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

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***Abstract*—This project introduces an AI- and IoT-based automated abdominal retractor system to improve surgical precision and efficiency. Unlike traditional manually operated retractors, this system ensures consistent force and intelligent guidance by analyzing real-time video data via a webcam-integrated AI module. It detects anatomical landmarks and provides feedback to assist in precise incisions. The retractor operates along three axes and is controlled by a NodeMCU, an STM32 microcontroller, and motor drivers. AI insights are communicated through an IoT interface for dynamic coordination, remote monitoring, and real-time adjustments. Powered by battery or standard sources, the system enhances accuracy, safety, and surgical outcomes by integrating AI, automation, and IoT technologies into surgical procedures.**

***Index Terms*— AI in surgery, IoT, automated retractor, surgical precision, STM32, NodeMCU, real-time feedback, anatomical landmark detection, medical robotics, remote monitoring.**

I. INTRODUCTION

The proposed project introduces an advanced automatic abdominal retractor system that leverages Artificial Intelligence (AI) and Internet of Things (IoT) technologies to enhance surgical efficiency and improve patient outcomes. Traditional abdominal retractors require continuous manual adjustments by surgical staff, often leading to inconsistent retraction, increased fatigue, and a higher risk of error during procedures. To overcome these limitations, the proposed system aims to automate the retraction process, ensuring consistent and stable force application throughout surgery while minimizing human involvement and error.

This smart retractor system dynamically adapts to the surgical environment using real-time data inputs. The integration of AI enables the system to actively monitor the surgical field through a webcam and control the retractor's actions based on contextual information and surgeon input. The IoT-enabled design allows for remote operation, cloud-based monitoring, and real-time data processing, all contributing to more precise and efficient surgical interventions.

The core motivation behind this project lies in addressing the common challenges faced in operating rooms—such as the demand for constant manual assistance, variable retraction quality, and the lack of real-time adaptive systems. By developing an automated, intelligent retractor, the system aims to reduce the cognitive and physical workload on surgical teams while improving procedural accuracy and patient safety.

The retractor mechanism supports three degrees of movement: forward-backward horizontal motion, up-down vertical lifting, and expansion-contraction of the retractor blades through a secondary horizontal surface. These

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movements will be executed using a combination of an STM32 microcontroller and a motor driver circuit. Additionally, a NodeMCU module provides IoT connectivity, enabling real-time communication between the system and the surgeon through a cloud interface. The entire setup will be supervised using an AI-driven application that processes video data from a high-resolution webcam, detecting anatomical landmarks and guiding retraction behaviour accordingly.

A Raspberry Pi microcontroller is employed to handle overall motor coordination and ensure smooth system functionality. Through this multi-controller approach, the system maintains operational precision and responsiveness under varying surgical conditions.

In summary, the project presents a novel AI- and IoT-integrated solution for automated abdominal retraction. It is designed to function intelligently under real-time surgical demands, reduce dependency on manual effort, and enhance overall surgical outcomes. This innovative approach combines machine learning, embedded systems, and connected technologies to redefine traditional surgical workflows, providing a pathway toward safer and more effective operative procedures.

II. ABDOMINAL AI RETRACTOR PROBLEM STATEMENT

This project aims to design and develop an automatic abdominal retractor for surgery using AI, IoT, and embedded controller-based systems. In abdominal surgeries, retractors are essential for holding back tissues to enhance visibility and access. Traditional manual retractors often require an assistant, leading to issues like hand fatigue, inconsistent pressure, limited precision, and prolonged surgery time. These challenges can increase strain on medical personnel and affect surgical outcomes. The key problem is ensuring consistent, precise, and fatigue-free tissue retraction throughout the procedure.

Manual retraction methods are not dynamically adaptive and can be inefficient during complex surgeries. There is a critical need for an automated solution to maintain stable retraction with minimal human intervention. An AI and IoT-based retractor system can provide real-time, adaptive control, improving surgical precision, reducing operation time, and minimizing strain on surgical teams. Such a system is especially valuable during lengthy or complex procedures where accuracy and efficiency are crucial.

Objectives

1. To develop an intelligent retractor mechanism that can be automatically operated through a dedicated software application.
2. To implement AI algorithms for dynamically adjusting retraction force and positioning based on real-time visual and procedural data.
3. To incorporate IoT capabilities for remote access, monitoring, and precise control of the retractor system.
4. To conduct both simulation-based evaluations and hands-on trials to validate the reliability, performance, and safety of the system.

