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Integrating Automatic Arm Lifting Systems to Minimize Wire Broom Damage in Electric Road Sweepers

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Abstrak

Electric road sweepers sering mengalami kerusakan pada komponen sapu kawat akibat kesalahan pengoperasian manual, khususnya saat melewati rintangan seperti polisi tidur. Untuk mengatasinya, sistem pengangkat lengan otomatis dengan sensor jarak dikembangkan guna meningkatkan efisiensi serta memperpanjang umur sapu. Studi ini berfokus pada merancang *wiring*, menentukan jarak deteksi sensor optimal, dan menilai kemiringan sudut sensor untuk prototipe *electric road sweeper*. Pengujian fungsional menentukan bahwa Sensor A harus ditempatkan 60 cm dari sapu kawat dengan sudut kemiringan 42,2˚, jarak 2936 mm ke tanah, dan 2800 mm ke objek untuk perintah pengangkatan. Untuk Sensor B, perintah penurunan memerlukan sudut kemiringan 49,4˚, jarak 20 cm dari sapu kawat, 2692 mm ke tanah, dan 2200 mm ke objek. Pengaturan ini memastikan sistem dapat mengangkat lengan penyapu secara efektif melewati rintangan, meningkatkan efisiensi dan daya tahan. Temuan ini menunjukkan potensi teknologi sensor canggih untuk memperbaiki peralatan pembersih perkotaan dan mendukung praktik pemeliharaan kota berkelanjutan.

Kata kunci: *electric road sweeper; sensor jarak; polisi tidur; kerusakan sapu kawat*

Abstract

Electric road sweepers often face damage to wire broom components due to manual operation errors, particularly when navigating obstacles like speed bumps. To mitigate this, an automatic arm lifting system using proximity sensors was developed to enhance efficiency and extend broom lifespan. This study focused on designing the wiring, determining optimal sensor detection distances, and assessing sensor angle inclinations for an electric road sweeper prototype. Functional testing determined that Sensor A should be placed 60 cm from the wire broom with a tilt angle of 42.2˚, a distance of 2936 mm to the ground, and 2800 mm to the object for lifting commands. For Sensor B, the lowering command requires a tilt angle of 49.4˚, a distance of 20 cm from the wire broom, 2692 mm to the ground, and 2200 mm to the object. These settings ensure the system effectively lifts the sweeper arm over obstacles, enhancing both efficiency and durability. The findings demonstrate the potential for advanced sensor technology to improve urban cleaning equipment and support sustainable city maintenance practices.

Keywords: *electric road sweeper; proximity sensor; speed bump; wire broom damage*

1. Introduction

Electric road sweepers play a crucial role in maintaining urban cleanliness by efficiently removing debris from streets [1]. However, these machines often face significant challenges that compromise their performance and longevity [2]. One of the primary issues is the damage to wire broom components caused by manual operation errors, particularly when navigating obstacles such as speed bumps. This frequent damage not only leads to increased maintenance costs but also reduces the operational efficiency of the sweepers, necessitating a solution that can mitigate these issues.

Over the years, various approaches have been attempted to solve this problem. Initial solutions involved manual control adjustments and operator training to enhance maneuverability and avoid obstacles. However, these methods proved insufficient as they relied heavily on the operator’s skill and attention, which can vary significantly. More advanced attempts included the integration of basic mechanical systems to lift the sweeping arm, but these lacked the precision and adaptability required to handle diverse urban environments effectively [3].

Recent advancements have introduced more sophisticated technologies to address the limitations of earlier methods. Automation and sensor-based systems have become increasingly popular, with researchers exploring different types of sensors such as ultrasonic [4–6], infrared [7–9], and laser-based detectors [10] to enhance the accuracy and reliability of obstacle detection. These systems aim to provide a more automated solution, reducing the dependency on manual intervention and improving the overall functionality of the sweepers [11].

