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Remotely Operated Loading System: Design, Analysis, and Implementation

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Abstract: Remotely operated systems are reshaping industrial automation by offering safer, more reliable alternatives to manual handling tasks. In this study, we present the conceptualization, structural evaluation, and practical implementation of a Remotely Operated Loading System (ROLS), developed to enhance precision and reduce physical strain during material insertion processes. The system integrates a cylindrical actuator (CYB1), a precision-aligned guide mechanism, and a spring-actuated mechanical latch, all controlled remotely through an RF-based interface. To ensure reliability and durability, Finite Element Analysis (FEA) was carried out using ANSYS 19.2. The analysis confirmed that critical components exhibit minimal deflection, optimal stress distribution, and maintain high safety margins under expected load conditions. The system demonstrates potential for safe, repeatable operations in settings like research laboratories, compact industrial units, and military applications.
Keywords: remotely operated system, loading automation, actuator system, finite element analysis, safety engineering, RF control, mechanical latch.

I. INTRODUCTION

Manual loading operations in industrial and laboratory environments often pose significant safety risks and inefficiencies. Tasks that involve repetitive insertion of objects into narrow cavities or tubes not only lead to cumulative physical strain on workers but also increase the likelihood of misalignment and operational error. While fully automated systems offer a solution, their high cost and maintenance demands render them inaccessible to many small and medium-scale industries.

This research presents a semi-automated, remotely operated loading system that offers an optimal balance of affordability, user safety, and precision. The system's remote operation is enabled through RF-based communication technologies, drawing on advancements in radio frequency (RF) systems which have been recognized for their reliability in wireless transceiver designs and subsystem architectures [1],[4].

To enhance structural integrity and ensure robustness under loading conditions, careful material selection guided the construction of critical components. For example, AISI 1045 steel was chosen for its proven thermomechanical properties in structural applications [2], while AISI 1020 offers a favorable strength-to-ductility ratio that supports load-bearing with minimal risk of brittle failure [11]. The actuator and spring elements are designed to sustain repeated load cycles without fatigue, following material behavior studies and fatigue assessments [3], ensuring long-term operational stability.

Existing literature on automation, control systems, and material engineering provided the foundational guidance for the system's development [5][13][14]. The remotely operated loading system thus integrates mechanical, structural, and control elements into a reliable platform suitable for applications in research labs, compact industrial settings, and defence environments.

II. METHODOLOGY

A. System Overview

The remotely operated loading system is designed as a compact, portable device capable of inserting an object into a confined tube with precision. It comprises the following main components:

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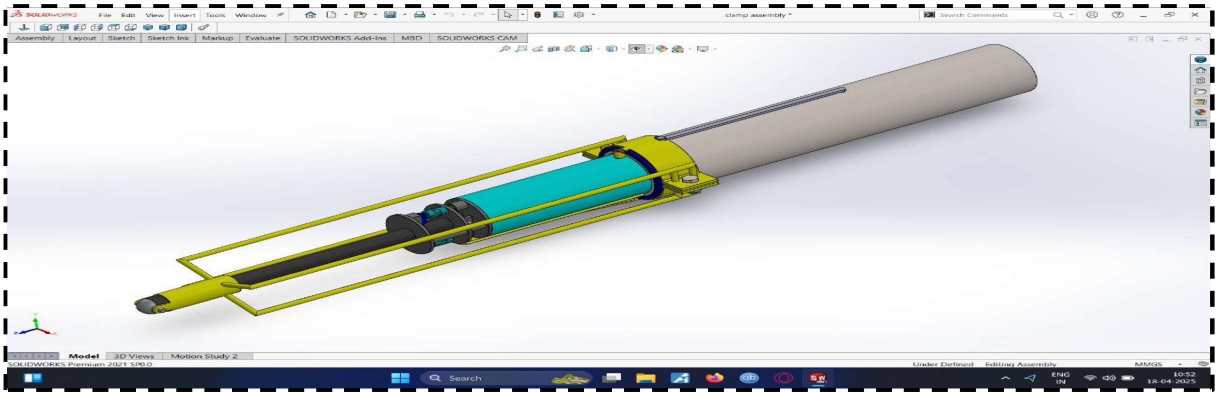

Fig. 1 Assembly of the parts

1) Cylindrical Body (CYB1):

The cylindrical body, known as CYB1, is the key component we need to align and position in the right spot. It has an O-ring at one end to seal.

