International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

INVESTIGATION ON PID CONTROLLER USAGE ON UNMANNED VEHICLE FOR STATBILITY CONTROL

Raveenthiran E, Thangadurai M, Vetrivel S B

[1]Studuent, Dept. of Electrical and Electronics Engineering, Anna University, IN
[2]Studuent, Dept. of Electrical and Electronics Engineering, Anna University, IN
[3]*Studuent, Dept. of Electrical and Electronics Engineering, Anna University, IN*

Abstract - *This investigation focuses on the application and effectiveness of Proportional-Integral-Derivative (PID) controllers integrated with sensor fusion for feeding filtered outputs to controllers of unmanned vehicles, including drones, autonomous ground vehicles, and underwater vehicles. Sensor fusion methods are widely used in control systems to enhance response time, reduce steady-state error, and improve overall system stability. This study leverages Simulink to simulate noisy sensor data and system dynamics, implementing sensor fusion algorithms to produce filtered state estimates. The entire control process, including PID control and sensor fusion, is simulated in MATLAB Simulink, where the primary outputs are the filtered state estimations and the resulting system responses. These outputs are critical in evaluating the effectiveness of PID control strategies and validating the noise reduction achieved through sensor fusion. Additionally, the study evaluates the limitations of PID controllers under dynamic and uncertain conditions, offering insights into potential enhancements for achieving optimal stability and robustness in real-time applications.*

Key Words: *Proportional-Integral-Derivative (PID), unmanned vehicles,. Sensor fusion, MATLAB Simulink, stability and robustness.*

1. INTRODUCTION

The project focuses on the design and development of an autonomous underwater vehicle (AUV) with a primary goal of achieving optimal stability and precise maneuvering through state estimation and control techniques. The stability of an AUV in underwater environments is critical, as it ensures consistent and reliable navigation, overcoming disturbances and maintaining orientation during various operations. To achieve this, accurate prediction and estimation of the vehicle's state are essential, which involves continuously updating the position, orientation, and velocity of the AUV. This process requires the integration of sensor data and dynamic state prediction methods, collectively known as state estimation. State estimation involves noise reduction and precise fusion of data obtained from sensors such as inertial measurement units (IMUs) and attitude and heading reference systems (AHRS). IMUs provide input data such as linear acceleration and angular velocity, which are critical for estimating the position and orientation of the AUV. However, IMU data are prone to noise and drift over time, necessitating advanced sensor fusion methods. To mitigate these issues and obtain accurate state estimates, we employ the Kalman filter, a mathematical algorithm that combines noisy measurements and predictive modelling to achieve optimal estimation of the vehicle's true state. The Kalman filter works by predicting the next state of the system based on a prior estimate and the process model while incorporating new sensor data to update and refine this estimate. This involves steps such as predicting the prior state and correcting it based on the posterior state, with a continuous cycle of prediction and correction. This recursive approach helps in reducing noise and uncertainties in sensor measurements and provides a refined, accurate estimate of the AUV's state.

The project implementation is carried out in MATLAB Simulink, where the IMU block inputs acceleration data and integrates it to derive velocity. The AHRS block processes orientation data. The sensor fusion process, implemented through Kalman filtering, predicts and corrects the state to reduce noise and produce an accurate estimate of the vehicle's orientation and position. This state estimation output, with noise-reduced values, is then fed into a PID controller. The PID controller uses this data to stabilize the AUV and ensure precise control over its movements during underwater operations. By integrating these components, the system aims to achieve stable, reliable, and accurate control of the AUV, overcoming the challenges posed by underwater environments.

1.1 Background of the Work

In modern control systems, achieving accurate and robust performance often relies on combining data from multiple sensors to estimate system states. The **Kalman filter** algorithm is used for sensor fusion due to its ability to handle noisy measurements and dynamic uncertainties. This background outlines the foundational concepts, the rationale for using Kalman filters in sensor fusion, and its integration into PID control systems.

1.2 Motivation and Scope of the Proposed Work

The motivation for this work arises from the limitations

International Research Journal of Education and Technology
Peer Reviewed Journal
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of traditional PID controllers in handling noisy measurements and uncertain dynamics, which can lead to instability, oscillations, and suboptimal performance. Modern systems, such as robotics, autonomous vehicles, and industrial automation, demand precise and robust control in complex and dynamic environments where sensors are prone to noise and bias. The Kalman filter addresses these challenges by optimally fusing noisy sensor data to provide accurate state estimates, even in the presence of uncertainties. Integrating the Kalman filter with a PID controller ensures noise-free and reliable feedback, enabling better control decisions and system stability. The scope of this work includes designing the Kalman filter for sensor fusion, integrating it into the PID loop, and validating the approach through MATLAB/Simulink simulations. Performance will be assessed under varying noise levels and dynamic conditions, and the system will be tested in practical applications like robotics and process control. This integration aims to enhance control accuracy, adaptability, and robustness, contributing to advancements in high-performance control systems.

2. METHODOLOGY

The methodology for this project involves a structured workflow that integrates sensor fusion, Kalman filter design, integration with PID controller. This structured methodology ensures a comprehensive approach to designing and validating a Kalman filter-based sensor fusion system for robust PID control in unmanned vehicles.