Despite these advancements, several aspects have escaped the attention of previous researchers. Most existing studies have focused on single sensor types or basic integration without optimizing sensor placement and settings for maximum efficiency. Additionally, there has been limited exploration into the combined use of multiple sensors to create a more robust and adaptable system. The potential for optimizing sensor angles and distances to improve detection accuracy and system responsiveness remains largely unexplored.

This study aims to address these gaps by developing an automatic arm lifting system using proximity sensors, focusing on the optimal configuration for sensor placement and settings. By conducting thorough functional and laser detection system testing, this research seeks to determine the most effective distances and angles for sensor operation. The goal is to enhance the precision of obstacle detection and ensure reliable lifting of the sweeper arm, thereby improving the efficiency and durability of electric road sweepers.

2. Material and method

This study begins with a literature study to find out the theoretical aspects and latest developments in the use of proximity sensors in electric sweepers, followed by the design, production and testing processes. All processes carried out in Vocational School, Universitas Gadjah Mada, Yogyakarta Indonesia. This study is outlined in the flowchart illustrated in Figure 1.

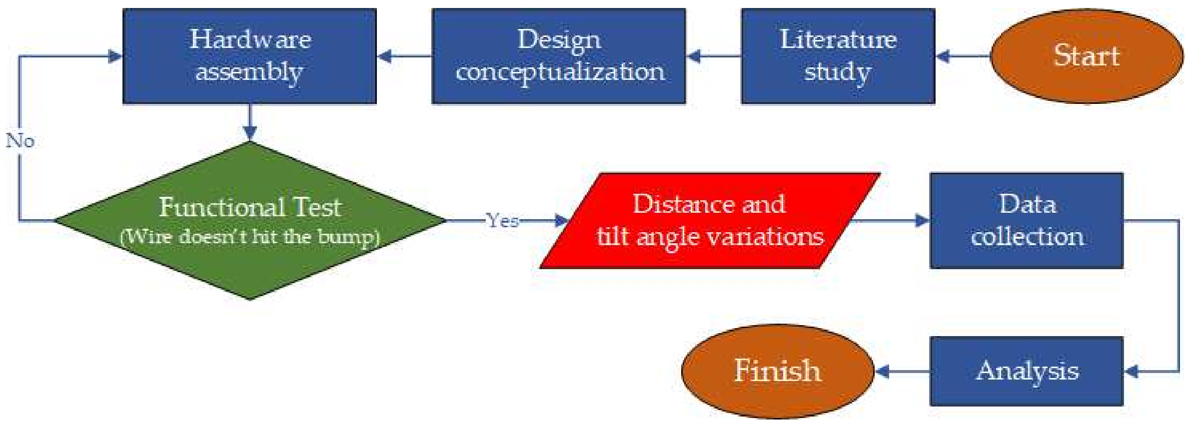

Figure 1. Flowchart of this current study

2.1. Design and assembly

Design conceptualization was conducted by designing a system block diagram to develop an automatic arm lifting system. This block diagram represents the interaction between components and visualizes the underlying control process of the system. The block diagram of the automatic arm lifting system can be seen in Figure 2.

