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Determination of the durability of a mobile agriculture platform through finite element analysis

Abstract – The objective of this work was to determine the robustness of a mobile agriculture platform for image capturing in different displacement conditions. Robustness was assessed using the finite element analysis method. The software ANSYS 2022 R2 and SolidWorks 2022 were used to analyze the stress and deformation of the structure in three different scenarios. The results were compared with those of the current literature. The highest stress estimated were 32.774 MPa by ANSYS and 31.550 MPa by SolidWorks. The total estimated deformations were 1.6767 mm by ANSYS and 3.452 mm by SolidWorks. These results indicate that the proposed platform is robust under the studied scenarios.

Index terms: agricultural technology, digital agriculture, farming systems.

Determinação da durabilidade de uma plataforma agrícola móvel por meio da análise de elementos finitos

Resumo – O objetivo deste trabalho foi determinar a robustez de uma plataforma agrícola móvel para captura de imagens em diferentes condições de deslocamento. A robustez foi avaliada por meio do método de análise de elementos finitos. Os programas ANSYS 2022 R2 e SolidWorks 2022 foram usados para analisar a tensão e a deformação da estrutura em três cenários diferentes. Os resultados foram comparados com os da literatura atual. As maiores tensões estimadas foram 32,774 Mpa pelo ANSYS e 31,550 Mpa pelo SolidWorks. As deformações totais estimadas foram 1,6767 mm pelo ANSYS e 3,452 mm pelo SolidWorks. Esses resultados indicam que a plataforma proposta é robusta nos cenários estudados.

Termos para indexação: tecnologia agrícola, agricultura digital, sistemas agrícolas.

The benefits of robots for accuracy, repeatability, and durability have potential to tackle agricultural challenges (Cariou et al., 2009). In order to achieve integrated autonomous farming systems, farming robots and platforms not only provide the means to perform the necessary agricultural tasks with less human work force, but also provide opportunity to exert more control over crops by reducing dependence on factors (Oetomo et al., 2009).

Agricultural robots are an inevitable trend (Albiero, 2019). However, agricultural conditions like high humidity, temperature extremes, large areas, posing communication problems at long distances, are some

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obstacles to the use of agricultural robots and smart machinery (Özgüven & Közkurt, 2021).

Examples of agricultural automation range from autonomous/automated-guided vehicle for planting (Nagasaka et al., 2013) to robots used for recognition and control of diseases, pests, and weeds (Madsen & Jakobsen, 2001; Oberti et al., 2016; Hu et al., 2019).

The most important feature of agricultural robots is to work under different terrain conditions (Bechar & Vigneault, 2017). Versatile and robust robots and platforms are needed in such areas (Roldán et al., 2017). Analytical and accurate dynamic modeling techniques have been used in order to reduce time and risk in their development (Han et al., 2019). According to Makange et al. (2015), ANSYS (ANSYS, Inc., Canonsburg, PA, USA) and SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) are the most used software to analyze machine stresses.

The objective of this work was to determine the robustness of a mobile agriculture platform for image capturing in different displacement conditions.

A mobile agricultural platform called METAZI was designed and manufactured to deal with the expected vibrations produced when moving on different agricultural areas, in order to take quality images of plants. The platform development encompassed five major phases, as follows: chassis manufacturing; placement of moving parts and electric motors; development of the control system; development of imaging tools; and integration of software and hardware.

The chassis was made of gray cast iron, a material with an excellent castability and sufficient mechanical properties (Baicchi et al., 2007). Although gray cast iron is widely used, its strength, plasticity, and toughness are lower than those of other cast iron types. Despite this, gray cast iron was chosen as it is more advantageous due to its high-wear resistance, low-notch sensitivity, and special vibration damping properties (Tu & Shi, 2020), as well as in terms of price in comparison with cold-rolled steel and aluminum materials. The gray cast-iron pipes used in METAZI had diameters between 28 and 32 mm, and a wall thickness of 1.5 mm. The platform was developed as a two chassis design, one lower chassis (sub-chassis) accommodating the mechanical moving parts, and a second chassis (platform) on top of it with the electronics. This design allows adjusting METAZI to work with different plant heights and in different areas (greenhouse and field), in order to capture images. Argon welding was used to join the pipes. In the sub-chassis, two moving parts were attached telescopically to the bar ends. Compartments were built in the right and left sides of the platform. These compartments protect the electronics and power units from the external environment and keep the center of gravity in balance. Since the operating speed of the agricultural mobile platform is low, a suspension or compensation system was not designed.