2.1 Sensor Fusion

In the first stage of our project, sensor fusion is implemented to enhance the stability and positioning accuracy of autonomous underwater vehicles (AUVs). Operating in an underwater environment poses challenges due to instability caused by varying hydrodynamic forces and the limitations of individual sensors. To address these challenges, sensor fusion integrates data from the IMU (Inertial Measurement Unit) and AHRS (Attitude and Heading Reference System), leveraging the capabilities of accelerometers, gyroscopes, and magnetometers to provide accurate state estimates. The accelerometers in the IMU measure linear acceleration along three axes, capturing changes in speed essential for calculating velocity and position. Gyroscopes provide angular velocity measurements, which help determine the rotational motion and orientation of the AUV. Magnetometers contribute by measuring the magnetic field strength and direction, offering heading information critical for maintaining directional stability. By integrating the data from these sensors, the IMU generates preliminary estimates of velocity and orientation. Sensor fusion further refines these estimates by combining the IMU data with AHRS outputs using advanced algorithms. This process enhances the accuracy of the AUV's position and orientation while mitigating the effects of noise and sensor uncertainties. The refined output is crucial for the next stage, where a Kalman filter processes the data to reduce noise and provide optimal state estimates. This integrated approach ensures that the AUV maintains stability and navigational precision even in the challenging and unpredictable underwater environment..

2.2 Kalman Filter Design

To Kalman filters are widely used for state estimation in dynamic systems by processing noisy measurements and combining them with a model of the system's behavior. They work well for linear systems, but nonlinear systems require modifications, such as the Extended Kalman Filter (EKF).

2.2.1 Extended Kalman Filters (EKF)

The EKF is designed for nonlinear systems, estimating object states (e.g., position, velocity) by linearizing nonlinear state and measurement equations using Jacobians. It is particularly suitable when measurements (e.g., azimuth, elevation, and range) are in nonlinear forms like spherical coordinates, while the states are expressed in Cartesian coordinates**.**

2.2.2 State Update Model:

The state update follows xk+1=f(xk,uk,wk,t), with Jacobians derived for the state transition (F(x)F(x)) and noise (F(w)F(w)). For additive noise, F(w)F(w) is the identity matrix.

2.2.3 Measurement Model

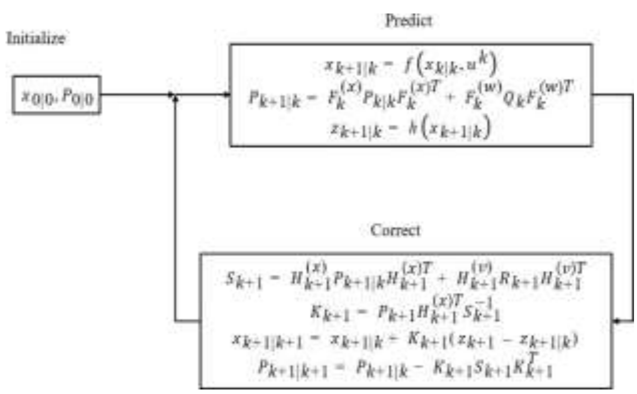
Measurements are modeled as zk=h(xk,vk,t), with Jacobians for the state (H(x)H(x)) and noise (H(v)H(v)). For additive noise, H(v)H(v) is the identity matrix.

2.2.4 Implementation in MATLAB

The EKF (trackingEKF object) computes Jacobians numerically by default but allows manual specification of StateTransitionJacobianFcn and MeasurementJacobianFcn for better accuracy and reduced computation time.

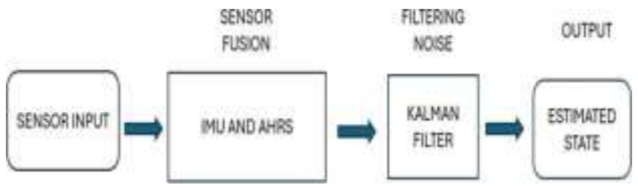
2.2.5 EKF Loop

Similar to linear Kalman filters but substitutes nonlinear state and measurement functions with their Jacobians.



2.3 Integration with PID controller

The final step in the system integrates the output of the Kalman filter with a PID controller to achieve precise stability and error correction for the autonomous vehicles. The Kalman filter provides a refined state estimate by combining sensor fusion data while minimizing noise and uncertainties. The PID controller takes the output differences generated by the Kalman filter, representing the deviation between the estimated states and desired values, as its input. By applying proportional, integral, and derivative control actions, the PID controller effectively regulates these differences. The proportional component addresses immediate discrepancies, the integral component eliminates steady-state errors over time, and the derivative component predicts future deviations to ensure smoother corrective actions. This integrated approach enables the PID controller to dynamically adjust the Autonomous vehicle's control inputs, compensating for the errors propagated through the Kalman filter and maintaining system stability. As a result, the combined system ensures precise navigation, minimizes disturbances, and maintains robust performance, even in challenging underwater environments. This structure—sensor fusion to Kalman filter, and Kalman filter to PID controller—provides a seamless pipeline for achieving optimal stability and error correction in real-time.



Flowchart

3. CONCLUSIONS

The integration of a Kalman filter with a PID controller enhances the performance of unmanned vehicles by providing accurate state estimation from noisy sensor data. This approach improves stability, precision, and robustness, addressing the limitations of traditional PID controllers in dynamic and uncertain environments. The methodology demonstrates the system's effectiveness in applications like autonomous navigation and obstacle avoidance, ensuring reliable and efficient operation of unmanned vehicles in real-world scenarios..

3.1 Suggestions for Future Work

1. **Integration of Advanced Kalman Filters**: Explore the use of Extended Kalman Filters (EKF) or Unscented Kalman Filters (UKF) for non-linear system dynamics to further enhance accuracy in complex environments.
2. **Incorporation of Machine Learning**: Combine the Kalman filter with machine learning algorithms to improve state estimation and adapt to varying noise levels and system uncertainties.
3. **Multi-Sensor Fusion**: Extend the framework to include additional sensors like cameras, radar, or ultrasonic sensors for improved perception and decision-making in unmanned vehicles.

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