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Autonomous Precision Docking of Container Truck*

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***Abstract*— Incorporating smart ports for logistics efficiency is a trend in developed nations, prompting similar endeavors in emerging markets like Indonesia. Manual docking of container trucks in docking stations is challenging and time-consuming, requiring skilled operators. This project aims to realize an autonomous precision docking system to enhance efficiency and accuracy. The container truck utilizes hydraulic-based motors, with electric signals coordinating propulsion, steering, braking, and lifting. A cabin-based drive-by-wire controller integrated with sensors and electrical circuits, to inject signaling into existing actuators, enable autonomous monitoring and control. Trials showcase accurate and precise dockings, aiming to alleviate logistic distribution challenges, enhancing Indonesia's maritime industry.**

I. INTRODUCTION

The continuous growth in shipping volume, both internationally and domestically, poses a persistent challenge of potential logistic congestion at ports. Recognizing this, many developed nations have embraced smart port technologies to enhance operational efficiency [1]. Indonesia, with its extensive archipelago, is a promising market for such advancements [2]. However, there is a noticeable lag in adopting these technologies, representing a missed opportunity.

Docking stations streamline container loadings and unloadings, facilitating unsynchronized operations between cranes and trucks. However, the manual docking of container trucks, a focal point of this project, demands highly skilled operators, presenting challenges and time constraints. Additionally, human errors in these operations pose risks to personnel safety, equipment damage, and increased operational costs [3][4]. This project aims to automate container truck docking operations, ensuring precision, efficiency, and safety. The modified container truck, capable of autonomous operation, is detailed in Fig. 1, with the project focused on the Teluk Lamong Terminal in Indonesia.

This paper is structured as follows: Section I provides an introduction, offering insight into the project's background motivation. Section II outlines key project actions to achieve desired outcomes, while Section III presents results of the developed autonomous precision docking system. Section IV concludes the paper.

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Fig. 1. The container truck utilized in the development of autonomous precision docking.

II. PROBLEM AND METHOD

A. Autonomous Control

The container truck's autonomous operation relies on hydraulic-based motors coordinated by electrical signals for propulsion, steering, braking, and lifting. To achieve autonomy, the project incorporates electrical circuits providing signals to actuator's electronic control units (ECUs). Real-time feedback from sensors, including tachometers, absolute encoders, valve position indicators, and laser distance sensors, ensures precise control. The drive-by-wire controller, featured in Fig. 2, integrates circuits and sensors for autonomous monitoring and control.

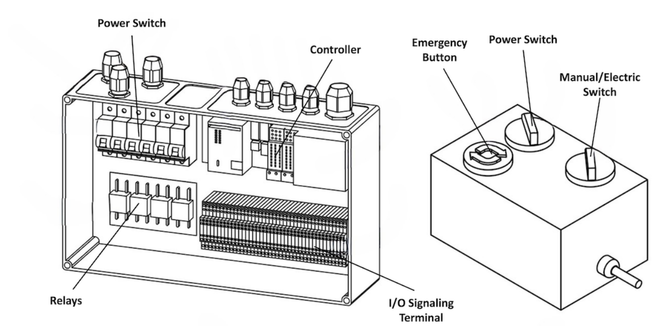

Fig. 2. Illustration of a drive-by-wire controller module, featuring relays, I/O signaling terminal, manual/electric switch, power switch, and emergency button.

The precision docking algorithm, detailed in [5], involves two stages: point stabilization and orientation control. These stages ensure the truck aligns with the docking pillar and achieves precise docking into the slot. Control laws are designed with the Lyapunov stability theorem in mind, to preserve nonlinearity and provide robustness to the system.

B. Localization

Localization sensors, crucial for autonomous mobile robot control, combine GNSS-Encoders fusion and 2D LiDAR for enhanced accuracy [6]. The fusion technique integrates a nonlinear observer for estimating the state of the nonlinear system and an unscented Kalman filter, a stochastic approach designed to handle Gaussian noises on signals (NLO-UKF). This integration leverages the strengths and weaknesses of both GNSS and absolute encoders. While GNSS offers high measurement accuracy, its availability is limited. On the other hand, encoders provide a frequent data flow but are susceptible to disturbances.

