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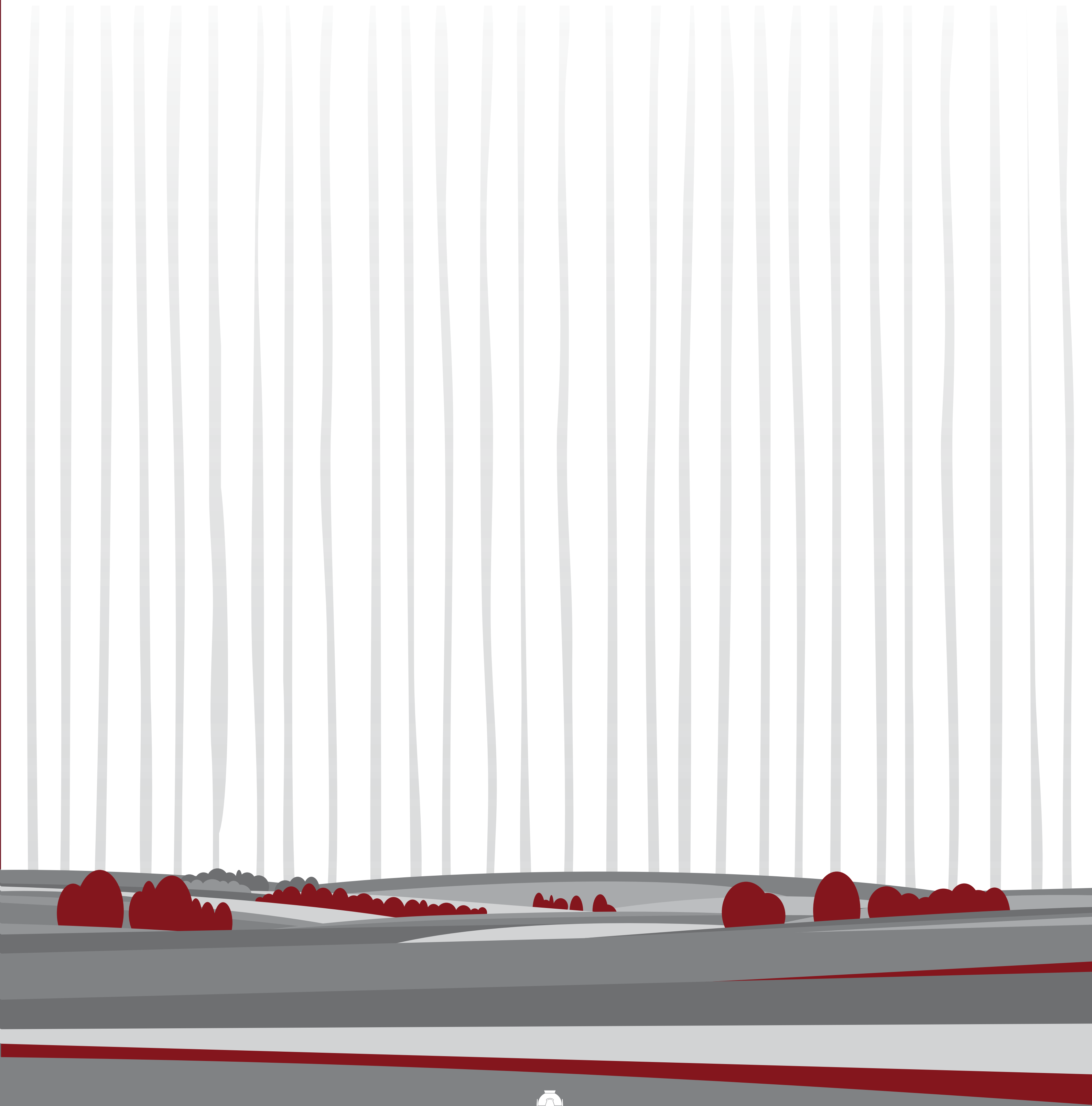

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Rockerbot: Rover Kinematics for Maize Farming

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ABSTRACT

Crop inspection plays a significant role in modern agricultural practices as it enables farmers to evaluate the condition of their fields and make informed decisions regarding crop management. However, existing methods of crop inspection are often labor-intensive, leading to slow and costly processes. Therefore, there is a pressing need for more efficient and cost-effective approaches to crop inspection to improve agricultural productivity, sustainability, and to deal with labor shortage. In this study, we present Rockerbot, a novel agricultural robot designed as a compact rover capable of navigating and surveying maize fields in their early growth stages. This technology is essential for timely landscape adjustments to ensure optimal crop production. The document offers a comprehensive review of the decisions made during the hardware and software development stages. The hardware section is centered around design choices influenced by the rover's kinematics, while the software section outlines the tasks that Rockerbot can perform using mobile perception, such as mapping, sensing, and detection.

