Design and development of a skid-steering robot for agricultural environment

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***Abstract*—As the demand for advanced technology solutions in agriculture increases due to challenges like labor shortages, the need for efficient resource utilization, and the quest for sustainable practices, the role of robotics has emerged as a possible solution to these issues. In response to this growing demand, we present the design, development, and validation of a skid-steering robot specifically built for agricultural tasks. This novel robot leverages the design choice of multiple outdoor robots, addressing the need for autonomous navigation in heterogeneous terrains and weather conditions, as well as large-scale data acquisition for machine learning applications. Our design has been tested in a virtual environment before implementing it in real-world settings, leading to the realization of a robust and efficient system able to navigate rough terrains in challenging conditions.**

***Index Terms*—agricultural robotics, skid steering, robot design**

Fig. 1. Image of the developed robot navigating a crop field.

I. Introduction

The agricultural sector, burdened by labor shortages, a growing population, and an increasing need for efficient resource utilization, is witnessing a seismic shift toward automation and robotics. Recent years have shown a fast-growing interest in agricultural robotics with significant investments from both industry and academia [1], driven by the potential to increase farm productivity through real-time monitoring and automated tasks drastically.

This paper focuses on the design, development, and validation of a skid-steering robot specifically built for agricultural terrains. Given the variable nature of agricultural fields, a traditional logistic robot's application falls short. Fields present narrow sections, limited visibility, and significantly challenging areas, requiring an autonomous system capable of navigating these rough terrains in different weather conditions daily. Addressing these challenges, we have developed an autonomous skid-steering robot. This machine's primary purpose is autonomous navigation and monitoring due to the small size of the system. It is then equipped with a full set of sensors able to perceive the environment, process the acquired data and plan the vehicle trajectory accordingly while monitoring the status of the plants.

The development process was guided by a simulation-driven approach, facilitating the identification of potential issues, fine-tuning of algorithms, and optimization of the robot's performance prior to deployment. Particular focus was posed on the modeling of the skid-steering system and the constraints that such cinematic has to obey to navigate rough terrains effectively. Following the initial simulation, comprehensive validation was carried out using the physical robot under real-world conditions, replicating diverse environments to test its performance thoroughly. This paper thus presents an in-depth analysis of our methodology, the challenges encountered, and the solutions implemented in our quest to create a robot capable of autonomous navigation and large-scale data acquisition. The outcome is a skid-steering robot that serves as an efficient tool for navigating difficult off-road terrains typical of agricultural environments and sensing the environment for tasks such as object recognition and autonomous navigation.

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II. Robot Design

The goal of the designed robot is to perform diverse tasks in an agricultural field, specifically a maize field. The critical parameters of this scenario include plant height ($0.3m$ - $0.4m$), row-to-row spacing of $0.75m$, and predominantly flat but well-drained terrain with minor irregularities. The robot is designed to have autonomous navigation capabilities, precisely moving between maize rows without inflicting damage, detecting obstacles, and identifying various objects. Additionally, it should provide flexibility by facilitating the attachment of different tools like additional and specialized cameras, small robotics arms, and spraying systems to enhance task diversity.

The locomotion and cinematic of the robot, shown in Fig. 1, have been chosen after an accurate analysis of the state of the art [2] and taking into account the operating environment. For simplicity and adaptability, a wheeled system was chosen, as opposed to legged robots. Several factors influenced the design decisions, such as field dimensions, terrain requirements, power distribution, and stability. The selected design consists of a robot with a $0.4m$ width, in-hub motorized wheels for even power distribution, and a four-wheel design to enhance weight distribution and ground contact area. These decisions ensure greater stability and reduce the likelihood of rollover due to irregular terrain.