The LiDAR, vital for precise docking, estimates the vehicle's pose relative to previously mapped environments. Challenges arise from varying vehicle heights during lifting operations (see Fig. 3), causing inaccuracies in LiDAR measurements. To address this, the environment is remapped and reference points are identified for precise control in three lifting modes: middle (normal operation), high (container retrieval), and low (container placement).

Fig. 3. The LiDAR position on the container truck and its height variability caused by lifting operations.

III. RESULTS

Numerous trials conducted at Teluk Lamong Terminal attest to the precision and accuracy achieved by the automated container truck docking system. The system consistently demonstrated an impressive accuracy level of approximately ± 5 cm throughout various stages of the trials completed each trial in less than 2 minutes of operations.

An example of the trial results for container retrieval is illustrated in Fig 4, providing a visual representation of the automated docking process.

These results underscore the effectiveness of the developed system in addressing the challenges and time constraints during the docking of container truck. The achievement of consistent precision and accuracy marks a significant milestone in enhancing operational efficiency and safety during container loadings and unloadings at docking stations.

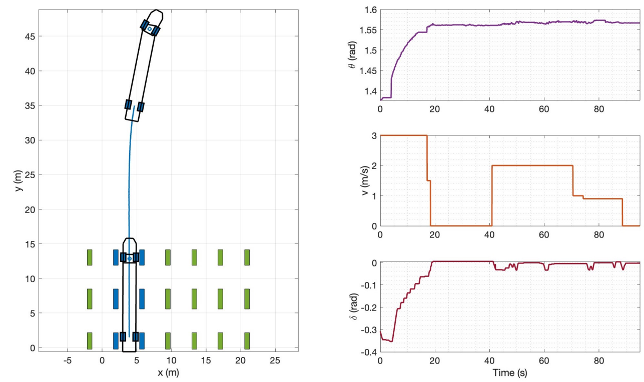

Fig. 4. Results from autonomous precision docking trials during container retrieval.

IV. CONCLUSION

This project aims to alleviate congestion and enhance logistic distribution efficiency in Indonesian ports by automating container truck docking operations. The developed algorithm, electrical modifications, and sensor integration have proven successful. Challenges in localization due to varying vehicle heights were addressed through remapping. The trials at Teluk Lamong Terminal showcase the effectiveness of the system, in hope for paving the way for broader implementation of smart port technologies in Indonesia. Future work includes refining localization robustness, minimizing the computational cost of environment mappings, extending the system to other vehicles, and optimizing cost-effective deployments.

REFERENCES

[1] K.-L. A. Yau, S. Peng, J. Qadir, Y.-C. Low, and M. H. Ling, "Towards smart port infrastructures: Enhancing port activities using information and communications technology," *IEEE Access*, vol. 8, pp. 83 387–83 404, 2020.

[2] N. Tu, D. Adiputranto, X. Fu, and Z.-C. Li, "Shipping network design in a growth market: The case of indonesia," *Transportation Research Part E: Logistics and Transportation Review*, vol. 117, pp. 108–125, 2018, special Issue on China's Belt and Road Initiative. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1366554517300674

[3] T. R. J. Maria and L. Liudmila, "Human errors: their psychophysical bases and the proprioceptive diagnosis of temperament and character (dp-tc) as a tool for measuring," *Psychology in Russia: State of the art*, vol. 7, no. 2, pp. 48–63, 2014.

[4] R. J. Sanchez, J. Hoffmann, A. Micco, G. V. Pizzolitto, M. Sgut, and G. Wilmsmeier, "Port efficiency and international trade: port efficiency as a determinant of maritime transport costs," *Maritime economics & logistics*, vol. 5, pp. 199–218, 2003.

[5] A. Widyotriatmo, I. A. Kuncara, H. Amri, A. Hasan, and Y. Y. Nazaruddin, "Leveraging digital twin for autonomous docking of a container truck with stabilization control," *Journal of Field Robotics*. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/rob.22283

[6] I. Kuncara, A. Widyotriatmo, A. Hasan, and Y. Nazaruddin, "Enhancing accuracy in field mobile robot state estimation with gnss and encoders," [Preprint]. Available at SSRN: https://ssrn.com/abstract=4646875 or http://dx.doi.org/10.2139/ssrn.4646875.