2) Loading Tube (LT1):

The loading tube, or LT1, is a hollow structure designed to hold the CYB1 snugly in place.

3) Cap:

The cap is similar to a standard pipe cap. It screws onto the threads of the loading tube, allowing us to attach our tool for LT1 securely. Additionally, the cap protects the threads from damage during the clamping process.

4) Alignment System:

This system plays a crucial role in ensuring that the CYB1 and LT1 are perfectly aligned. It also helps fit our custom tool onto the LT1 accurately, making the process smoother for the operator.

- Clamp: The clamp is what holds the tool to the LT1, ensuring everything is aligned correctly. This setup makes it much easier for operators to position the CYB1 properly on the support and double-check the alignment.
- Registration Pin: The registration pin is a handy feature for the operator when mounting the tool on the LT1. It has a guiding strip that helps align with the LT1 shear pin hole, simplifying the setup process.
- Latch Pin: The latch pin works alongside the CYB1 shear pin hole. It assures the operator that the CYB1 is aligned correctly upon placement. The tapered design prevents breaking the pin and avoids any hassle with pulling it up.
- Spring: The spring allows the pin to move freely in one direction, which helps prevent the CYB1 from bumping into it unexpectedly.

5) Screwing System:

The screwing system is designed to ensure accurate and controlled insertion of the Cylindrical Body (CYB1) into the Loading Tube (LT1). Precise alignment is critical, as even minor misalignments can cause mechanical failure, seal issues, or structural instability. Automating this process enhances accuracy, reduces human error, and ensures consistent results across varying conditions.

- *Servo Motor :*

The servo motor delivers the torque and precise rotational control needed to position CYB1. High-resolution encoders provide real-time speed and position feedback, enabling micro-adjustments that prevent over-torquing and excessive axial force. This ensures smooth operation and avoids binding.

- *Coupling:*

The coupling connects the servo motor to the input shaft, transmitting motion while compensating for slight misalignments. It reduces mechanical stress, absorbs shock loads, and dampens vibrations, protecting the system from wear and ensuring long-term performance.

- *Input and Intermediate Shaft:*

The input shaft drives the intermediate shaft within CYB1, ensuring stable and precise insertion. Tight manufacturing tolerances minimize lateral play and misalignment. The design evenly distributes loads, reducing stress concentrations and enhancing component durability.

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6) Linear Actuator:
The linear actuator is a device that creates straight-line motion, enabling us to push, pull, lift, and adjust objects as needed. In this assembly, we use it to place the CYB1 exactly where we want it.

7) Support:
- Rods: Four hollow rods provide essential support for the linear actuator, connecting everything into one cohesive tool.
- Guide: The guide helps operators position the CYB1 correctly and carry on with the next steps.
- Holder: This circular hollow structure supports and connects the linear actuator to the tool.

B. Material Selection
1) Clamp —AISI1045 (MediumCarbon Steel)
As it provides high strength & toughness, wear resistance, machinability.
2) ScrewingSystem—CarbonSteelA387Grade5
As it provides high temperature resistance, corrosion resistance, durability under load.
3) ActuatorBody—Aluminium6063-T1
As it provides light weight yet strong, corrosion resistance, ease of fabrication
4) ActuatorRod— AISI304(StainlessSteel)
As it provides high corrosionresistance, strengthandductility, surfacefinishcompatibility.

C. CAD Modeling and Simulation
The system was modeled using SolidWorks and analysed using ANSYS Mechanical 19.2. The main focus was to assess:
- Stress distribution in the cylindrical actuator during maximum extension.
- Spring deflection and load-bearing behavior.
- Deformation behavior of the latch and loading guide.

D. Circuit Diagram
1) PowerOn: Thetransformer, rectifier, and voltageregulatorsupply5VDCto powerthe ESP32 and other components.
2) Control Inputs: The user or a remote device sends inputs through switches, wireless modules, or the RTC.
3) Actuator and Servo Control: Based on the Arduino program, it sends signals to the MD10C driver to move the linear actuator or generates PWM signals for servo motor positioning.