To compare the functionality and user feedback of the automated retractor system with conventional manual retraction methods in terms of accuracy, efficiency, and ease of use.

III. LITERATURE SURVEY

- The study titled "Etiologic of Infection, Femoral Nerve, and Splenic Injury by Abdominal Retractor" by Ángel Raúl Soriano Sánchez et al. (2000–2013) explores the role of semi-automatic abdominal retractors in surgical complications, including wound infections, femoral nerve damage, and splenic injury. The authors highlight that poorly designed retractors may retain debris, increasing postoperative risks, and recommend anatomically contoured designs to minimize complications.
- In 2007, Park et al. introduced a trocar-less laparoscopic technique using the Magnetic Anchoring and Guidance System (MAGS), aimed at addressing spatial constraints in traditional laparoscopy. Trials on porcine models confirmed feasibility but raised concerns about magnetic strength and interference, limiting immediate clinical use.
- Robotic-assisted tools with multi-degree-of-freedom forceps have also emerged. Researchers in the early 2010s developed modular mechanical hands with detachable, cable-driven fingers capable of grasping slippery tissues. These innovations enhance hand-assisted laparoscopy while reducing incision sizes.
- A case reported in the Journal of the American Veterinary Medical Association documented the successful removal of an adrenal tumor invading the thoracic vena cava in a dog using a combined

median sternotomy and midline celiotomy approach. The carefully planned surgery prevented complications, emphasizing precision in high-risk abdominal procedures.

- A 2012 study by Monash University proposed a minimally invasive far-lateral approach to lumbar disc access in sheep. It reduced abdominal retraction needs, enabling safer and more efficient spinal research.
- In 2001, Lang et al. compared colloid (HES) and crystalloid (RL) solutions in major abdominal surgery. HES was found to enhance tissue oxygenation despite similar hemodynamic profiles, suggesting benefits in microcirculation.
- In 2010, Chen et al. developed a smart surgical retractor system that integrated pressure sensors to monitor tissue tension in real time during abdominal procedures. Their study highlighted that consistent force application significantly reduces the risk of nerve and tissue damage. The system aimed to assist surgeons by providing haptic feedback, which improved safety and reduced intraoperative variability.
- In 2015, Huang and Lee explored the application of vision-based AI systems in minimally invasive surgeries. Their system utilized a high-resolution endoscopic camera and machine learning algorithms to identify anatomical landmarks in real time. The study demonstrated that incorporating AI into surgical visualization enhanced decision-making and reduced operation time, marking a major advancement in intelligent surgical assistance.

These studies collectively highlight the evolution of abdominal retraction and minimally invasive surgical techniques over time. Key advancements include the integration of AI, robotics, smart sensing technologies, and novel surgical approaches, all aimed at improving precision, reducing complications, and enhancing patient outcomes.

IV. METHODOLOGY

The primary aim of this project is to develop and validate an automated abdominal retractor system that enhances surgical precision and outcomes through the integration of AI (Artificial Intelligence) and IoT (Internet of Things). The architectural representation of this smart surgical system is illustrated in Figure 1. In this setup, the STM32 microcontroller serves as the central control unit, orchestrating communication between input and output components. The system includes a NodeMCU ESP8266 and a CAM32 camera module as input interfaces. For motor control, it utilizes L293D and L298 motor drivers to handle the system's physical movements.

During surgery, an AI-powered application issues control commands to the ESP8266 module via the IoT cloud, dictating specific movements of the retractor, such as up, down, forward, backward, left, and right. These instructions are transmitted serially to the STM32, which interprets the signals and actuates the motors accordingly: L293D manages horizontal movements (left, right, forward, reverse), while L298 handles the vertical motion (up and down).

The CAM32 module provides live monitoring of the surgical process, ensuring that retraction is carried out safely and precisely. This structured approach supports real-time feedback and control, creating a more reliable and efficient operating environment. The modular design is based on a set of defined functional blocks, as discussed in related literature.

