Wheel Speed Estimation for Ground Vehicles Based on ABS Sensors Using Adaptive Moving Average Filter

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Abstract. This paper proposes a wheel speed estimator for ground vehicles, using Anti-lock Braking System (ABS) sensor. Wheel speed estimation using ABS sensors presents challenges due to the pulse-counting method, which causes noise levels to vary with changes in wheel speed. To address this issue, we developed an adaptive moving average filter (AMAF) that dynamically adjusts the window size in real time based on the wheel speed, improving noise suppression and estimation accuracy. Experimental results across various speeds demonstrate that the adaptive filter outperforms fixed-window approaches. With a data output rate exceeding 40 Hz, the algorithm is suitable for real-time automotive applications. These findings confirm the method's effectiveness for robust and precise wheel speed estimation under diverse driving conditions.

Keywords: Adaptive Moving Average, Adaptive Filtering Techniques, wheel Speed Sensor, ABS Sensor, Ground Vehicle.

1 Introduction

Accurate vehicle speed estimation is critical for autonomous driving, braking control, and overall vehicle safety. Various sensors, including Inertial Measurement Units (IMUs), GPS, and Anti-lock Braking System (ABS) sensors, have been investigated for this purpose. However, IMUs tend to suffer from drift over time, and GPS is prone to signal blockages and speed drift phenomena [1]. To address these issues, researchers have turned to wheel rotation-based speed estimation, which directly reflects the vehicle's movement.

Among these options, ABS sensors provide a distinct advantage by directly measuring wheel rotation, enabling more reliable speed estimation without the shortcomings of GPS or IMU systems. Previous studies have employed Kalman filters to process ABS sensor data [2], but these methods typically assume constant noise characteristics, which limits their performance. In real-world driving conditions, the presence of nonlinear and time-varying noise, as well as sudden signal changes, can reduce the effectiveness of such filters.

To address these challenges, this study proposes an Adaptive Moving Average Filter (AMAF) for accurate wheel speed estimation in ground vehicles. The algorithm is designed to process ABS sensor data effectively, reducing noise under different speed conditions while ensuring accuracy. The AMAF adapts dynamically, minimizing noise at high speeds and ensuring rapid convergence at low speeds, overcoming the limitations of traditional fixed-window approaches [3-5]. Additionally, an outlier removal mechanism enhances the reliability of the filtered signal. The performance of the proposed algorithm is further validated by experiments.

2 Working Principle of ABS Sensor & Signal Characteristic

Most modern vehicles are equipped with ABS sensors on wheels. The sensor consists of a magnet and a coil as shown in Fig. 1. As the gear attached to the wheel rotates, it causes changes in the surrounding magnetic field, generating a pulse-shaped voltage signal. Each cycle of the pulse wave is produced when the gear rotates by its pitch. Therefore, the wheel rotational speed ω and wheel travel speed V can be represented by the half of pitch θ as

$$\omega = \theta / T \tag{1}$$

$$V = d_1 / T \tag{2}$$

where T denotes the duration for the gear to rotate by θ. $d_1 = |r\theta|$ represents the travel distance of wheel per the half of pitch and r is the effective radius of the tire. However, calculating the wheel speed directly from the pulse can introduce noise, and the noise level may vary depending on the wheel speed.

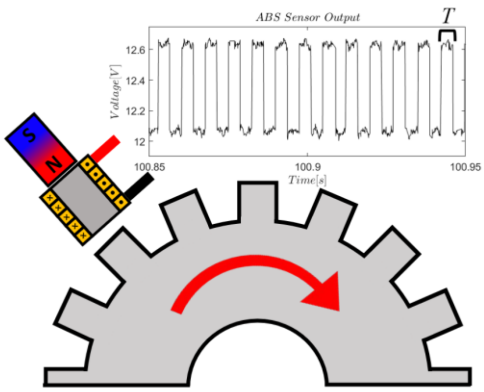

Fig. 1. ABS Sensor Schematic and Output Signal

3 Wheel Speed Estimator

Fig. 2 illustrates the overall schematic of the proposed wheel speed estimator based on the AMAF. First, the duration of pulses from each wheel's ABS sensor is stored using the First-In-First-Out (FIFO) method. Next, a moving average filter is applied to smooth the stored durations within a moving window. Outliers in the window are then removed, and the mean duration from all the ABS sensors is calculated. Finally, an exponential moving average filter is applied for further smoothing, and the wheel speed is computed using (1) and (2).

