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Proposal of Pedestrian Touch Vehicle Manipulation Control without Force Sensor for Low-speed Unmanned In-Wheel Motor EV

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Pedestrian Force Manipulation (PFM) allows low-speed electric vehicles (EVs) to stop via a light human touch, complementing conventional pedestrian recognition in unmanned driving. However, current PFM often causes unintended stops by misinterpreting external forces from road unevenness, gradients, and turning as pedestrian contact. To address this, we propose an improved PFM method that distinguishes these environmental forces from actual human contact, ensuring the EV stops exclusively when touched by a pedestrian, regardless of driving conditions.

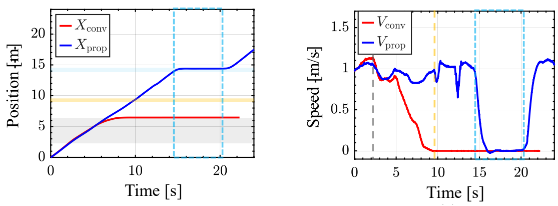
This study proposes a method that extracts and separates only the "pedestrian contact force" from the external forces acting on a low-speed EV without using external or force sensors, enabling safe stopping and restarting unaffected by environmental factors such as turning, gradients, and road surface unevenness.

The proposed external force separation method consists of the following five processes:

- **External Force Separation Filter Focusing on Frequency Characteristics** It utilizes the characteristic that the resistance force from gentle gradients and turning is dominated by extremely low-frequency components (close to direct current), while pedestrian contact force has higher-frequency components. By attenuating the low-frequency components using a high-pass filter, the effects of gradients and turning are removed, allowing only the pedestrian-induced force to pass through.
- **Dynamic Gradient Model Compensation** On road surfaces with significant gradient changes, frequency components in the same band as pedestrian contact occur, which cannot be completely removed by the filter alone. Therefore, the external force during gradient changes is calculated based on a vehicle model to perform feedforward compensation in advance.
- **Estimation of the Gradient Entry Period** Since the above model compensation involves integral calculations that accumulate errors (drift) over time, the application of the compensation is strictly limited to the "period when the front and rear wheels pass through the gradient." The entry timing is accurately identified by analyzing the specific suspension resonance generated when the wheels touch a change in the road surface.
- **Dynamic Determination of Restart Torque** The restart torque is not set as a fixed value but is instead optimized according to the actual gradient environment. By subtracting the already separated pedestrian contact force from the overall estimated external force, the gradient resistance is back-calculated. By adding a compensation force to offset this resistance, an appropriate restart torque is determined in response to the gradient change.
- **Road Surface Unevenness Separation via Control Switching** To deal with external forces originating from road surface unevenness that are difficult to model, such as speed bumps, the system switches from pedestrian-force-dependent control to "speed control" for only a brief moment when the unevenness is detected via suspension resonance.
- This prevents the large reaction force from the unevenness from being misrecognized as pedestrian contact.

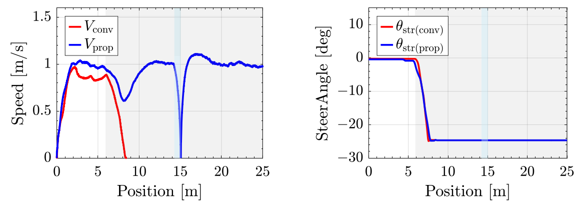
By combining these five elements, the system can separate running resistance and pedestrian contact force with high precision even in complex driving environments, preventing unintended stops while enabling reliable safety control.

Fig. 1 shows the results of an experiment in which the vehicle climbed a gradient and passed over road surface unevenness using both the proposed and conventional methods. The red and blue lines represent the conventional and proposed methods, respectively. The gray, orange, and light blue areas indicate the gradient change zone, the road surface unevenness contact position, and the pedestrian contact position, respectively. The results demonstrate that only the proposed method is unaffected by the gradient and road surface unevenness, stopping exclusively upon pedestrian contact.Fig. 2 shows the results of a turning experiment performed with the vehicle using the proposed and conventional methods. The gray area indicates the period during which the vehicle is turning. The results show that the proposed method is unaffected by turning resistance, stopping exclusively upon pedestrian contact.



(a) (b)

Fig. 1 Experimental result (slope & bump)



(a) (b)

Fig. 2 Experimental result (cornering)