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Implementation of Predictive Control Model and Obstacle Avoidance Fusion Sensor in Autonomous Vehicles

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ABSTRACT

This research aims to develop an autonomous vehicle system based on swerve drive that is able to perform obstacle avoidance maneuvers in a precise, adaptive, and real-time manner. The system is designed by integrating three main components, a swerve drive mechanism to produce omni-directional movement, a fusion sensor (lidar, camera, and CMPS12 orientation sensor) to improve the accuracy of environmental perception, and a Predictive Control Model (MPC) as the main controller to set a stable and smooth motion trajectory. The prototype of the vehicle was designed using the Arduino Mega 2560 as the low-level controller and the ROS as the data processing center. The test was carried out in an indoor environment with basic movement scenarios, steering angle stability, object detection, and obstacle avoidance at various distances. The results showed that the swerve drive system was able to produce forward, lateral, rotation, and diagonal movements stably with an average steering angle error of 2–4 degrees. The fusion sensor shows consistent object detection performance, especially at a distance of ≥80 cm. The initial implementation of the MPC successfully resulted in a smooth obstacle avoidance maneuver, although actuator response and parameter tuning still need to be optimized for near-range (<50 cm) obstacle scenarios. Thus, this study proves that the combination of swerve drive, sensor fusion and MPC is an effective approach to improve the navigation and safety capabilities of autonomous vehicles. The developed system can be the basis for further development towards autonomous vehicles that are more intelligent, responsive, and adaptive.

INTRODUCTION

Autonomous vehicle technology is currently very developed, especially in the type of wheel drive, the models offered are very diverse depending on the function of use (Bathla et al., 2022; Betz et al., 2022; Guan et al., 2024; Negash & Yang, 2023). Currently, autonomous vehicles generally use drive wheels such as *differential wheels*. In the application of wheel drive, the control system used can vary, because the calculation of the movement depends greatly on the model used. Vehicles that are able to move without a driver need precise controllers and reliable sensors in carrying out their mission. One of the concerns of autonomous vehicles is how the movement of the vehicle is both in maneuvering to avoid overtaking obstacles to prevent accidents (Pandian, 2019; X. Li et al., 2019), moving along existing road paths (Landolfi & Dragan, 2018; Davnall, 2020) and parking (Jhang & Lian, 2020; Zhang et al., 2018; B. Li et al., 2018).

The swerve drive *system* is one of the omni-directional movement systems that can provide high maneuver flexibility in autonomous vehicles. However, its implementation on a large scale is still challenging because each wheel has speed control and angular direction that must work well and precisely.

A swerve drive is a modular assembly, consisting of a drive wheel and a base, that rotates around a vertical axis that passes through the center of the wheel (Vranas & Mourtos, n.d.). There are two motors, one that drives the wheels, and the other that turns the direction of the wheels. This method is widely used to run mobile robots that can move freely because they have omni-directional movements. In this movement, the robot usually uses wheels that vary in number depending on the implementation (Deng et al., 2021) and the robot's ability in the area needed.

The urgency of this research is underscored by the pressing need for more effective obstacle avoidance systems in autonomous vehicles to prevent accidents and improve overall traffic safety. Collisions significantly contribute to traffic accidents and road congestion, making vehicle safety during driving conditions critical. Current autonomous vehicle systems demonstrate limitations in detecting and responding to obstacles, particularly in complex and dynamic environments. The integration of sensor fusion techniques combining LiDAR, cameras, radar, and ultrasonic sensors has emerged as a promising approach to overcome the limitations of individual sensors. Research has shown that sensor fusion systems combining LiDAR and camera data can achieve 96.5% detection accuracy with 0.2% collision rates, significantly improving obstacle detection and distance estimation capabilities. However, these systems still require sophisticated control strategies to translate perception data into safe and precise vehicle movements.

The novelty of this research lies in the integration of three key technologies—swerve drive, multi-sensor fusion, and Model Predictive Control (MPC)—into a unified autonomous vehicle system. While previous studies have explored these technologies individually, this research presents an original combination that addresses the limitations of existing approaches. The swerve drive system provides omni-directional movement capability, the sensor fusion (LiDAR, camera, and CMPS12 orientation sensor) enhances environmental perception accuracy, and the MPC algorithm ensures stable and smooth trajectory planning. This integrated approach represents a significant advancement over previous research, which typically focuses on individual components without addressing their synergistic integration. The use of ROS (Robot Operating System) as the data processing center further distinguishes this research, enabling seamless communication between perception, planning, and control modules.