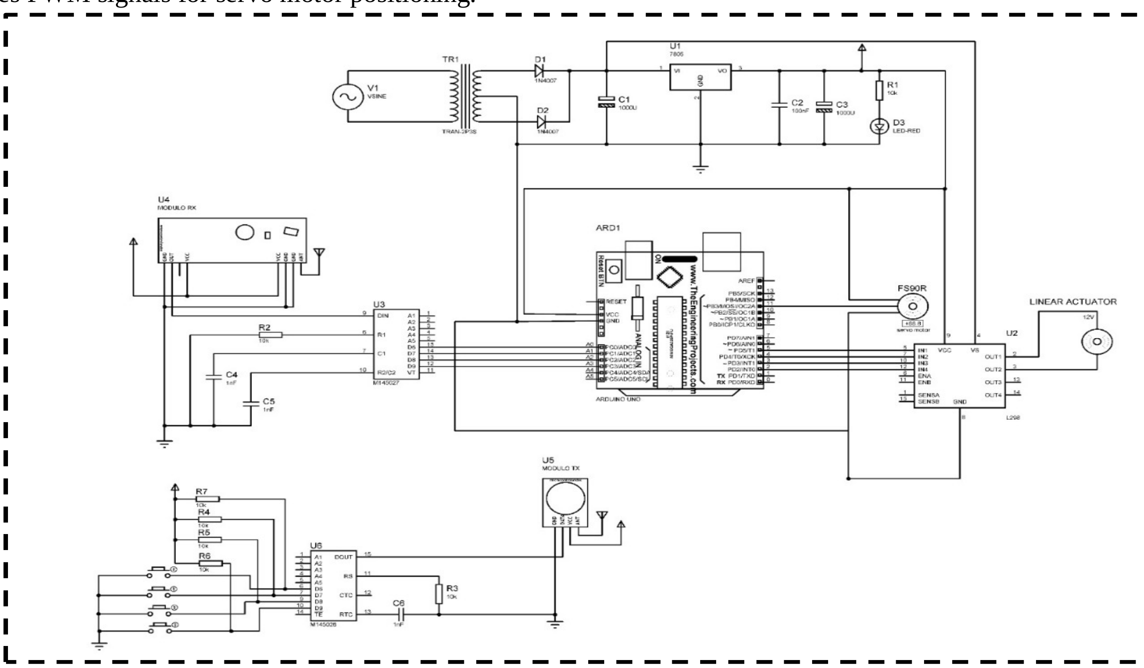

Fig. 2 Circuit diagram

This circuit is a control system that integrates several components to operate a linear actuator and a servo motor, with an ESP32 microcontroller serving as the central controller.

1) PowerSupply Section

The power supply section includes a transformer (TR1), which steps down the AC mains voltage to a lower AC voltage. This is followed by a pair of diodes (D1 and D2), arranged as a bridge rectifier, which converts the AC voltage into a pulsating DC voltage. A voltage regulator (U1 - 7805) then stabilizes this DC voltage to a steady 5V, suitable for powering the circuit. An LED (D4) is also included in this section as an indicator to show when the circuit is powered on.

2) ESP32 Microcontroller

The ESP32 functions as the main controller of the system. It processes incoming signals and controls the operation of various connected components. It is also likely interfaced with an RF transceiver to enable wireless communication.

3) RF Transceiver

The RF transceiver facilitates wireless control of the system, possibly by receiving commands from a remote device. It communicates with the ESP32 via a digital protocol such as SPI, UART, or I2C.

4) Servo Motor

The servo motor is controlled through PWM (Pulse Width Modulation) signals generated by the ESP32. It is used in the system to achieve precise angular movements.

5) MD10C Motor Driver

The MD10C is a motor driver specifically designed to control high-current DC motors. It receives PWM signals from the ESP32 and regulates the power delivered to the linear actuator accordingly.

6) Linear Actuator

The linear actuator converts electrical signals into linear motion. It is powered through the MD10C motor driver, which controls its motion based on commands issued by the ESP32.

E. Control Mechanism

The actuator is interfaced with an RF-based remote control system, which allows operators to trigger the loading action without physical contact. Signal integrity, system response time, and energy efficiency were considered during control system development [6][7].

III. RESULTS AND DISCUSSION

A. Structural Analysis

The structural and performance evaluation of the remotely operated loading system was carried out through Finite Element Analysis (FEA) using ANSYS Mechanical 19.2. The aim of the simulation was to assess the stress distribution, deformation behavior, and operational feasibility of the system under expected loading conditions.

