Design and Integration of an Automated Implant Driver System with Real-Time Intraoperative Livestreaming for Enhanced Precision in Orthodontic and Endodontic Procedures

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Abstract - *Current implant procedures in dentistry face challenges such as excessive radiation exposure, manual placement errors, and lack of real-time feedback, which compromise surgical outcomes and efficiency. This study presents the design and development of an Automated Implant Driver System integrated with real-time intraoperative livestreaming. The proposed system employs a Raspberry Pi 5 (4GB) as the central processor, a Raspberry Pi Camera Module 3 Wide for visual mark detection, and a 3-axis robotic arm driven by MG996R servo motors. The drilling function is controlled by an N20 300 RPM DC motor managed via an L298N motor driver. Servo coordination is handled through a PCA9685 PWM driver. The doctor places a visual mark on the implant site, which is identified using image processing techniques. The robotic arm aligns with the mark and executes the drilling operation while streaming the entire process in 4K resolution to remote specialists and interns. The system significantly reduces the number of required X-rays, enhances placement precision, lowers operational time, and supports remote collaboration and training.*

***Key Words*:** Dental robotics, implant driver, intraoperative livestreaming, Raspberry Pi, image processing, robotic surgery, orthodontics, endodontics, real-time guidance

1.INTRODUCTION

Dental implant procedures are critical interventions in orthodontic and endodontic care, often hindered by manual inaccuracies, high radiation exposure, and limited intraoperative feedback. Conventional methods rely on multiple X-rays and subjective decision-making, increasing the likelihood of complications and prolonging recovery times. Despite technological progress in other surgical domains, dental implantology still lacks cost-effective solutions that offer real-time visual guidance, automation, and precision.

This paper introduces an Automated Implant Driver System that integrates robotic actuation and high-definition livestreaming to address these issues. By automating the drilling process and offering real-time intraoperative visual feedback, this system promises to significantly enhance surgical precision, reduce health risks, and improve procedural outcomes.

2. Related Work

Prior research has explored robotics and image processing in various surgical applications. Systems like robotic-assisted implant placement have shown increased accuracy, but they often lack affordability and real-time streaming capabilities [1][2]. Additionally, conventional guidance systems heavily rely on CT or X-ray imaging, contributing to radiation exposure [3]. Few existing models integrate livestreaming or real-time mark detection for autonomous drilling, which positions our approach as a novel contribution.

3. System Design and Architecture

The system is an integrated solution combining both hardware and software components to perform precision-guided robotic drilling, primarily intended for medical or experimental procedures.

- Controller: The central processing unit is a Raspberry Pi 5 (4GB RAM), responsible for handling image processing, decision-making, and communication between various modules.
- Camera Module: An Official Raspberry Pi Camera Module 3 Wide is mounted on the setup to provide high-resolution, wide-angle visual input. It continuously captures images of the workspace, particularly focusing on a visual marker placed by the doctor or operator.
- Robotic Actuation: A 3-axis robotic arm forms the core of the physical movement system. It is powered by high-torque MG996R servo motors, enabling precise positioning and alignment based on processed image data.
- Drill Mechanism: The drilling action is performed by an N20 motor rated at 300 RPM, which offers a compact yet powerful solution. This motor is controlled using an L298N dual H-bridge motor driver, allowing for efficient and reliable control of speed and direction.
- Servo Control Interface: A PCA9685 12-channel PWM driver is used to manage the servo motors independently with precise timing signals, ensuring smooth and accurate motion across all three axes.

- Power Supply: The system draws its primary computational power from the official Raspberry Pi power adapter, while the mechanical components such as the DC drill motor are powered by a dedicated pack of three 3.7V Li-ion batteries, ensuring adequate current supply and electrical isolation from the Raspberry Pi.

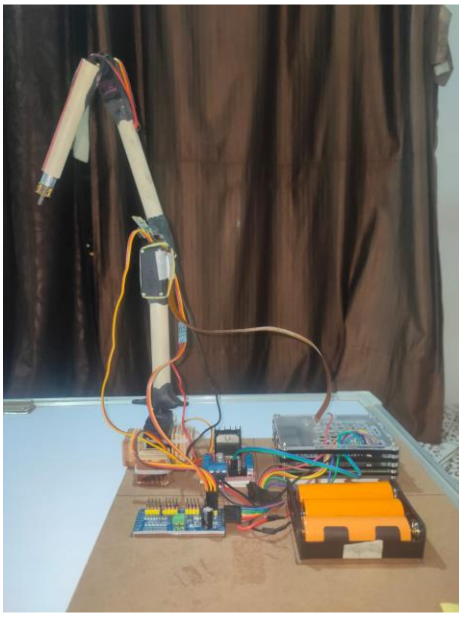
Fig -1: Prototype Image

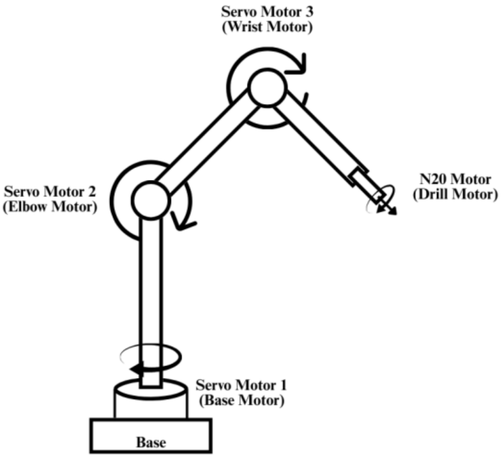

Fig -2: Robotic Arm Design

4. Methodology

The procedure begins with a visible mark placed by the doctor on the target implant site. The Raspberry Pi camera detects this mark in real time using OpenCV-based image processing. The system computes the coordinates and actuates the robotic arm through the PCA9685 PWM controller. Once the arm aligns with the target, the N20 motor initiates the drilling process. The system ensures low-latency, high-definition video transmission, allowing doctors and interns to monitor and interact with the procedure remotely.

5. Calculations

1) Angular Velocity (ω)
Formula:
$\omega = (2\pi \times \text{RPM}) / 60$

At 5 RPM:
$\omega = (2\pi \times 5) / 60 = \pi/6 \approx 0.524$ rad/s

2) Time per Rotation (T)
Formula:
$T = 60 / \text{RPM}$

At 5 RPM:
$T = 60 / 5 = 12$ seconds
12 seconds per rotation allows fine adjustments and precise control during surgery.

3) Heat generated $Q \propto \omega$

At $\omega = 0.524$ rad/s, heat generation is low.

Excessive heat (>47°C) causes bone necrosis. Lower ω ensures thermal safety.

6. Implementation and Testing

Testing was performed on simulation models to calibrate the arm and validate mark detection accuracy. The arm demonstrated repeatable alignment within acceptable tolerance levels. The use of image-based guidance successfully reduced the number of X-rays to just one or two per procedure. Livestream latency was minimal, and the camera delivered consistent 4K video for surgical review and teaching.

7. Results and Discussion

The prototype achieved significant improvements in accuracy, consistency, and safety. Operative time was reduced by automating mark detection and arm positioning. Feedback from observers confirmed enhanced educational value through livestreaming. Limitations included the sensitivity of detection to lighting conditions and minor servo calibration drifts, which are areas for future refinement.

8. Conclusion

The prototype achieved significant improvements in accuracy, consistency, and safety. Operative time was reduced by automating mark detection and arm positioning. Feedback from observers confirmed enhanced educational value through livestreaming. Limitations included the sensitivity of detection to lighting conditions and minor servo calibration drifts, which are areas for future refinement.

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