In dealing with these problems, this study proposes the use of *Predictive Control (* MPC) models combined with fusion sensors (cameras, lidar, proximity sensors). This combination is expected to result in a more precise, more stable, more effective navigation system in avoiding objects and having good maneuverability.

METHODS

Swerve drive was one of the omni-directional drive methods that can make high maneuverability. Each swerve drive module consists of one wheel drive motor and one actuator motor which is in charge of rotating the direction of the wheel angle so that the vehicle can move in all directions without having to change the body orientation of the autonomous vehicle. The mechanical design and gear structure used in this system have been developed in various studies (Vranas & Mourtos, n.d.; Gu et al., 2016; Dzikrullah, 2024).

Some other types of robot drives that are often used are differential wheels (Deng et al., 2021), omni wheels (Wang et al., 2018) and mecanum wheels (Yuan et al., 2020). However, swerve drives have advantages in directional stability and maneuverability, making them more suitable for large-scale autonomous vehicle applications. Previous research has applied swerve drives to mobile robots and humanoid robots with various control approaches such as sliding mode control (Changoski et al., 2022), fuzzy logic controller (Caroline et al., 2025), and fuzzy logic type-2 (Suprapto et al., 2024; Dwijayanti et al., 2025).

The Predictive Control model is one of the modern control methods that has a working system by predicting the condition of the system at a certain period of time (prediction horizon) and determining the optimal control action based on the mathematical model of the system. The Predictive Control model excels at handling nonlinear systems, taking into account actuator limitations, and ensuring smoother movement.

In the context of autonomous vehicles, the Predictive Control Model is used for various applications such as speed stability, steering system angle control, and safe navigation planning (Jhang & Lian, 2020; Zhang et al., 2018). Research shows that the Predictive Control Model can reduce the risk of collisions because it is able to provide a faster and more accurate response than traditional control methods (Hu et al., 2025; Tagliavini et al., 2024).

This research began by designing a prototype-scale swerve drive. This is chosen to ensure that what is designed can work as intended at the time of actual creation. The prototype design as seen in Figure 1.

In the design of this prototype it consists of several components including sensors, microcontrollers, and actuators. This prototype uses a CMPS12 sensor, an A2M12 RPLIDAR sensor, and a potentiometer that has been designed so that autonomous vehicles are able to detect surrounding objects and maneuver well. Furthermore, the microcontroller used is the Arduino Mega 2560 with the advantage of having many pin outs that it has up to 54 pins so that it is able to control the entire system. And there are two actuators used, namely a stepper motor as a control of the steering angle of the car which uses the A4988 driver and a DC motor as a wheel speed controller which is controlled through the driver motor BTS7960.

Figure 1. Design Prototype scale drive

In this prototype system, a swerve drive system has been used as seen in Figure 2. This design is designed using various types of gears such as spur gear, straight bevel gear, and straight bevel pinion.

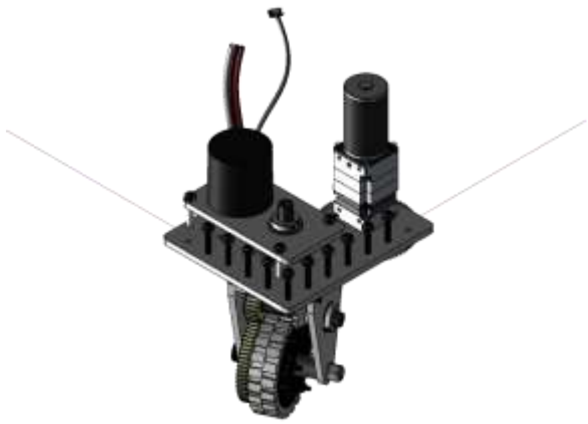

Figure 2. Design of a prototype of a swerve drive

The next stage is to design a control system that is integrated with various components so that it can maneuver properly automatically. The process starts from the collection of position data through webcams, lidar and encoder. This data will be used in the program to test whether an improved swerve drive system will be more effective compared to conventional ones. This information will be as input for primary control (laptop) through ROS (Robot Operating System) in serial communication, this ROS plays a very important role in managing communication between components such as Arduino input programs, path planning programs, and object road detection programs sent to the main control system through ROS. Furthermore, the primary control system will output a signal to the microcontroller through ROS through serial communication to control the motor through two methods, namely the pulse step to drive the stepper motor and PWM (Pulse Width Modulation) for the DC motor.