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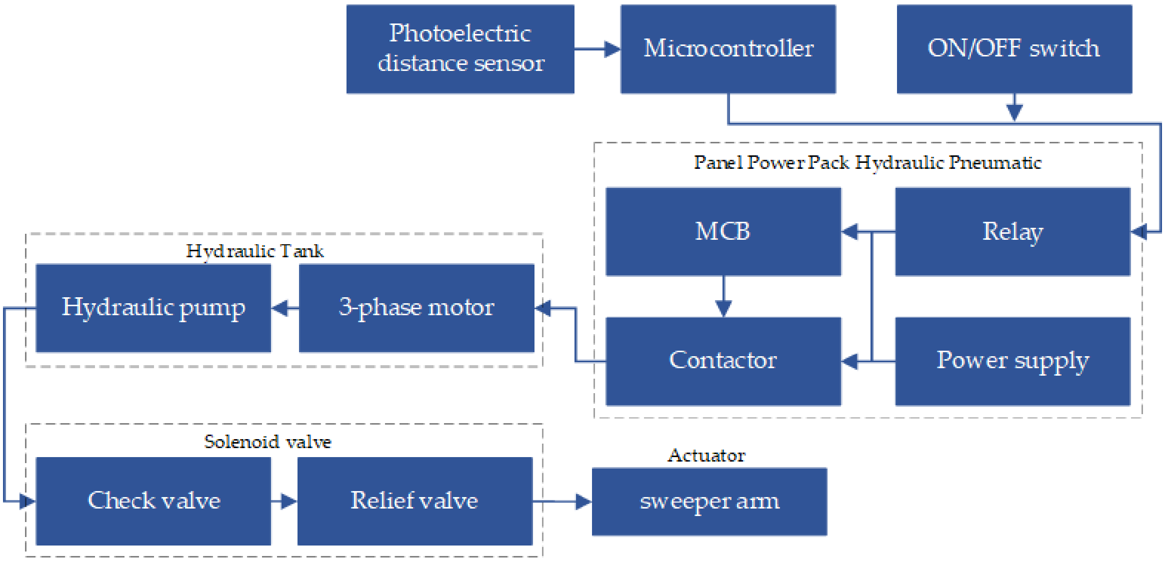

Figure 2. Block diagram of automatic arm lifting system

The block diagram system in Figure 2 illustrates that when the switch is in the ON position, the sensor detects an object and forwards the data to the receiver. Subsequently, the conversion of physical quantities into electrical quantities is performed by the transducer (microcontroller). Then, the signal data is transmitted to the pneumatic hydraulic powerpack panel via a relay. The relay will activate the contactor which, upon receiving current and voltage supply from the turned-on MCB, will drive the three-phase motor to pump hydraulic oil from the tank to the solenoid valve. Afterwards, the solenoid valve acts as a flow control valve directing the hydraulic oil flow towards the actuator as the output.

2.2. *Sensor optimization testing*

Photoelectric distance sensor type IFM O1D100 was used in this study because of its sensitivity [12]. The sensor was installed at the top of the car facing the object with the appropriate angle setting shown in Figure 3.

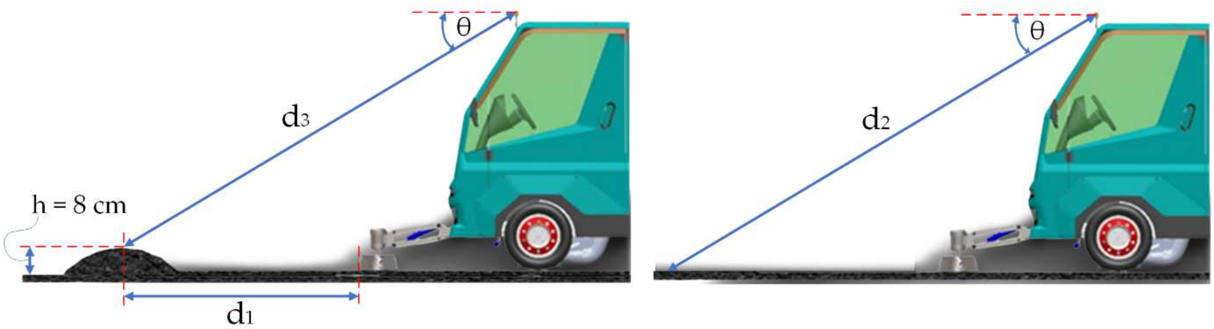

Figure 3. Proximity sensor test scheme

Figure 3 shows a scheme for testing the optimal distance and angle that will be used as proximity sensor input. The distance between the wire broom and laser detection point / speed bump (d1) is varied from the furthest 140 cm to the closest every 20 cm until failure (the lifting arm response is too late so the wire broom hits the speed bump). The speed bump height (h) used in this study is 8 cm, which is the standard speed bump height according to the regulation of the

Indonesian Minister of Transportation (Permenhub No PM 14, year 2021). The distance of the sensor to the road surface (d2) and the sensor to the speed bump (d3) for each variation were measured.