Keywords: agricultural robotics, smart agriculture, autonomous navigation, watering, mapping

INTRODUCTION

The rapid growth of the global population and the challenges posed by climate change have placed immense pressure on the agricultural sector to meet the increasing demand for food while minimizing environmental impacts. Among various crops, maize stands out as one of the most extensively cultivated crops worldwide, serving as a staple food source for millions of people (Statista, 2021; Erenstein et al., 2022). Addressing the need for enhanced agricultural productivity and sustainability in maize farming has become crucial, and the integration of robotics has emerged as a promising solution.

Advancements in robotics technology have opened up new possibilities for transforming traditional farming practices (Sparrow and Howard, 2021). With the ability to perform repetitive and labor-intensive tasks with precision and efficiency, robots offer significant potential for revolutionizing agriculture. Autonomous navigation, particularly in wide-ranging maize fields, has become a focal point for research and development, as it promises to automate the sector and improve overall productivity.

The automation of maize farming through the deployment of robotics allows for several key advantages. Firstly, the introduction of autonomous navigation systems in vast agricultural areas enables robots to efficiently traverse and survey the fields, ensuring comprehensive coverage and data collection. This capability facilitates the implementation of site-specific management strategies, leading to optimized resource utilization and improved crop health. Furthermore, due to global warming posing new challenges for maize pest control (Diffenbaugh et al., 2008), existing farming practices will be intensely scrutinized year after year. Automation undoubtedly contributes to the enhancement of autonomous analysis. Secondly, the need for automation in agriculture is driven by the swift expansion of the global population. This growth is creating an exponential demand for food that our current land resources are struggling to meet (Ritson, 2020).

Related Works

Autonomous navigation in crop fields is an emerging area of study, and the current state-of-the- art offers limited solutions for effectively accomplishing this task. The existing literature primarily focuses on either the vision or point cloud domain in terms of perception.

Real-Time Kinematic (RTK) and Differential Global

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Positioning System (DGPS) are advanced techniques used to enhance the accuracy of location data from satellite-based positioning systems like GPS (Global Positioning System). RTK is a type of DGPS that uses a newer technology and protocol for more precise measurements. RTK-DGPS relies on signals from satellites to perform triangulation, a process where it measures the distances between you and at least four satellites to calculate your precise location on Earth. (Bakker et al., 2010) introduced an early method for autonomous maize navigation using RTK-DGPS technology to navigate the maize fields. This information provides coordinates, such as latitude and longitude, facilitating accurate navigation regardless of external landmarks. The initial trajectory is established by recording the first line formed by the edge point A-B. Subsequently, a complete parallel trajectory to the initial segment A-B is generated for navigation purposes. It is important to note that this route plan does not account for headlands and requires prior information about field boundaries, specifically at certain points. However, since RTK-DGPS is not universally accessible, alternative navigation systems independent of RTK-DGPS began to be explored within the research community, aiming to provide reliable positioning solutions in scenarios where RTK-DGPS signals may be limited or denied, particularly in remote or densely vegetated agricultural areas.

In the agricultural sector, particularly in crop fields, vision-based systems are favored due to their cost-effectiveness when compared to LiDARs and radars. The employment of vision-based systems has been extensively suggested as a potential solution for this task (Yang et al., 2018; Chen et al., 2020; Liu et al., 2016). (Yang et al., 2018) presented a vision system capable of filtering images based on the red color to detect the visible roots of maize plants. This detection was then refined using the least square method to determine the optimal path to be followed. In a similar vein, (Chen et al., 2020) proposed an alternative approach by employing the Hough transformation to identify the central navigation line. Another variation was introduced by (Liu et al., 2016), who developed a monocular vision navigation system for maize canopy based on RBF (Radial Basis Function). This method, unlike the least square and Hough transformation techniques, exhibited better handling of line following in the presence of curvature. However, it is worth noting that all of these methods have been specifically tuned for a particular life stage cycle of maize.

Indeed, LiDAR-based systems have been developed to account for the changes that occur throughout the life cycle of plants. (Reiser et al., 2016) demonstrated the feasibility of offline route planning by utilizing laser scan data collection paired with RANSAC fitting (Fischler and Bolles, 1981). Nevertheless, their research was limited to greenhouse settings, and real-time performance is not guaranteed as no further data processing was performed. In contrast, (Hiremath et al., 2014) proposed a probabilistic model based on a particle filter, using a 2D LiDAR sensor. This approach showcased promising performance across different conditions, as it was specifically designed to address uncertainties, although the same particle filter approach applied to the 3D LiDAR point cloud could suffer computational complexity.