Both the delay and noise level of the estimates are significantly influenced by the window size of moving average filter. As vehicle speed increases, the frequency of pulses generated by the ABS sensor also rises. With shorter pulse intervals, small fluctuations or noise may occur more frequently. A larger window size incorporates more data, making the estimate less sensitive to transient noise or variations. By averaging over a larger number of samples, unnecessary noise is reduced, resulting in more stable estimates. However, a larger window size also introduces more delay. This trade-off between noise reduction and responsiveness must be carefully balanced to ensure accurate and timely wheel speed estimation.

Therefore, the window size N should be dynamically adjusted based on the vehicle's travel speed to maintain this balance. The window size can be updated according to the previous wheel speed estimate as

$$N(k+1) = d_2(k)/d_1 \tag{3}$$

$$d_2(k) = V(k)/f \tag{4}$$

where d_2 represents the travel distance during a single sampling interval of the filter, and f denotes the frequency of the filter. As seen in Equation (4), the window size is inversely proportional to the frequency of the filter. An effective approach to balance stable speed estimation and responsiveness is to filter using only the pulse intervals occurring within the sensor output cycle.

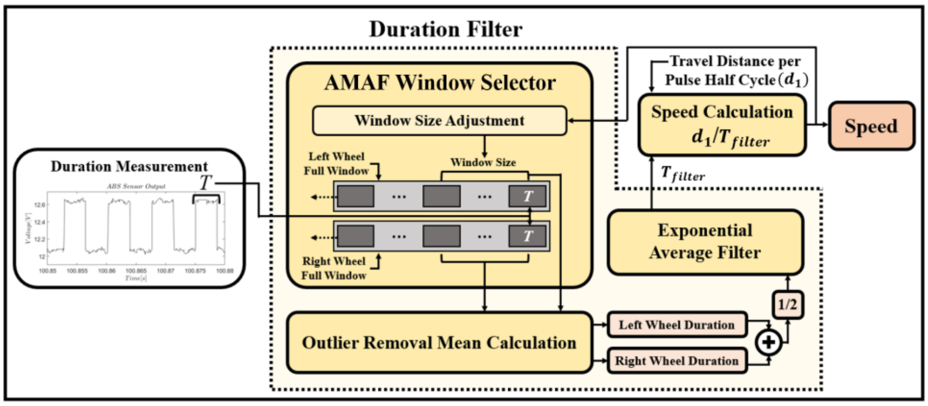

Fig. 2. Overview of Filtering Algorithm for Speed Estimation

4 Experimental Procedure & Results

The performance of the estimator is validated experimentally with the 12-inch wheel and ABS sensor with $\theta = 3.83°$. Both high and low speed experiments are conducted to evaluate the effectiveness of the adaptive window size. The estimator operates at a frequency of 40 Hz. The experimental results are further verified by comparing them with data obtained from a motion capture system. In this setup, eight reflective markers are tracked by motion capture cameras to calculate the wheel speed, as shown in Fig. 3.

Fig. 3. Experimental setup with motion capture system

Fig. 4 shows the speed estimation results at high-speed using fixed windows and adaptive windows. Smaller windows lead to large errors that cannot keep up with the speed profile because they are vulnerable to noise, as they are unable to average out the noise effectively. Whereas, According to Eq. (4), the size of adaptive window becomes 34 at 90 km/h. The adaptive algorithm and larger windows leverage the noise reduction capability of the moving average filter by averaging out sudden fluctuations or irregular values. This process reduces the influence of noise and emphasizes the actual trend of the data, resulting in more accurate outcomes.