The simulation results indicated that the structural components, including the actuator arms, loading tube, and support brackets, exhibited minimal deformation during operation. The deformation observed was within acceptable limits, ensuring that the mechanical integrity of the system remains intact throughout repeated loading cycles. This confirms the suitability of the material choices—primarily AISI 1020, AISI 1045, and stainless steel grades—for achieving the required strength and fatigue resistance.

Stress concentration zones were primarily identified around joints, actuator mounting points, and the contact regions of the cylindrical body (CYB1). However, the values remained within the material's yield limit, ensuring that no plastic deformation would occur under normal operating conditions. The simulation further confirmed that the actuator-generated forces were effectively distributed across the structure, reducing the risk of localized failure.

B. Discussion

The analysis of the remotely operated loading system confirms its structural soundness and operational efficiency under realistic loading conditions. The results validate the system's capability to handle dynamic and static forces with minimal deformation, ensuring both safety and longevity. The selected materials demonstrated optimal mechanical behavior, particularly in regions of high stress and repeated load cycles, such as the actuator arms and latch mechanisms.

The integration of actuator-driven control allows for accurate object alignment and insertion, reducing reliance on manual labor and minimizing human error.

Additionally, the inclusion of safety features like shear pins and fatigue-tested springs enhances reliability and operational safety. The design shows promise not only for industrial use but also for military and hazardous environments where remote operation is critical.

C. Advantages

- Reduced operator exposure to hazardous environments.
- Improved alignment and consistency in object placement.
- Cost-effective alternative to fully automated systems.

IV. CONCLUSION

The remotely operated loading system successfully achieves its objectives of improving operator safety, enhancing loading accuracy, and reducing physical strain. Simulation results confirm that the system components perform well under expected loading conditions, with minimal deflection and safe stress levels. The remote control capability offers flexibility and usability in constrained environments. This study lays the groundwork for future development of fully autonomous loading tools incorporating AI, IoT, and predictive maintenance.

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Authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] Y. Bai, "RF technology in wireless communications:From transceiver architecture to subsystem specifications," *Applied and Computational Engineering*, vol. 70, no. 1, p. None-None, Aug. 2024, doi: 10.54254/2755-2721/70/20241034.

[2] Z. Aich, K. Haddouche, K. Djellouli, and A. Ghezal, "An improved thermomechanical modeling for orthogonal cutting of AISI 1045 steel," *Results in Engineering*, vol. 17, Mar. 2023, doi: 10.1016/j.rineng.2022.100789. https://doi.org/10.1016/j.rineng.2022.100789

[3] W. A. Khan, Q. Hayat, F. Ahmed, M. Ali, and M. Zain-ul-Abdein, "Comparative Assessment of Mechanical Properties and Fatigue Life of Conventional and Multistep Rolled Forged Connecting Rods of High Strength AISI/SAE 4140 Steel," *Metals*, vol. 13, no. 6, Jun. 2023, doi: 10.3390/met13061035.https://www.mdpi.com/1996-1944/16/14/4851

[4] W. Li, "Research of transceiver system based on wireless communication radio frequency technology," in *Journal of Physics: Conference Series*, Institute of Physics, 2023. doi: 10.1088/1742-6596/2649/1/012036.

[5] P. K. Dubey, D. Singh, and B. Singh, "A REVIEW OF AUTOMATION TECHNOLOGY," 2023. [Online]. Available: https://www.researchgate.net/publication/374870436