Previous research (Cudrano et al., 2022) has demonstrated that the process of autonomous navigation in agricultural fields can be divided into two main stages: navigating through rows and executing turns. The stage of row navigation employs 2D LiDAR scans and clustering algorithms to distinguish between crop rows. The detection of the end of a row triggers the transition to the turning stage. During this stage, the ROS (Robot Operating System) navigation stack and SLAM (Simultaneous Localization and Mapping) work together to generate a laser-based map, which aids in planning and localization. The two-stage process emphasizes the importance of identifying the end of a row for spatial perception and turn planning. Recognizing the row's end is crucial, informing spatial understanding and enabling effective turning strategies, thereby enhancing overall navigation efficiency in agricultural settings.

Proposal

This study builds upon our prior work (Cudrano et al., 2022) and introduces a novel robotic platform, Rockerbot, specifically engineered for autonomous farming tasks in maize fields (Fig. 1). The main role of our system is to autonomously navigate through maize rows that are 0.70 – 0.75m wide. Rockerbot's ability to execute complex maneuvers, such as navigating around obstacles with accurate turns, is dependent on its mapping capabilities, which are facilitated by LiDAR sensors. In addition to its primary navigation tasks, Rockerbot is also equipped to detect objects and simultaneously irrigate side crops.

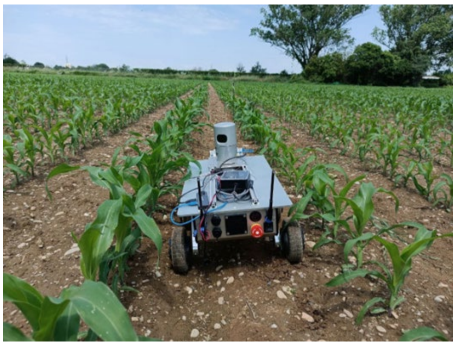

Figure 1: Rockerbot navigating through a maze field

MATERIAL AND METHODS

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 0.70 – $0.75m$, 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 kinematics of the robot, shown in Fig. 2, have been chosen after an accurate analysis of the state of the art (Rubio et al., 2019) and taking into account the operating environment.

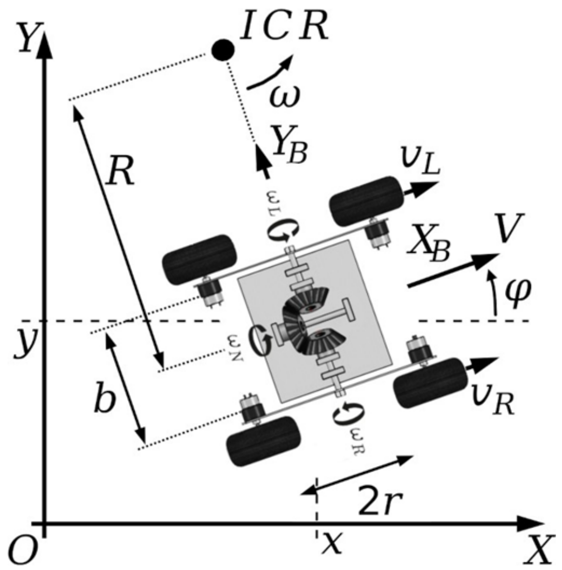

Figure 2: Kinematic scheme of Rockerbot with its bevel gear suspension system

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. Furthermore, a skid-steering mechanism was integrated into the robot's steering system, preserving both construction simplicity (Kozłowski and Pazderski, 2004) and the overall robustness of the system. The direct kinematics of this robot remain similar to a differential drive (Wang et al., 2015), 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.

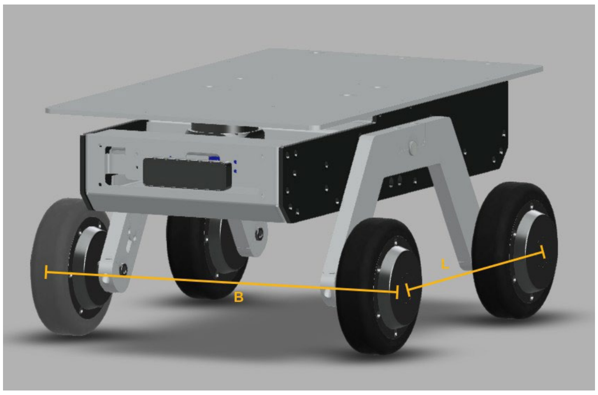

Figure 3a: Rockerbot's chassis and dimensions for wheel placement

Figure 3b: Suspension system with a single- wheel bump

Figure 3c. Deployment of Rockerbot in a Real- World Cornfield

Figure 3: Perspectives collection of Rockerbot's design

In Fig. 3, it is possible to see the compact chassis of Rockebot (Fig. 3a), along with its mechanism for averaging out irregularities in ground conditions either in testing conditions (Fig. 3b) or in real scenarios (Fig. 3c).