3. Result and Discussion

The mechatronic system for the automatic arm lifting system was assembled as shown in Figure 4. The figure illustrates the placement of two photoelectric distance sensors, type IFM OID100, with Sensor A and Sensor B positioned at the front upper section of the sweeper vehicle. Sensor A functions to issue lifting commands, while Sensor B is used for lowering commands. These sensors are connected to the sweeper arm located at the bottom front of the vehicle, just above the wire broom, which is operated by a rotating motor with a modified planetary transmission as a speed reducer [13].

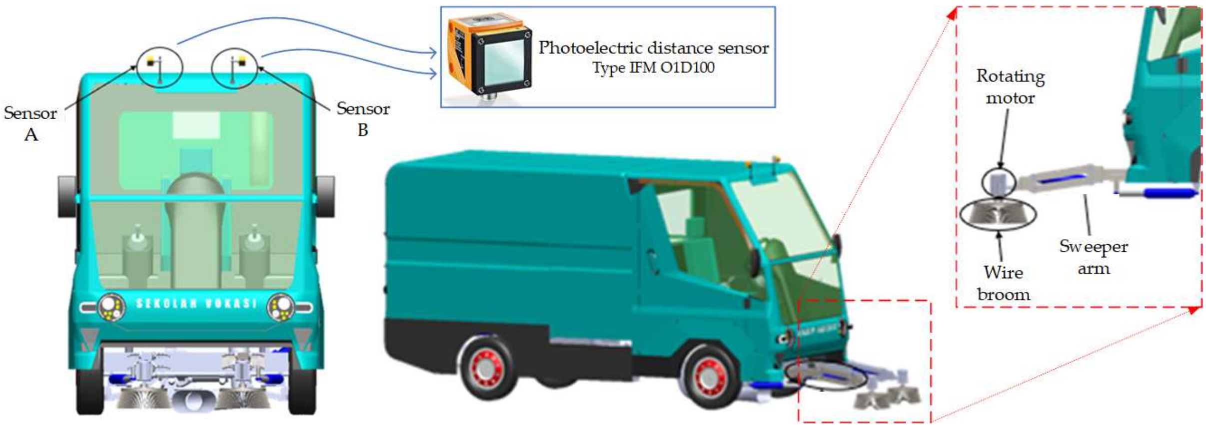

Figure 4. Automatic arm lifting system in electric road sweeper

The wiring diagram shown in Figure 5 illustrates the electrical connections, starting from the power supply routed through a Miniature Circuit Breaker (MCB) for protection, proceeding to contactors and a switch which serve as control points. The system's core is a Programmable Logic Controller (PLC) within the PANEL PP PLC, interfacing with relays (Relay A and Relay B) that process signals from Sensors A and B.

