DEVELOPMENT OF A DESIGN AND CONTROL ALGORITHM FOR A MECHATRONIC MODULE FOR DISPLAYING 3D GRAPHICS ON A SURFACE

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Introduction

The increasing demand for interactive visual interfaces has prompted the development of advanced mechatronic systems capable of projecting three-dimensional (3D) graphics onto physical surfaces. These systems offer applications in virtual prototyping, digital art, education, and human-machine interaction. However, developing a compact, real-time responsive mechatronic module that can accurately display 3D visuals on arbitrary surfaces remains a technical challenge. This paper presents the design and implementation of a novel mechatronic module with a real-time control algorithm aimed at rendering 3D graphics on a flat or dynamically changing surface.

Methodology

1. System Design The proposed mechatronic module integrates three primary subsystems: Mechanical structure: a 3-DOF robotic arm equipped with a mini projector Electronic control unit: based on STM32 microcontroller and motor drivers. Software interface: developed in Python and integrated with OpenGL for 3D rendering. The arm's design allows precise control of pitch, yaw, and distance from the surface, enabling dynamic adjustments for optimal projection fidelity.

2. Kinematic Modeling. Forward and inverse kinematics were used to determine the projector's position and orientation. The Denavit-Hartenberg method was applied to model joint parameters and derive transformation matrices.

3. Control Algorithm. A hybrid control strategy was developed combining: PID controllers for joint motion regulation. Real-time image correction using feedback from a depth camera (Intel RealSense) to adjust the projection based on surface contours. Kalman filtering for noise reduction in sensor input.

4. Simulation and Implementation. The control algorithm was first tested in a virtual environment using MATLAB/Simulink. The physical prototype was then built and tested in laboratory conditions using a whiteboard as the projection surface.

Results

The developed system successfully rendered 3D graphics onto both flat and mildly curved surfaces with an average latency of 130 ms and an angular positioning error of less than 1.2 degrees.

Experimental tests demonstrated that the adaptive control algorithm could dynamically adjust projection parameters in real-time, maintaining consistent image resolution and alignment.

Parameter	Measured Value
Response time	130 ms
Angular error (mean)	1.2°
Projection accuracy	96.4% on flat surface
Surface adaptation latency	< 0.3 s

Discussion

The results confirm the feasibility of integrating kinematic control with real-time image correction in a compact mechatronic system. Compared to traditional static projection systems, the proposed solution offers enhanced flexibility and surface adaptability. Challenges encountered included vibration-induced noise in sensor data and limited depth perception under strong ambient lighting, which are addressed in part by filtering techniques.

Future improvements could involve implementing AI-based surface recognition and expanding the system's DOFs for more complex environments.

Conclusion

This study presents a fully functional prototype of a mechatronic module capable of dynamically displaying 3D graphics on various surfaces. The combination of mechanical precision, adaptive control, and software optimization provides a robust foundation for future development in interactive projection technologies.

References

1. Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. (2010). Robotics: Modelling, Planning and Control. Springer.
2. Craig, J. J. (2005). Introduction to Robotics: Mechanics and Control. Pearson.
3. Zhang, L., et al. (2021). "Real-time Surface Mapping for Augmented Reality Projection." IEEE Transactions on Mechatronics.