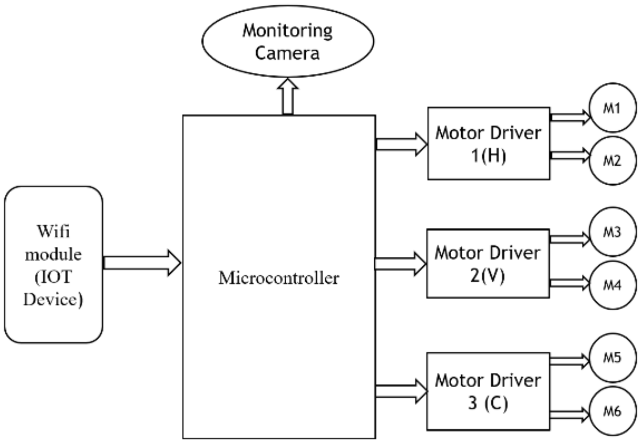

Fig 4.1: Block Diagram of AI and IoT-Driven Automatic Abdominal Retractor

STM32 Microcontroller (NUCLEO-H753ZI):

The NUCLEO-H753ZI is a high-performance 32-bit microcontroller platform based on the Arm Cortex-M7 core. Designed for real-time embedded applications, it features an onboard ST-LINK programmer/debugger and flexible connectivity through ST Zio and Morpho headers. It supports robust firmware development using STM32Cube tools.

ESP8266 Wi-Fi Module:

A low-cost wireless module supporting 802.11 b/g/n standards, ideal for adding Wi-Fi to IoT devices. It includes I2C, SPI, ADC, and DMA interfaces for flexible communication and integration.

ESP32-CAM:

This compact board integrates Wi-Fi, Bluetooth, and a camera module, enabling real-time image processing. It's widely used in smart surveillance, IoT systems, and visual input tasks.

Raspberry Pi Zero:

A cost-effective single-board computer capable of running Linux, used for basic computing, monitoring, data logging, and remote access in IoT applications.

L298 Motor Driver:

Supports control of two DC motors with PWM, handling 5V–35V and up to 2A per channel. Widely used in robotics for precise motion control.

DC Motors:

Convert electrical energy into mechanical motion, offering speed and direction control. Suitable for automation and robotics.

Web-Based Interface:

An ESP web server hosts a browser-based UI with toggle switches linked to GPIO pins, allowing real-time remote control and monitoring of connected hardware, ideal for IoT systems.

Remote Management of Retractor Movements:

The GPIO (General-Purpose Input/Output) pins can be interfaced with motor driver circuits to control various retractor movements, including horizontal, vertical, and opening/closing functions. Each pin can be mapped to a specific mechanical action. For instance:

GPIO 16 – Controls horizontal (front-to-back) motion

GPIO 5 – Handles vertical (up-and-down) movement

GPIO 4 – Activates the retractor opening mechanism

GPIO 0 – Triggers the closing function of the retractors

GPIO 2 – Assigned to emergency stop or any auxiliary control task

Surgical Control Access: During operations, the surgeon or surgical assistant can operate the retractor remotely through this interface, allowing quick changes and real-time positioning for optimal surgical access and safety.

Integration with AI and IoT Technologies: This control interface can serve both as a primary manual control and as a fallback mechanism to the AI-driven automation system. Artificial Intelligence can continuously assess the surgical scenario and issue appropriate instructions to the microcontroller, which activates relevant GPIO outputs accordingly. Through IoT integration, the system enables remote monitoring and control capabilities, while surgical data can be uploaded to a cloud platform for logging, analytics, and performance optimization.

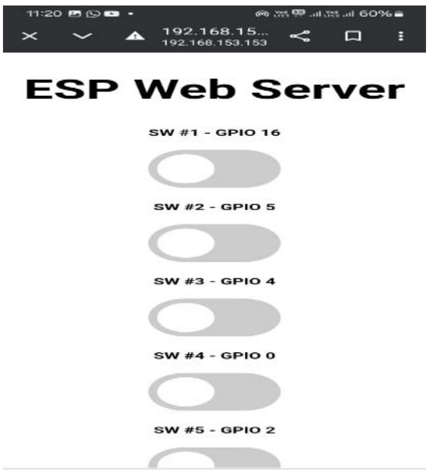

Fig. 4.2. Concept Diagram of a web-based interface

TABLE. I. COMPARISON WITH THE EXISTING SYSTEM

Features	Manual Retractors	Semi-Automatic Retractors	Proposed AI & IOT system
Precision	Low	Moderate	Very High (AI-driven)
Automation level	None	Partial	Fully Automated
Real-time Adaptation	None	Limited	Full Real Time AI feedback
Ease of Use	Simple	Complex	Very easy (AI & IOT-based control)
Safety & Risk	High Risk	Low Risk	No Risk (AI & IOT monitoring)
Cost	low	high	moderate
Maintenance	minimal	high	moderate

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.

