease of development. The unparalleled range of STM32 microcontrollers, based on an industry-standard core, comes with a vast choice of tools and software to support project development, making this family of products ideal for both small projects and end-to-end platforms. STMICROELECTRONICS Manufacturer Part No: NUCLEO-H753ZI STM32 microcontroller in LQFP144 package the NUCLEO-H753ZI, STM32H753ZI, STM32 Nucleo-144 board provides an affordable and flexible way for users to try out new concepts and build prototypes by choosing from the various combinations of performance and power consumption features, provided by the STM32 microcontroller. For the compatible boards, the internal or external SMPS significantly reduces power consumption in Run mode. The ST Zio connector, which extends the Uno V3 connectivity, and the ST morpho headers provide an easy means of expanding the functionality of the Nucleo open development platform with a wide choice of specialized shields. The STM32 Nucleo-144 board does not require any separate probe as it integrates the ST-LINK debugger/programmer. The STM32 Nucleo-144 board comes with the STM32 comprehensive free software libraries and examples available with the STM32Cube MCU Package.

WIFI Module (ESP8266): The Node MCU (Node Microcontroller Unit) is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266 Wi-Fi module comes with a boot ROM of 64 KB, user data RAM of 80 KB, and instruction RAM of 32 KB. It can support 802.11 b/g/n Wi- Fi network at 2.4 GHz along with the features of I2C, SPI, I2C interfacing with DMA, and 10-bit ADC.

ESP32-CAM: It is a low-cost ESP32-based development board with onboard camera, small in size. It is an ideal solution for IoT application, prototypes constructions and DIY projects. The board integrates Wi-Fi, traditional Bluetooth and low power BLE, with 2 high- performance 32-bit LX6 CPUs. ESP32 provides Wi-Fi and (in some models) Bluetooth connectivity for embedded devices – in other words, for IoT devices. While ESP32 is technically just the chip, the modules and development boards that contain this chip are often also referred to as “ESP32” by the manufacturer.

Motor Driver L293D: The L293D is a popular dual H-bridge motor driver integrated circuit (IC) commonly used in robotics and other electronic projects. It can control the direction and speed of two DC motors or one stepper motor. Its features include built-in protection diodes, thermal shutdown, and high output current capability. Motor driver L293D is generally standard 16 pin DIP (dual in package). This motor driver IC can simultaneously control two small motors in either direction; forward and reverse with just 4 microcontroller port lines. L293D IC is a typical motor driver IC that allows the DC motor to drive in any direction.

Motor Driver L298: The L298N is a dual H-Bridge motor driver which allows speed and direction control of two DC motors at the same time. The module can drive DC motors that have voltages between 5 and 35V, with a peak current up to 2A. following is the Basic pins of driver. The L298 motor driver allows you to control the direction and speed of two DC motors using an H-bridge configuration. By interfacing the L298 with an STM32 microcontroller, you can precisely control the motors for various applications such as an automatic abdominal retractor. The enable pins (ENA, ENB) control the speed via PWM, while the input pins (IN1, IN2, IN3, IN4) control the direction of the motors.

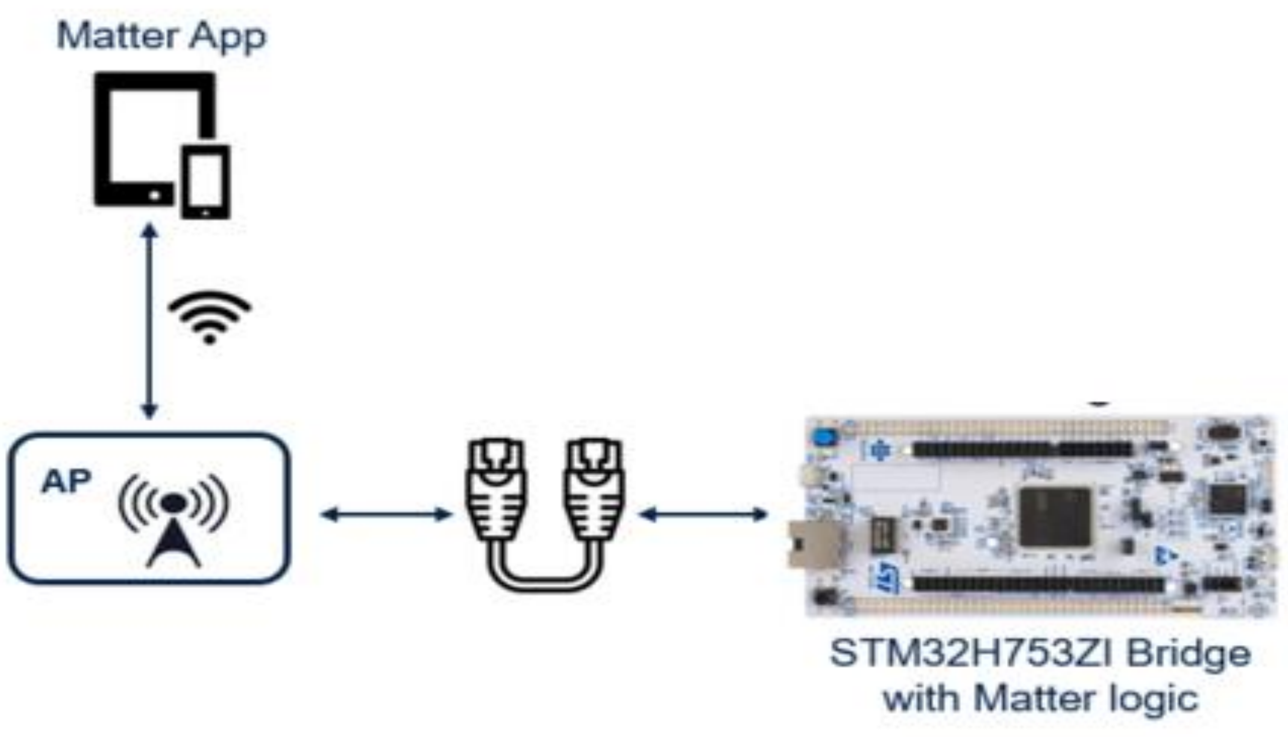

Fig. 4. Concept Diagram of STM32 & WIFI module communication

DC Motor: DC motors are electric motors that run on direct current (DC) electricity. They convert electrical energy into mechanical energy, generating rotational motion. They are commonly used in various applications such as robotics, industrial machinery, electric vehicles, and household appliances. DC motors come in different types including brushed DC motors and brushless DC motors, each with its own advantages and applications.

V. CONCLUSION

The AI and IoT-driven automatic abdominal retractor system represents a significant advancement in surgical technology, automating key aspects of surgical procedures while offering real-time control and adaptability. The use of AI for incision location detection and retraction adjustment enhances precision, reduces variability, and improves patient outcomes. The system's flexible power supply options, either battery or power supply-operated, ensure that it can be used in a wide variety of clinical settings, making it a practical and innovative solution for modern surgery.

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