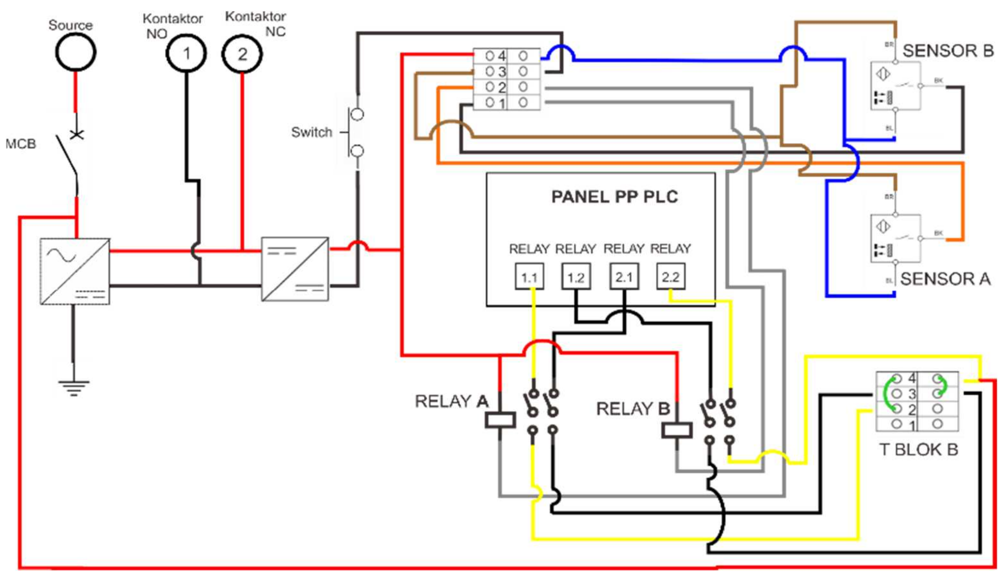

Figure 5. Wiring diagram of automatic arm lifting system

When the switch is turned ON, the power supply converts the voltage from AC to DC and then distributes it to the sensors and relays. Sensors A and B emit laser beams that are reflected back by the detected object and received by the receiver, with the reflection time proportional to the object's distance. The received laser is converted into an electrical signal by the transducer and processed by the microcontroller. The Arduino sends signals to relays A and B to activate or deactivate the data sent to the relays in the powerpack panel.

The data received by the relays in the powerpack panel will activate or deactivate the PLC system. The PLC system monitors the input data from the sensors and processes it to control the solenoid valve in the hydraulic system. Relays 1.1 and 2.1 send commands to lower the hydraulic arm of the sweeper, while relays 1.2 and 2.2 send commands to raise the hydraulic arm of the sweeper.

The test results for setting the tilt angle and proximity sensor A distance are shown in Table 1. The distance was initially set at a relatively far 140 cm with a tilt angle of 32.5˚, where the automatic arm lifting system successfully lifted the wire broom over the speed bump. The distance was then gradually reduced by 20 cm increments. However, at a distance of 40 cm with a tilt angle of 45.3˚, the timing of the wire broom lift was inaccurate, causing it to hit the speed bump.

Table 1. Wire broom avoidance of speed bumps at various sensor A angles

No.	d1 (cm)	θ (degrees)	d2 (mm)	d3 (mm)	Wire broom to speed bump
1	140	32.5˚	3588	3463	Delay; Hit
2	120	34.5˚	3418	3300	Delay; Hit
3	100	36.7˚	3265	3155	Delay; Hit
4	80	39.2˚	3044	2965	Delay; Hit
5	60	42.2˚	2936	2800	Pass
6	40	45.3˚	2820	2775	Haste; Hit

θ = tilt angle

d1 = Distance of laser detection point (speed bump) to wire broom

d2 = Distance of sensor to the road surface

d3 = Distance of sensor to the speed bump

Sensor B functions as the input provider for the command to lower the sweeper arm. The optimal distance setting for Sensor B was determined as follows: the distance between the wire broom and the laser detection point is 20 cm, the object height (t) is 88.5 cm, the distance from the laser detection point to the ground surface is 2692 mm, the distance from the laser detection point to the object is 2200 mm, and the tilt angle is 49.4˚, as illustrated in Figure 6.

This distance setting proved to be the most effective. During trials with different distance settings and tilt angles, the laser detection point on the object was found to be in the middle of the BLDC motor (which has perforated cover). This indicates that the laser could not detect the object properly, and as a result, the sensor could not provide the feedback signal needed to command the sweeper arm to lower. Therefore, these alternative distance settings and tilt angles were either inaccurate or unsuitable.