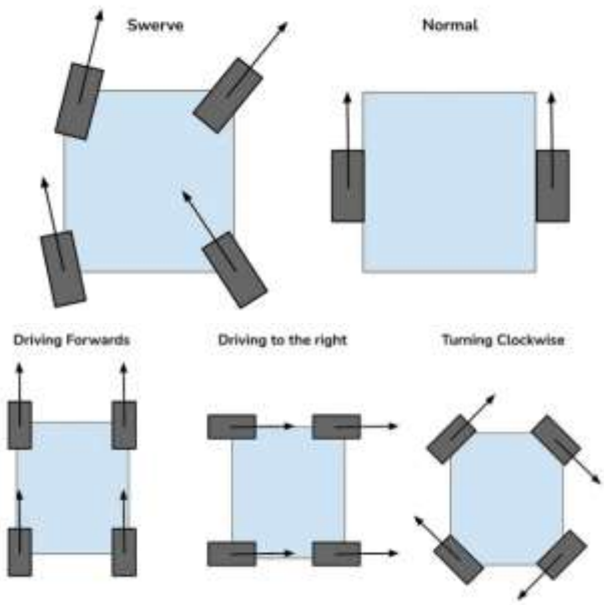

Figure 3. Direction of swerve drive motion on autonomous vehicles

In Figure 3, the direction of the autonomous vehicle's maneuver motion in all directions is produced by the swerve drive. Kinematics and odometric systems are used to calculate the speed and angle required for each swerve drive module to achieve the desired movement. Omnidirectional movements allow robots to perform complex and efficient maneuvers.

The main focus of this study is to optimize the predictive control module control system and sensor fusion in identifying and detecting objects as well as movement actions avoiding objects. As can be seen in Figure 4, it is a diagram of an autonomous vehicle in moving to avoid obstacles which aims to minimize accidents and be able to move more precisely, stably and accurately.

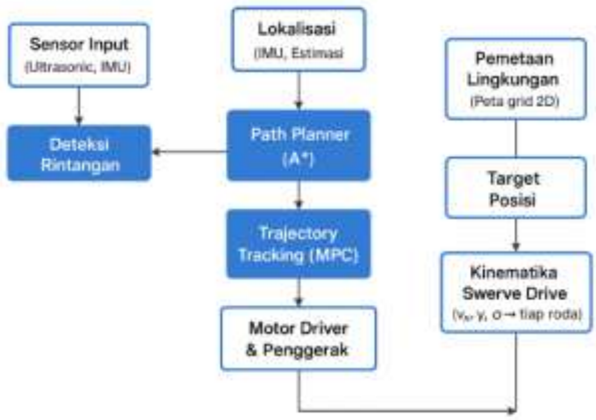

Figure 4. Autonomous vehicle obstacle detection diagram

RESULTS AND DISCUSSION

Figure 5 is the result of a prototype autonomous vehicle that has been completed for laboratory scale. The Swerve Drive drive module that has been made is a wheel mechanism that can move in all directions and a mechanically tested gear design. The integration of stepper motors and DC motors with each driver has been successfully carried out.

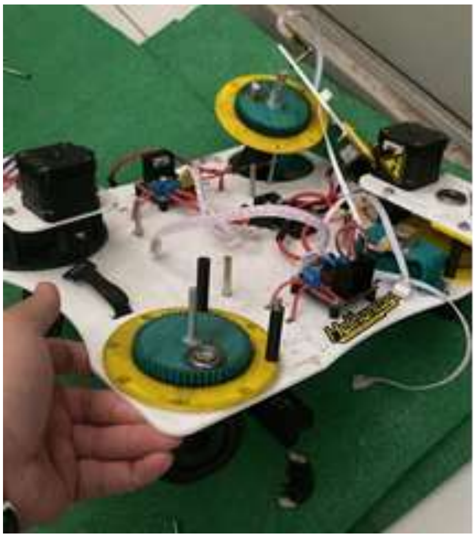

Figure 5. Prototype *Swerve Drive* robot

The assembly of the sensor system is also almost complete. Figure 6 is the result of the installation and testing of the sensors. The CMPS12 sensor is installed and has been tested to read the orientation well. The A2M12 RPLIDAR lidar is already connected and displays the distance data in the ROS. The camera for object detection has been integrated into the primary control system.