The robot incorporates a bevel gear suspension system, enabling smooth movement and facilitating cleaner data acquisition from onboard sensors by minimizing terrain-induced vibrations. This suspension system allows for the replication of movement from one side of the robot to the opposite side, thereby evenly distributing torque and smoothing out the effects of terrain irregularities. Moreover, a skid-steering mechanism was implemented for the robot's steering, maintaining a low complexity in construction [3] and the overall strength of the system. The direct kinematics of this robot remain similar to a differential drive [4], where the primary difference lies in the baseline, which depends on wheel slippage rather than the actual distance between the wheels. These particular design choices enable the robot's effective operation within the agricultural environment, demonstrating the potential to handle various tasks efficiently and effectively.

III. Experimental validation

The validation of the robot design was first performed in a simulated environment to identify the perfect setup and sensor suite for the robot and then in the real world to address the sim-to-real gap.

In evaluating the performance of the skid-steering robot, the initial validation test focused on its steering capability, specifically its ability to turn in place. We observed that this ability is linked to the wheelbase dimension. Various experiments were then conducted within a uniform, flat environment to assess this behavior. The wheel separation, i.e., the distance between the left and right wheels, was kept constant during these tests, while the wheelbase (i.e., the distance between the front and rear axles of the robot) was changed. Three robot models were tested, with a wheelbase of $0.15m$, $0.32m$, and $0.41m$. The results clearly highlighted how the robot's turning capability is significantly impacted by the wheelbase size. A larger wheelbase resulted in a diminished capacity for the robot to turn in place. We therefore opted for a trade-off between the short wheelbase, which increased the turning capabilities, and a higher one, which guarantees better stability of the robot, particularly the final design of the robot has a wheelbase of $0.32m$.

Next, a series of validation tests were conducted on the robot's suspension mechanism, both in simulation and in real-world environments. In each case, the robot traversed a flat terrain with a bump, designed such that only the right front and rear wheels encountered the bump. The robot's pitch angle profile served as the primary evaluation metric for the analysis. Each environment was subjected to two tests: one with an active suspension mechanism, the other with the suspension blocked, simulating a scenario without the suspension system. Simulation results indicated a peak-to-peak pitch angle of $12.33°$ for the active suspension, and $25.61°$ when immobilized, marking an improvement of 51.8% with the suspension system. Real-world testing yielded consistent findings with values of $18.63°$ with the suspensions enabled

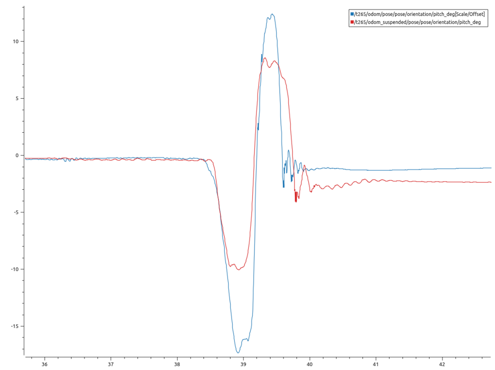

Fig. 2. Pitch profile comparison in the real environment obtained with suspension blocked (red line) and with suspension activate (blue line).

TABLE I
RMSE error of the T265 and wheels encoder with respect to the Optitrack trajectory

	RMSE
Encoder odometry	2.432022
T265 odometry	0.596588

and $29.76°$ with immobilized suspensions, translating to a 38.4% improvement, as shown in Fig. 2.

The final component required to perform autonomous navigation is a source for the robot's odometry. Traditionally this is computed using wheel encoders. But, due to the high slippage of the wheel in the rough terrains and the employed cinematic, which accentuates this behavior, we introduced an additional sensor, a visual odometry camera (i.e., Intel T265). To evaluate the two systems, we recorded both the odometry from the encoders and the one by the camera and compared them with the one returned by a high-accuracy motion capture system. To evaluate them, we computed the Absolute Position Error (APE) between trajectories. The Root Mean Squared Error (RMSE) for the APE is reported in Table I, which highlights the need for an external odometry source, like the T265 camera, to compensate for the high error of the encoders-based odometry in a skid-steering robot.

IV. Conclusions

In this work, we presented the design and development process of a small agricultural robot for autonomous navigation and monitoring of crop fields. The design choices were first tested and validated in simulation and then in the real field, bridging the gap between simulation and the real world.

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