The most used traction systems in automated-guided vehicles are wheels and tracks. Although the crawler system is generally used in large equipment or equipment requiring high performance, its manufacturing and maintenance costs are high (Tabile et al., 2010). Due to these disadvantages, a 4-wheel system was chosen. Air wheels of 400×25×8 mm (diameter × tire tread × tread depth) with hub bearing were used. The platform was built to be front-wheel drive and rear-steerable. In the front-wheel, a two-speed 12V DC wiper motor featured with four reductions was used. In the steering wheel, the same type of motor was used, but featuring two reductions. The rotation angle was accomplished by adjusting the braking shoes.

The control system was a ten-channel radio remote control. It was possible to control the vehicle forward, backward, left, and right, as well to control the camera up and down, the gimbal mechanism left, right, up, and down, and the motor speed. The pulse position modulation (PPM) signal received by the platform was converted into a pulse width modulation (PWM) signal to control the motors. Differently, the signal received to control the 2-axis gimbal was PPM.

The image was captured using the Go Pro Hero 7 Black camera (GoPro, Inc., San Mateo, CA, USA) placed on the platform. The camera functions were controlled using a tablet. Infrared sensor was used to prevent the camera mechanism from hitting any plant during imaging. This sensor had from 30 cm to 80 cm distance detection range.

Two programming languages were used. The C++ was employed in signal expansion and remote control. The BASIC (beginner's all-purpose symbolic instruction code) was used for motor triggering.

As to electronics, an Arduino Nano card was used for PPM to PWM signal conversions. The 12F675 (Microchip Technology Inc., Chandler, AZ, USA) peripheral interface controller, operated with a 5V trigger, was used to drive the DC motor (relay circuit). The relay circuit of the steering wheel motor was controlled using an Arduino Mega card receiving the PWM signal from the Arduino Nano card. The vehicle was powered using two batteries of 12 V 60 Ah. Three hours were estimated to charge the batteries.

The Ackermann steering geometry (Kolekar et al., 2017) was used to steer METAZI. The Ackermann approach states that rotation speed is directly proportional to load transfer. In low-speed turns, the Ackerman geometry is preferred, to prevent the wheels from losing momentum due to friction (Vala & Yadav, 2023). Ackermann steering geometry is determined by the steering angle (δ) in relation to the platform's center of mass (Ko et al., 2015). The instantaneous radius of curvature of the platform is determined by the following equations:

$$\tan\delta_r = \frac{l}{R - \frac{w}{2}};\ \tan\delta_l = \frac{l}{R + \frac{w}{2}}$$

where δ_r is the steering angle of the right wheel, δ_l is the steering angle of the left wheel, l is the length of the platform, R is the turning radius, and W is the width of the platform.

The mechanical structure of the platform was modeled in the SolidWorks 2022. The performance parameters of the gray cast iron material used in the finite element analysis were the following: Young's modulus, 110 GPa; Poisson's ratio, 0.28; density, 7.20 kg mm^{-3}; compressive strength, 820 MPa; and tensile strength, 240 MPa. Nonstructural elements such as boxes, batteries, motors, and steering were excluded from the analysis, in order to simplify the model (monolithic assembly). Static analyses were performed on the highest and largest telescopic tube size of the platform.

The strength analyses were carried out using ANSYS 2022 R2 and SolidWorks 2022. The node-to-surface method was used in both software. The structural performance was assessed through stress and deformation. The von Mises yield criterion was used to evaluate equivalent stress measurements. The model was subjected to three displacement scenarios: straight, slope, and maneuvering. The robustness of the platform was assessed by comparing the results of the two software, as well as comparing them with results of the literature.