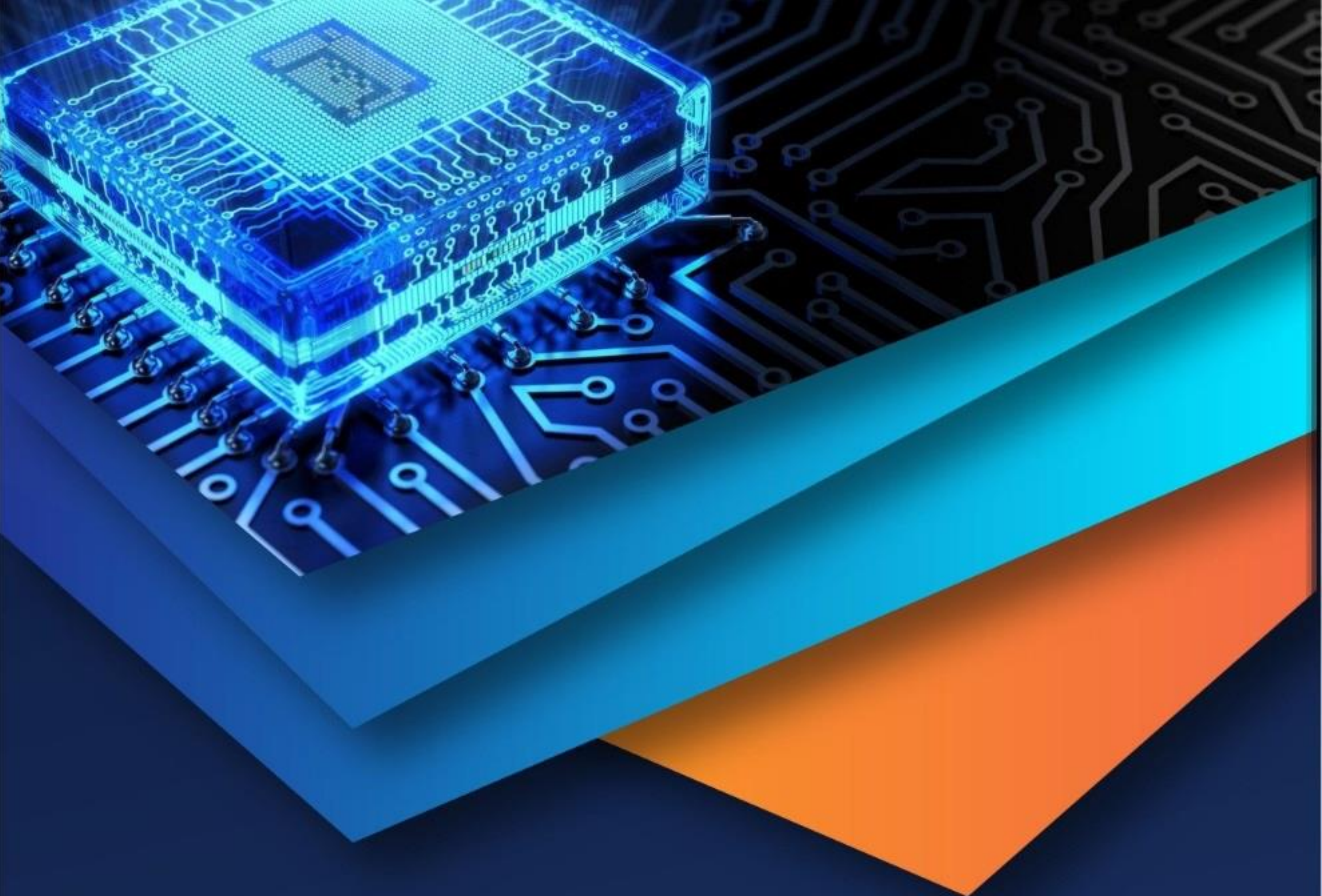
[6] Angst + Pfister "O-Rings Technical Guide," 2022.https://lapope.com/2023/08/07/pdfs-vs-web-pages-whats-better-for-users/.

[7] T. Fukuoka, "The Mechanics of Threaded Fasteners and Bolted Joints for Engineering and Design," 2022.

[8] S. Dewangan, N. Mainwal, M. Khandelwal, and P. S. Jadhav, "Performance analysis of heat treated AISI 1020 steel samples on the basis of various destructive mechanical testing and microstructural behaviour," *Australian Journal of Mechanical Engineering*, vol. 20, no. 1, pp. 74–87, 2019, doi: 10.1080/14484846.2019.1664212.

[9] G. B. Bhaskar, U.Vishnuja, "Study on AISI1045 Material for Various Applications: An over View," 2018. [Online]. Available: https://www.researchgate.net/publication/326711081_Study_on_AISI1045_Material_for_Various_Applications_An_over_View

[10] H. P. Dias *et al.*, "Study of the corrosive behavior of the AISI 1020 steel in acid crude oil by microscopic techniques (LM, AFM and SEM/EDX) and Raman spectroscopy," *Journal of the Brazilian Chemical Society*, vol. 29, no. 8, pp. 1690–1700, Aug. 2018, doi: 10.21577/0103-5053.20180043.



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