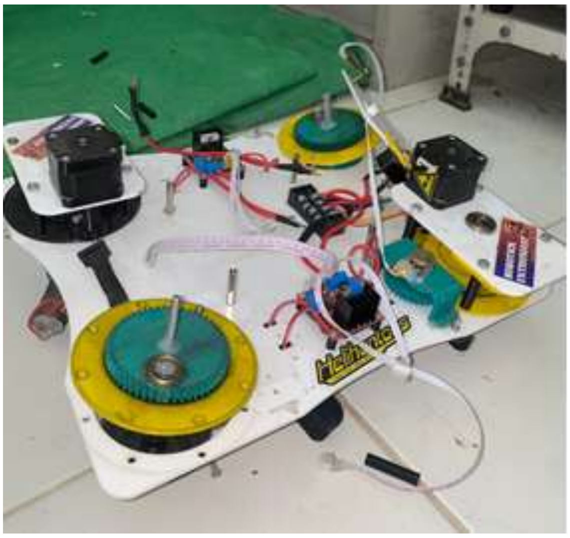

Figure 6. Assembly and positioning of sensors

This test is carried out to find out how quickly and accurately the motor stepper changes the orientation of the wheel as commanded. Table 1 is the result of the stability test of the robot's swerve drive steering angle.

Table 1. Wheel Orientation Angle Testing

Target Angle	Angles Achieved	Error	Response Time
0o	0.5o	0.5o	120 ms
45th	48th	3rd	150ms
90th	93	3rd	155 ms
135th	139th	4o	165 ms
180th	183	3rd	170 ms

Figure 7 is a graph of the level of accuracy of the motor stepper in reaching the commanded steering angle. The smaller the error value, the better the performance of the swerve drive system.

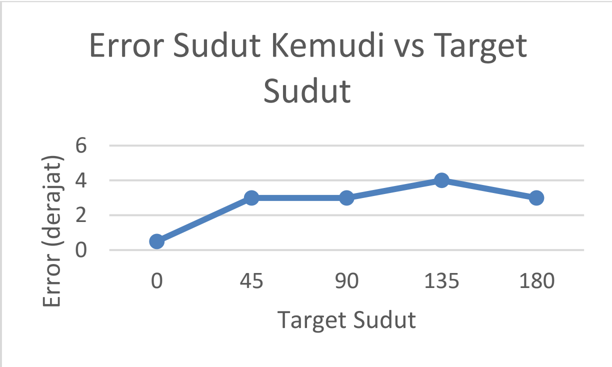

Figure 7. Graph of the steering angle against the target

The graph in Figure 9 is a response to how quickly the swerve drive module changes the orientation of the wheel from the starting position to the command angle.

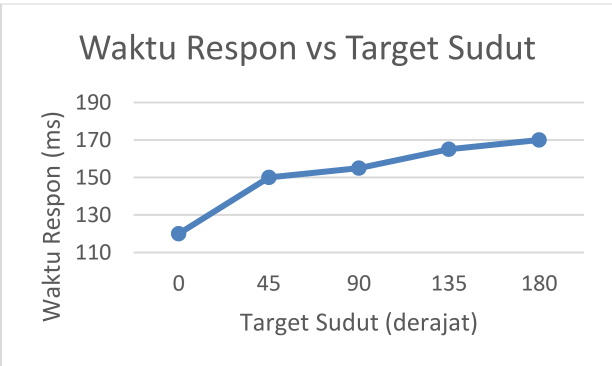

Figure 8. Graph Response time to target

CONCLUSION

This research succeeded in creating a prototype *of an autonomous vehicle* based on *swerve drive with stable* omni-directional *moving capabilities*. The integration of fusion sensors (lidar, camera, and orientation sensors) improves detection accuracy and avoids obstacles. The implementation of *the Predictive Control Model* (MPC) shows promising results in producing more efficient and adaptive obstacle avoidance maneuvers. The test results showed that the vehicle was capable of detecting objects and performing dodging maneuvers automatically, although further optimization and actuator response were still needed. Overall, this study proves that the combination of *swerve drive*, sensor fusion, and MPC is an effective approach to improve *autonomous vehicle navigation.*

REFERENCES

Bathla, G., Bhadane, K., Singh, R. K., Kumar, R., Aluvalu, R., Krishnamurthi, R., Kumar, A., Thakur, R. N., & Basheer, S. (2022). Autonomous vehicles and intelligent automation: Applications, challenges, and opportunities. *Mobile Information Systems*, *2022*(1), 7632892.

Betz, J., Zheng, H., Liniger, A., Rosolia, U., Karle, P., Behl, M., Krovi, V., & Mangharam, R. (2022). Autonomous vehicles on the edge: A survey on autonomous vehicle racing. *IEEE Open Journal of Intelligent Transportation Systems*, *3*, 458–488.