Structural studies of agricultural mobile platforms and robots are commonly carried out using loads of 100 N on different materials (Sharifi et al., 2016; Chen et al., 2020; Baskaran & Kumar, 2021). For comparability reasons, the present study used the same 100 N load applied to the platform structure. In order to simulate a straight displacement, the fixed support (rigid) point was applied at the top-middle part of the platform, and a force was applied at the bottom front part (obstacle). In the maneuvering scenario, the rigid point was located on the left and top of the platform, while the force was applied closest to the right front wheel. In the slope scenario, the rigid point was located on the left side of the platform, while the force was applied on the upper right side.

The highest deformation and the highest stress were observed in the maneuvering scenario (Figure 1). ANSYS estimated a stress of 32.774 MPa, and a total deformation of 1.6767 mm. SolidWorks estimated a stress

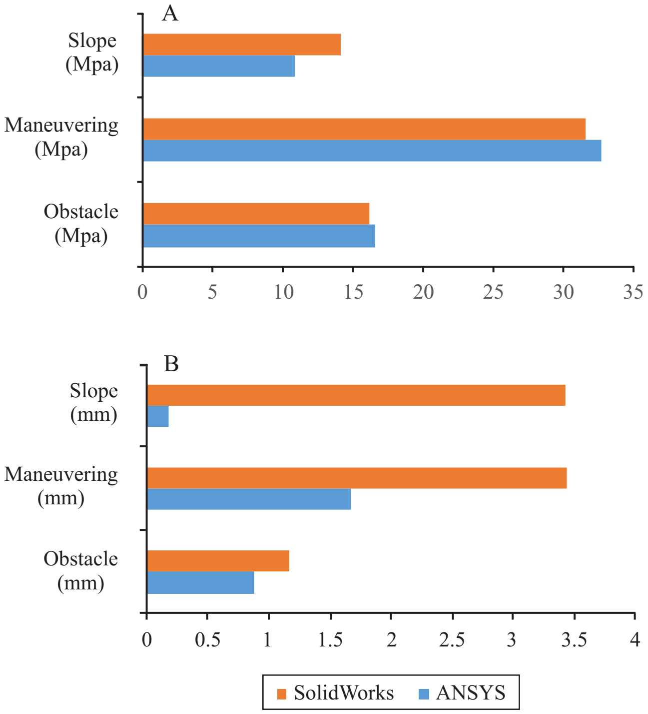

Figure 1. Comparison of the estimated results under three displacement scenarios, calculated by the SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) and ANSYS (ANSYS, Inc., Canonsburg, PA, USA) software: A, maximum equivalent stress; and B, maximum total deformation.

Table 1. Comparison of published results of equivalent stress and total deformation of different materials and loads, using the method of finite element analysis, estimated by the ANSYS (ANSYS, Inc., Canonsburg, PA, USA) and SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) software.

Literature	Material	Load (N)	Software	Max. equivalent stress (MPa)	Max. total deformation (mm)
Tabile et al. (2010)	Steel	500	ANSYS	274.89	6.902
Sharifi et al. (2016)	Ingeo PLA (polylactic acid)	100	ANSYS	1.978	0.015
Pramod & Jithinmon (2019)	C17 mild steel	25	ANSYS	52.650	0.003
Chen et al. (2020)	Aluminum 7075	450 430 330 100	ANSYS	39.897	4.331
Baskaran & Kumar (2021)	Aluminum 6060-T5	100	ANSYS	8.4942	0.049
Present study	Gray cast iron	100	ANSYS	32.774	1.676
			SolidWorks	31.550	3.442

of 31.550 MPa, and a total deformation of 3.442 mm. The stress results, in both software are quite close.

For the results of the finite element analysis of robots and platforms in the literature (Table 1), the SolidWorks software was used only in the model design. Tabile et al. (2010) concluded that steel presents large deformations, despite its high strength, whereas Sharifi et al. (2016) found that polylactic acid presents low stress and deformation. Furthermore, Pramod & Jithinmon (2019) noted that C17 mild steel can exhibit significant tensile values even under low forces.

Based on finite element analysis, METAZI shows durability as a mobile agricultural platform that is designed to obtain high-quality images under various field conditions.

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Declaration of use of AI technologies

No generative artificial intelligence (AI) was used in this study.

Conflict of interest statement

The authors declare no conflicts of interest.

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