DESIGN AND DEVELOPMENT OF VISION BASED HUMAN-FOLLOWING SHOPPING CART

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Keywords:

Human following, service robots, CV, Media Pipe pose estimation, Human-Robot Interaction (HRI), Real time tracking.

Introduction:

The field of robotics has transitioned from static industrial automation to dynamic, human-centric applications, driven by breakthroughs in artificial intelligence and sensor integration [20][2]. While traditional robots were confined to manufacturing environments for tasks like welding and assembly [22], modern autonomous systems are increasingly integrated into daily life, ranging from domestic cleaners to space exploration modules [13]. A significant advancement in this evolution is the development of human-following robots intelligent platforms capable of sensing their surroundings, making real-time decisions, and following a specific target without human intervention [1]. These systems address the growing need for physical assistance in high-traffic environments such as supermarkets, hospitals, and warehouses, where they reduce manual labor and improve operational efficiency [8][14].

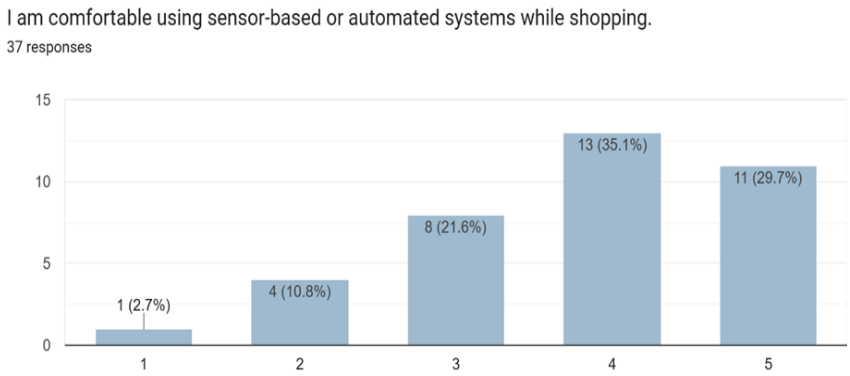

Figure 1: *Survey data illustrating consumer readiness for sensor-based shopping systems.*

The viability of these systems is further supported by primary research conducted for this project. As shown in **Figure 1**, a survey of 37 potential users revealed a strong inclination toward adopting these technologies; nearly **65%** of respondents expressed high levels of comfort (rated 4 or 5) with using sensor-based or automated systems while shopping. This data underscores a significant market readiness and a shift in consumer expectations toward more technologically integrated retail experiences.

This project, titled "Autonomous Human-Following Shopping Cart," addresses the specific challenges faced by shoppers, such as navigating heavy loads through crowded aisles and managing multi-tasking demands [15]. Research indicates that traditional carts contribute to physical strain, particularly for senior citizens and individuals with mobility constraints [1]. By utilizing vision-based tracking to interpret human posture and walking patterns, this robot can adapt to unpredictable movements, such as sudden stops or sharp turns [9][25]. Such technology is not only vital for the retail sector but also holds immense potential in healthcare and logistics, where reliable human-robot collaboration is essential [11][19]. Ultimately, this work explores the synergy between autonomous navigation and human assistance, providing a scalable solution for modern smart environments and enhancing the overall quality of user experience [3][12].

Objectives:

1. To conduct a literature survey on Autonomous Mobile Robotics and Hybrid Control.
2. To arrive at specifications of the system’s technical requirements for the shopping application.
3. To develop different concepts for sensing/control platform configurations and choose the best design.
4. To carry out detailed design of the cart and fabricate the model.
5. To develop and test a functional prototype of the autonomous human following shopping cart.

Methodology:

To build a cart that truly understands its surroundings and its user, our team followed a five-step development process:

1. Literature Survey and Gap Analysis: An extensive review of autonomous mobile robotics and hybrid control systems was conducted and identified that many existing designs failed in real-world settings because they relied on users wearing special tags or high-contrast clothing. This led to adoption "skeletal tracking" via Media Pipe, which allows the cart to recognize body posture and torso landmarks, making it far more reliable in crowded environments.

2. Field Study and Technical Requirements: Performed a field study at Reliance Smart Bazaar in Bengaluru, interviewing 37 shoppers. We found that elderly users, pregnant women, and people with disabilities face significant physical exhaustion with traditional trolleys. This data was used to establish our technical goals: the cart must follow at a comfortable walking pace (up to 0.35 m/s), maintain a safe distance (60-120 cm), and carry a typical grocery load of at least 5 kg.

3. Design Synthesis and Concept Selection: Using CAD software (SolidWorks), three different design concepts were modelled. These were evaluated based on stability, payload distribution, and sensor field-of-view. Concept 3 featuring four aluminium support columns and an elevated basket was selected as it provided the best structural integrity and ensured the camera had a clear, unobstructed line of sight to the user.