Caroline, Amirulsyah, A. R., Hermawati, H., Dwijayanti, S., & B. Y. S. (2025). Positioning control system on the movement of wheeled humanoid robot using swerve drive model based on fuzzy logic controller. *Journal of Electrical Engineering*, *21*(1), 27–35.

Changoski, V., Gjurkov, I., & Jordanoska, V. (2022). Improving vehicle dynamics employing individual and coordinated sliding mode control in vehicle stability, active front wheel steering and active rear wheel steering systems in co-simulation environment. *IOP Conference Series: Materials Science and Engineering*, 12026.

Davnall, R. (2020). Solving the single-vehicle self-driving car trolley problem using risk theory and vehicle dynamics. *Science and Engineering Ethics*, *26*(1), 431–449.

Deng, W., Xu, J., Song, Y., & Zhao, H. (2021). Differential evolution algorithm with wavelet basis function and optimal mutation strategy for complex optimization problem. *Applied Soft Computing*, *100*, 106724.

Dwijayanti, S., Suprapto, B. Y., & Rizky, I. A. (2025). Practical implementation of a type-2 fuzzy logic controller for steering a service robot. *Results in Control and Optimization*, 100558.

Dzikrullah, Q. L. (2024). *Implementation of swerve drive for straight motion movement stability of robots*.

Gu, T., Dolan, J. M., & Lee, J.-W. (2016). Human-like planning of swerve maneuvers for autonomous vehicles. In *2016 IEEE Intelligent Vehicles Symposium (IV)* (pp. 716–721). IEEE.

Guan, Y., Liao, H., Li, Z., Hu, J., Yuan, R., Zhang, G., & Xu, C. (2024). World models for autonomous driving: An initial survey. *IEEE Transactions on Intelligent Vehicles*.

Hu, T., Xu, X., Nguyen, T.-M., Liu, F., Yuan, S., & Xie, L. (2025). Tire wear aware trajectory tracking control for multi-axle swerve-drive autonomous mobile robots. *Journal of Automation and Intelligence*.

Jhang, J.-H., & Lian, F.-L. (2020). An autonomous parking system of optimally integrating bidirectional rapidly-exploring random trees and parking-oriented model predictive control. *IEEE Access*, *8*, 163502–163523.

Landolfi, N. C., & Dragan, A. D. (2018). Social cohesion in autonomous driving. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 8118–8125). IEEE.

Li, B., Yang, L., Xiao, J., Valde, R., Wrenn, M., & Leflar, J. (2018). Collaborative mapping and autonomous parking for multi-story parking garage. *IEEE Transactions on Intelligent Transportation Systems*, *19*(5), 1629–1639.

Li, X., Rakotonirainy, A., & Yan, X. (2019). How do drivers avoid collisions? A driving simulator-based study. *Journal of Safety Research*, *70*, 89–96.

Negash, N. M., & Yang, J. (2023). Driver behavior modeling toward autonomous vehicles: Comprehensive review. *IEEE Access*, *11*, 22788–22821.

Pandian, A. (2019). Challenges in autonomous vehicle development. In *International Conference on Industrial Engineering and Operations Management*.

Suprapto, B. Y., Dwijayanti, S., & Amri, D. (2024). Development of a position control system for wheeled humanoid robot movement using the swerve drive method based on fuzzy logic type-2. *Elektronika ir Elektrotechnika*, *30*(1), 4–13.

Tagliavini, L., Botta, A., Colucci, G., Baglieri, L., Duretto, S., & Quaglia, G. (2024). Kinematic modelling of swerve-drive-based mobile robots. In *Proceedings of Jc-IFToMM International Symposium* (Vol. 7, pp. 225–231). Japanese Council of IFToMM.

Vranas, M., & Mourtos, N. J. (n.d.). Compact shaft-rotating swerve drive with prong structure for highly-maneuverable and agile robots. *Athens Journal of Technology & Engineering*.

Wang, C., Liu, X., Yang, X., Hu, F., Jiang, A., & Yang, C. (2018). Trajectory tracking of an omni-directional wheeled mobile robot using a model predictive control strategy. *Applied Sciences*, *8*(2), 231.

Yuan, Z., Tian, Y., Yin, Y., Wang, S., Liu, J., & Wu, L. (2020). Trajectory tracking control of a four mecanum wheeled mobile platform: An extended state observer-based sliding mode approach. *IET Control Theory & Applications*, *14*(3), 415–426.

Zhang, X., Liniger, A., Sakai, A., & Borrelli, F. (2018). Autonomous parking using optimization-based collision avoidance. In *2018 IEEE Conference on Decision and Control (CDC)* (pp. 4327–4332). IEEE.