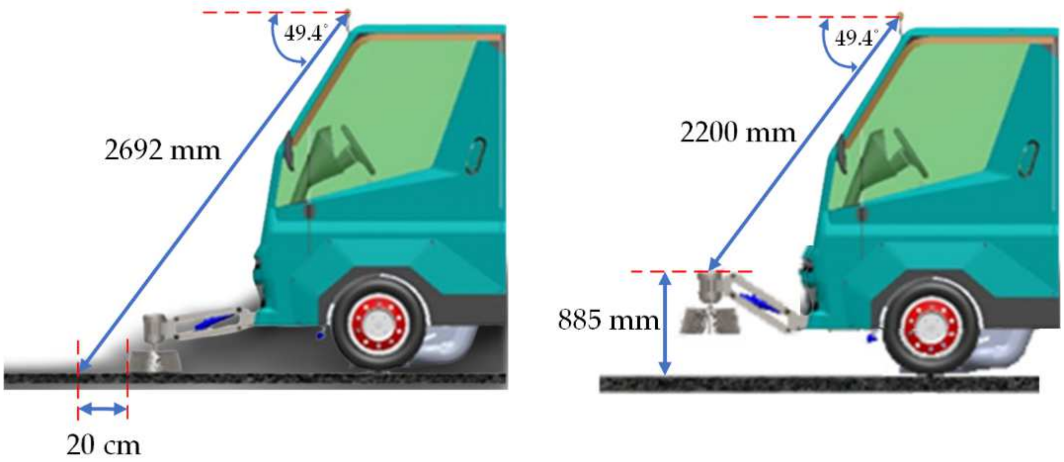

Figure 6. Best setting for sensor B

The use of photoelectric distance sensors in road sweepers has been shown to significantly enhance the efficiency and longevity of cleaning components, such as the wire broom. According to Amato et al. (2010), the optimization of sensor technologies in street cleaning vehicles can lead to an improved detection of road conditions, thereby enabling precise adjustments that minimize wear and tear. Their findings reveal that accurate sensing directly impacts the operational effectiveness of the cleaning mechanisms, mitigating the risk of unnecessary friction and damage. This supports the application of photoelectric distance sensors in the automatic arm lifting system, as their precision and reliability ensure that the sweeper arm engages with the road surface only when needed, thereby extending the wire broom's lifespan and reducing maintenance costs. The adoption of such advanced sensor technology aligns well with the overarching goals of enhancing operational efficiency and sustainability in urban road maintenance [14].

Complementing this, Koyama et al. (2018) developed a high-speed, high-precision proximity sensor capable of detecting tilt, distance, and contact. The sensor described by Koyama et al. demonstrates significant advancements in measurement accuracy and speed, with a peak-to-peak distance error less than 31 μm and a measurement time under 1 ms. Such capabilities are crucial for real-time adjustments in dynamic environments, making these sensors highly suitable for application in road sweepers. The sensor's robust contact detection, which is independent of the target object's reflectance, tilt angle, or surface shape, further underscores its practicality for ensuring the sweeper arm's optimal engagement with the road surface. By integrating these advanced sensors, road sweepers can achieve higher precision in arm positioning, ultimately enhancing the cleaning efficiency and extending the lifespan of cleaning components [15].

4. Conclusion

The automatic arm lifting system of the electric road sweeper was successfully developed and functions according to requirements. The distance between the wire broom and the laser sensor detection point influences the laser detection reading, which in turn affects the system's command response for lifting the sweeper arm. The optimal proximity sensor settings for the automatic arm lifting system are as follows: for Sensor A (lift command), a tilt angle of 42.2˚, a distance of 60 cm between the wire broom and the laser detection point, a distance of 2936 mm from the laser detection point to the ground, and a distance of 2800 mm from the laser detection point to the object. For Sensor B (lowering command), a tilt angle of 49.4˚, a distance of 20 cm between the wire broom and the laser detection point, a distance of 2692 mm from the laser detection point to the ground, and a distance of 2200 mm from the laser detection point to the object. The implementation of the automatic arm lifting system significantly reduces manual intervention, enhancing safety and productivity in road cleaning operations while minimizing equipment and environmental damage. This advancement can lead to cost savings in maintenance owing to increased reliability and a longer lifespan of the equipment. Future studies could explore the integration of machine learning algorithms to improve system adaptability across various environmental conditions, along with real-time data analytics for ongoing sensor calibration enhancements. Additionally, connecting this technology with smart city infrastructure could further elevate urban cleaning efficiency.