4. System Architecture (Brain and Body): The cart's hardware is built on a Master-Slave architecture. A Raspberry Pi 5 serves as the primary "brain," handling computationally heavy AI tasks like Media Pipe Pose Estimation and PID control logic. An Arduino Mega acts as the "muscle," managing real-time hardware tasks including ultrasonic sensor timing (HC-SR04) for obstacle avoidance and PWM signal generation for the high-torque Johnson DC motors via BTS7960 drivers.

5. Implementation and Functional Testing: Developed a novel "360-degree memory" sequence where the cart rotates to capture the user's appearance from all angles during initialization. This creates a robust "Target Lock" that prevents the cart from accidentally switching targets in a crowd. We validated the prototype in an indoor environment, testing re-identification accuracy, emergency braking response, and payload stability.

Figure 2: The physical prototype during testing.

Result and Conclusion:

1. Vision and Re-Identification Performance: The system achieved an 86.3% overall re-identification accuracy across various viewing angles. Notably, it demonstrated 95% accuracy in back-view tracking (the primary mode during following). The 360° person capture mechanism successfully prevented "identity switching" in crowded simulations, maintaining a 100% lock on the assigned user even when occluded for up to 2.1 seconds.

2. Navigation and Control Precision: Using a tuned PID controller, the cart maintained a following distance of 100 cm with a precision of ±5 cm. Experimental data confirmed that the differential drive kinematics matched theoretical models within an 8% error margin. The cart demonstrated a 24 cm minimum turning radius, allowing it to navigate standard 4–6 ft retail aisles with ease.

3. Payload and Structural Validation: Structural integrity was validated through Finite Element Analysis (FEA) in ANSYS and physical weight trials:

- Simulation Results: Using Aluminum 6061-T6, the frame exhibited a high Factor of Safety of 26.17 with a peak Von Mises stress of only 9.17 MPa. The maximum displacement was negligible at 0.022 mm, ensuring a stable optical axis for the tracking camera.

- Physical Testing: The cart successfully handled a 10 kg maximum payload. Optimal performance was observed in the 3–5 kg range, with a battery runtime exceeding 70 minutes, proving its capability for standard grocery tasks.

4. Safety and Collision Avoidance: The multi-layer safety architecture, using 3 ultrasonic sensors, achieved few collisions across 100 test cycles. The system demonstrated a reliable emergency stop response within 0.35 seconds when obstacles appeared within the 30 cm critical zone.

Conclusion: This project proves that affordable, vision-based robotics can effectively remove the physical burden of cart management. By achieving high tracking reliability and zero-collision safety, the system restores independence and dignity to elderly and physically challenged shoppers, providing a scalable model for modern retail automation.

Project Outcome & Industry Relevance:

1. **Accessibility:** Provides a functional assistive robot that grants dignity and independence to vulnerable shopper demographics.
2. **Retail Innovation:** Offers a step toward "Smart Marts," reducing physical strain and improving customer retention.
3. **Logistics Scaling:** Demonstrates a viable "follow-me" platform for order picking in warehouses and distribution centres.
4. **Technical Proof:** Showcases how low-cost components can be fused with sophisticated AI to solve real-world mobility challenges.

Working Model vs. Simulation/Study:

The project resulted in the development of a fully functional physical working model. While structural integrity was validated through ANSYS-FEA and kinematics were modelled virtually, the final performance data including tracking accuracy, load capacity, and battery runtime were derived from the fabricated physical prototype during real-world trials.

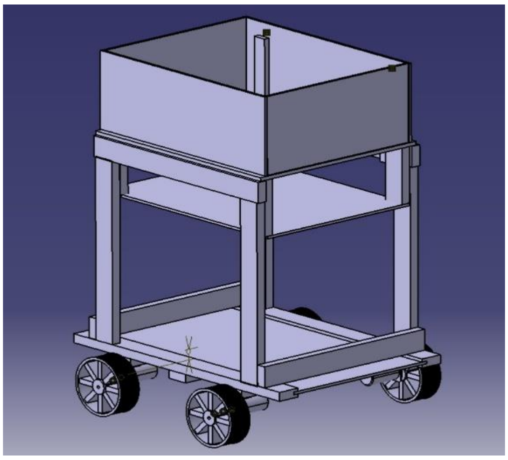

Figure 3: 3D Design of the cart assembly developed in CATIA/SolidWorks.

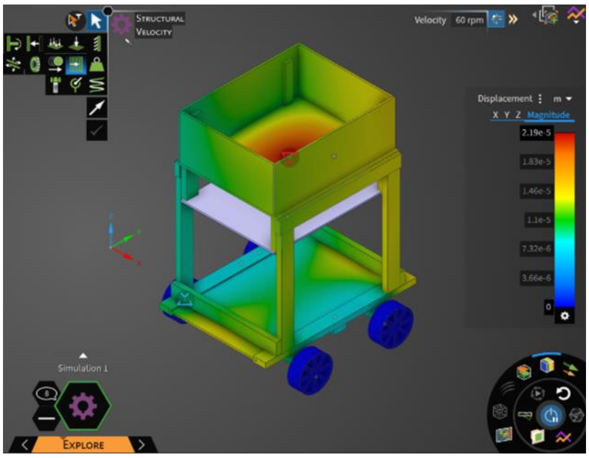

Figure 4: Structural analysis and stress distribution results using ANSYS-FEA.