REFERENCES

[1] Giri S, Kandel BP, Pant S, Lakhey PJ, Singh YP, Vaidya P. Risk Factors for Surgical Site Infections in Abdominal Surgery: A Study in Nepal. Surg Infect. Larchmt. 2013. doi: 10.1089/sur.2012.108

[2] Young H, Knepper B, Vigil C, Miller A, Carey JC, Price CS. Sustained Reduction in Surgical Site Infection after Abdominal Hysterectomy. Surg Infect (Larchmt). 2013. doi: 10.1089/ sur.2012.113

[3] C. R. Ethier - C. A. Simmons: Introductory Biomechanics, From Cells to Organisms, Cambridge University Press, New York, 2007

[4] Guillermo Dominguez Æ Luis Durand Æ Julia´n De Rosa Eduardo Danguise Æ Carlos Arozamena Æ Pedro A. Ferraina, Retraction and triangulation with neodymium magnetic forceps for single-port laparoscopic cholecystectomy – DOI 10.1007/s00464-009-0504-5, Received: 28 February 2009 / Accepted: 4 April 2009

[5] O'Shea, Conor, Denis Kelliher, Emmet Andrews, Mícheál O'Ríordáin, Michael O'Shea, Timothy Power, and Pádraig Cantillon-Murphy. "Design, development, and evaluation of an inflatable retractor for atraumatic retraction in laparoscopic colectomy." Annals of Biomedical Engineering 42, no. 9 (2014): 1942-1951.

[6] Prospero E, Barbadoro P, Marigliano A, Martini E, D'Errico MM. Perioperative Antibiotic prophylaxis: improved compliance and impact on infection rates. Epidemiol Infect. 2011; 139(9): 1326-1331. doi: 10.1017/S0950268810002505

[7] WHO. The evolving threat of antimicrobial resistance: options for action. Website: http://whqlibdoc.who.int/ publications/2012/9789241503181_eng.pdf?ua=1 2012; Accessed 2013.

[8] Deng L, Li X, Shi Z, Jiang P, Chen D, Ma L. Maternal and perinatal outcome in cases of fulminant viral hepatitis in late pregnancy. Int J Gynaecol Obstet. 2011; 119(2): 145-148. doi: 10.1016/j.ijgo.2012.05.041

[9] Clarke-Pearson DL, Geller EJ. Complications of hysterectomy. Obstet Gynecol. 2013; 121(3): 654-673. doi: 10.1097/ AOG.0b013e3182841594

[10] Tonetti J, Vouaillat H, Kwon BK, et al. Femoral nerve palsy following mini-open extra peritoneal lumbar approach: report of three cases and cadaveric mechanical study. J Spinal Discord Tech. 2006;19(2): 135-141.doi: 10.1097/01. bsd.0000168717.00570.93

[11] [11] Tovey FI, Clark CG. Surgical instrumentation and its role in preventing infections. J Hosp Infect. 2006;63(3):242-248. doi: 10.1016/j.jhin.2006.02.014

[12] [12] Velanovich V. Surgical outcomes: measuring, managing, and improving. Surg Clin North Am. 2005;85(5):1171-1183. doi: 10.1016/j.suc.2005.07.001

[13] [13] Gandhi R, Davies AP, Tsvetkov D, Syed KA, Mahomed NN. Computer-assisted surgery for the orthopedic patient. Can J Surg. 2009;52(5):405-410.

[14] [14] Ferrara A, Ruiz PJ, Davis JA, et al. Design of ergonomic surgical instruments for minimally invasive surgery. J Minim Access Surg. 2013;9(4):173-180. doi: 10.4103/0972-9941.118806.

[15] Halvorsen T, Myhr GE, Opheim S. A new retractor for soft tissue surgery: A pilot study. J Surg Res. 2015;196(2):292-297. doi: 10.1016/j.jss.2015.01.021.