However, limitations exist in the study. Repeated testing to determine the success rate at the selected distance and tilt angle was not conducted; the variation of input data led to a single successful point, resulting in the assumption of a 100% success rate. Additionally, the study did not account for potential environmental variables such as lighting conditions or unexpected obstructions, which could affect sensor reliability and accuracy.

Daftar Pustaka

[1] Ye J, Pan J, Ai H, Wang J. Pure Electric Sweeper Performance Analysis and Test Verification of Dust Extraction Port. Appl Sci. 2022;12(10).

[2] Yim S, Kim W. Rollover prevention control for autonomous electric road sweeper. Electron. 2021;10(22).

[3] Ragazzi M, Zuccato C, Schiavon M, Rada EC. Overview and possible approach to street sweeping criticalities. Energy Reports. 2023;9(February):117–24.

[4] Alika R, Mellouli EM, Tissir EH. Adaptive Cruise Control of the Autonomous Vehicle Based on Sliding Mode Controller Using Arduino and Ultrasonic Sensor. J Robot Control. 2024;5(1):301–11.

[5] Adnan Yusuf S, Khan A, Souissi R. Vehicle-to-everything (V2X) in the autonomous vehicles domain – A technical review of communication, sensor, and AI technologies for road user safety. Transp Res Interdiscip Perspect. 2024;23(July 2023):100980.

[6] Beycimen S, Ignatyev D, Zolotas A. A comprehensive survey of unmanned ground vehicle terrain traversability for unstructured environments and sensor technology insights. Eng Sci Technol an Int J. 2023;47:101457.

[7] Choi JD, Kim MY. A sensor fusion system with thermal infrared camera and LiDAR for autonomous vehicles and deep learning based object detection. ICT Express. 2023;9(2):222–7.

[8] Peruffo M, Caon A, Branz F, Francesconi A. Test characterization of infrared phototransistors-based sensors for close-proximity operations. Acta Astronaut. 2024;220(April):173–84.

[9] Segovia Ramírez I, Parra Chaparro JR, García Márquez FP. Unmanned aerial vehicle integrated real time kinematic in infrared inspection of photovoltaic panels. Meas J Int Meas Confed. 2022;188.

[10] Zeng Y, Núñez A, Li Z. Measuring transfer functions of track structures in a test rig with laser Doppler vibrometer and accelerometers on a moving vehicle. Mech Syst Signal Process. 2024;214(April).

[11] Jamil S, Mukhtar T, Ali RH, Qaiser I, Ahmed B. Design and Development of an Electric Remote-Controlled Road-Sweeper Vehicle †. Eng Proc. 2022;12(1).

[12] Gromke C, Ruck B. Vehicle-induced aerodynamic lateral loads on cyclists in overtaking maneuvers - Field measurements and universal model description. J Wind Eng Ind Aerodyn. 2023;243(November).

[13] Munahar S, Purnomo BC, Köten H. Fuel Control Systems for Planetary Transmission Vehicles: A Contribution to the LPG-fueled Vehicles Community. Mech Eng Soc Ind. 2021;1(1):14–21.

[14] Amato F, Querol X, Johansson C, Nagl C, Alastuey A. A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods. Vol. 408, Science of the Total Environment. 2010. p. 3070–

84.

[15] Koyama K, Shimojo M, Senoo T, Ishikawa M. High-Speed High-Precision Proximity Sensor for Detection of Tilt, Distance, and Contact. IEEE Robot Autom Lett. 2018 Oct 1;3(4):3224–31.