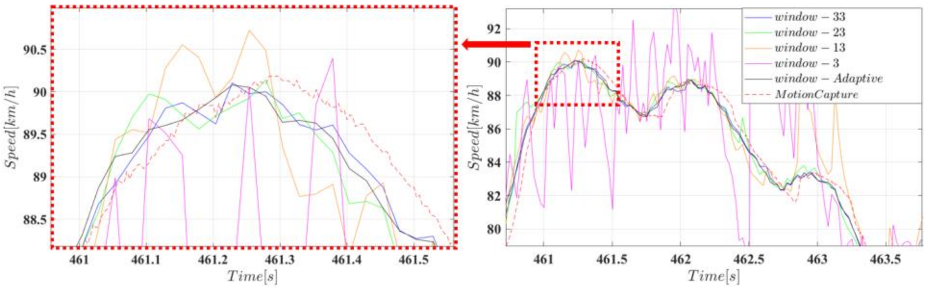

Fig. 4. Speed Estimation Results by the Number of Windows at High Speed

Fig. 5 illustrates that at low speeds, larger windows cause more delay, but the strategy of using fewer windows effectively minimizes this delay. The delay occurs because larger windows average over more past data, making the system slower to respond to changes. As a result, the moving average lags behind the actual speed profile, particularly in scenarios where rapid adjustments are needed. As a result, adopting a strategy of increasing the window size at high speeds and decreasing it at low speeds, speed estimation while ensuring a quick response to speed variations.

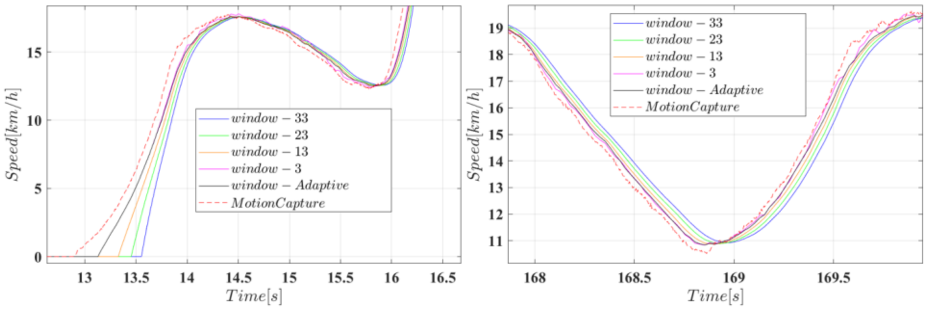

Fig. 5. Speed Estimation Results by the Number of Windows at Low Speed

5 Conclusions

In this study, we proposed a robust wheel speed estimation algorithm for ground vehicles using an AMAF applied to ABS sensor data. The adaptive nature of the filter allows the window size to dynamically adjust based on vehicle speed, effectively balancing noise suppression and responsiveness. Through both high- and low-speed experiments, we demonstrated that the AMAF outperforms traditional fixed-window approaches by minimizing estimation errors and improving stability. The experimental results, verified using a motion capture system, confirmed that the adaptive filter yields more accurate estimates at high speeds and reduces delay at low speeds by dynamically adjusting the window size.

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References

1. **Girbés-Juan, V., Armesto, L., Hernández-Ferrándiz, D., Dols, J.F., Sala, A.:** Asynchronous sensor fusion of GPS, IMU and CAN-based odometry for heavy-duty vehicles. *IEEE Transactions on Vehicular Technology* **70**(9), 8617–8626 (2021)
2. Liu, G., Zhang, Q., Wang, Y., & Zhou, T. An investigation of digital filter technology on ABS wheel speed signal. *Proceedings of the 2004 International Conference on Information Acquisition,* 151-154. (2004)
3. **Johnston, F., Boyland, J., Meadows, M., Shale, E. A.:** Some properties of a simple moving average when applied to forecasting a time series. *Journal of the Operational Research Society* **50**(12), 1267–1271 (1999)
4. Andrasto, T., Ristanto, R.D., Sukamta, S., Aufa, A., Hafidz, C.M., Sandyawan, B., Alfarisi, A.F.: Method EWMA (Exponentially Weighted Moving Average) as a Filter to Fine

and Remove Noise on Time Series Data. *IOP Conference Series: Earth and Environmental Science* 1203(1), 012012 (2023)

5. **Zhuang, Y., Chen, L., Wang, X.S., Lian, J.:** A weighted moving average-based approach for cleaning sensor data. In: *Proceedings of the 27th International Conference on Distributed Computing Systems (ICDCS '07),* pp. 38–38. IEEE, Toronto (2007)