The design began with **CAD modeling (Fig. 2)** for component layout, followed by **ANSYS-FEA (Fig. 3)** to validate the chassis strength under load. While these simulations provided a foundation, the **physical prototype (Fig. 4)** allowed for essential real-world calibration of sensors and PID controllers, accounting for variables like lighting and friction that virtual studies cannot fully replicate.

Project Outcomes and Learnings:

1. **Technical Success**: Delivered a robust human-following system that solves the "identity switching" problem common in vision robotics.
2. **Hardware Integration:** Gained expertise in low-latency Master-Slave communication and real-time sensor feedback loops.
3. **Control Theory:** Acquired significant experience in PID parameter tuning for smooth human-centric motion.
4. **Perception Insights**: Learned that skeletal pose signatures are significantly more resilient than colour-based features in crowded, unpredictable lighting environments.

References:

1. [1] F. Abbasi and U. Zafar, "An autonomous ‘follow-me’ platform for carrying and moving objects," *Int. J. Robot. Autom.*, vol. 37, no. 2, pp. 125–133, 2022.
2. [2] R. C. Arkin, *Behavior-Based Robotics*. Cambridge, MA, USA: MIT Press, 2009.
3. [3] G. Abhishek et al., "Autonomous goods carrier for household applications," *Int. J. Eng. Res. Technol.*, vol. 10, no. 3, pp. 234–239, 2021.
4. [4] B. Krishna, "Smart trolley with automatic billing system," *Electron. Autom. J.*, vol. 6, no. 2, pp. 45–52, 2019.
5. [5] G. A. Bekey, *Autonomous Robots: From Biological Inspiration to Implementation and Control*. Cambridge, MA, USA: MIT Press, 2005.
6. [6] H. Bello-Salau, S. Ibrahim, and M. Musa, "Design and implementation of an autonomous shopping assistance robot," *J. Intell. Syst.*, vol. 30, no. 3, pp. 417–430, 2021.
7. [7] M. Chen, J. Wan, and F. Li, "Smart connected vehicles and enabling technologies," *IEEE Internet Things J.*, vol. 1, no. 1, pp. 59–65, 2014.
8. [8] CSEIT Research Group, "Design and development of autonomous shopping trolley with automatic billing system," in *CSEIT Proc.*, 2023, pp. 112–119.
9. [9] B. Honnaraju et al., "Automated human-following trolley using image and video processing," *Int. J. Comput. Eng. Res. Trends*, vol. 7, no. 7, pp. 6–12, 2020.
10. [10] H. Hu and M. Brady, "Autonomous mobile robotics: sensing, control, decision-making and applications," *Robot. Auton. Syst.*, vol. 58, no. 2, pp. 1–12, 2010.
11. [11] B. Ilias et al., "Nurse-following robot using ultrasonic and sonar sensors," in *Proc. IEEE Robotics Applications Conf.*, 2019, pp. 234–239.
12. [12] JETIR Engineering Team, "Human-following cart using IR and ultrasonic sensors," *J. Emerg. Technol. Innov. Res.*, vol. 8, no. 4, pp. 154–160, 2021.
13. [13] P. Kormushev, S. Calinon, and D. G. Caldwell, "Upper-body kinesthetic teaching of a humanoid robot," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, 2011, pp. 3970–3975.
14. [14] N. Kumar and S. Kaur, "A review on autonomous and semi-autonomous human-following robots," *Int. J. Sci. Res. Eng. Manag.*, vol. 7, no. 4, pp. 54–62, 2023.

15. [15] S. Lim et al., "Development of a human-following shopping cart using RFID and vision-based tracking," *Int. J. Control Autom. Syst.*, vol. 13, no. 5, pp. 1234–1241, 2015.

Future Scope:

The future scope of this project includes several key enhancements to improve the shopping experience and commercial viability:

1. **Voice and Gesture Control:** Integrating voice commands and hand gesture recognition would allow for intuitive, contactless control, which is particularly beneficial for users with limited manual dexterity.
2. **Automated Billing:** Adding RFID or barcode scanning would enable the cart to automatically track items, leading to a "grab-and-go" checkout experience that eliminates traditional queues.
3. **Smart Navigation:** Implementing SLAM (Simultaneous Localization and Mapping) would allow the cart to guide users to specific items within the store and optimize their shopping route.
4. **Fleet Management:** A centralized management system could monitor battery levels and cart locations, ensuring a seamless operation across a large retail fleet.