Kinematic model

The kinematics of the proposed robot adhere to a skid-steering model and incorporate a distinctive feature known as the *Averaging Mechanism*. This mechanism serves to dampen ground shocks by maintaining equilibrium in the pitch angle between the right and left wheel pairs. While bearing similarities to the 'Rocker-Bogie Suspension System' introduced in the literature by NASA in 1988, our kinematics presents a simplified iteration with four wheels, as opposed to the original six-wheel design.

Skid-steering robots are vehicles that use differential steering for motion control. They have two wheels or tracks, each independently driven by its motor. The kinematic equations for a skid-steering robot describe how its position and orientation change over time based on the inputs to the two wheels or tracks. Here are the basic kinematic equations for such a robot:

Let:

- v be the linear velocity of the robot (speed along a straight line).
- ω be the angular velocity of the robot (rate of rotation).
- L be the distance between the two wheels or tracks (the wheelbase).
- R be the radius of the wheels.

The kinematic equations are as follows:

1. Linear Velocity (v):

$$V = \frac{R}{2} \cdot (\omega_r + \omega_l) \tag{1}$$

where ω_r and ω_l are the angular velocities of the left and right wheels, respectively.

2. Angular Velocity (ω):

$$V = \frac{R}{L} \cdot (\omega_r + \omega_l) \tag{2}$$

where ω_r and ω_l are the angular velocities of the left and right wheels, respectively.

3. Robot's Position Update: The robot's position can be updated using the following Euler integration, assuming that θ is the current orientation angle of the robot:

$$x_{new} = x_{old} + v \cdot \cos(\theta) \cdot \Delta t, \tag{3}$$

$$y_{new} = y_{old} + v \cdot \sin(\theta) \cdot \Delta t, \tag{4}$$

$$\theta_{new} = \theta_{old} + \omega \cdot \Delta t, \tag{5}$$

where Δt is the time step between updates.

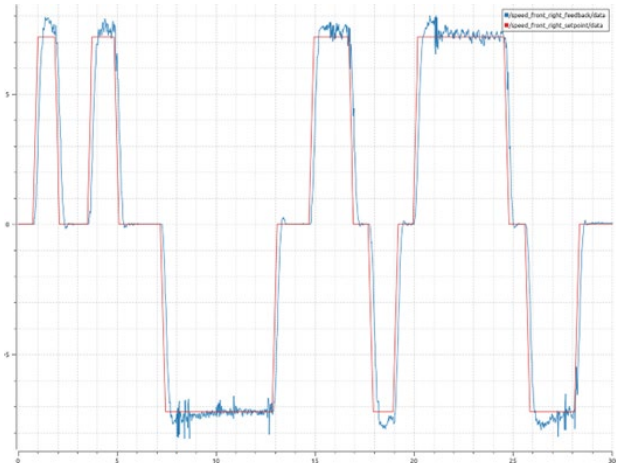

Figure 4a: PID control input sequence where the red line is the command value to be followed, and the blue one is the robot's response

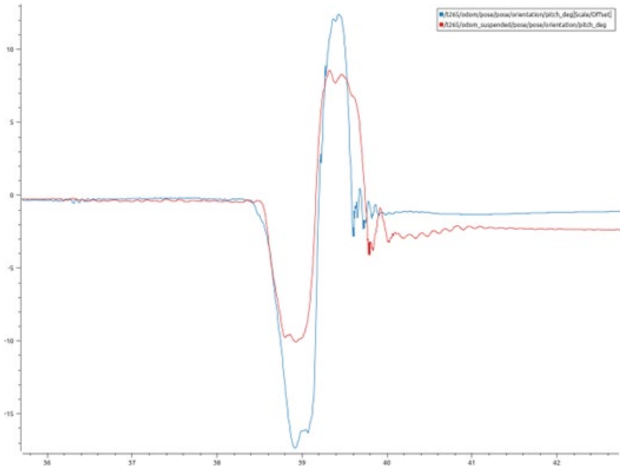

Figure 4b: Bump test comparison in stability with (red line) and without (blue line) active suspension system for soil irregularities

Figure 4: The design decisions for the Rockerbot are illustrated in the accompanying diagrams

The equations in question delineate the relationship between a skid-steering robot's linear and angular velocities and the wheel velocities (ω_r and ω_l). Furthermore, they illustrate how its position and orientation change over time based on these velocities. This mathematical model plays a pivotal role in programming the robot's motion control and carrying out tasks such as path following and odometry. To ensure motion stability with the command input $[v, \omega]^T$, we fine-tuned a PID controller empirically. The optimal values obtained were $P = 0.02$, $I = 0.8$, $D = 0$, as depicted in Fig. 4a by comparing the command value to Rockerbot's response to the input.

Bevel gear suspension system

The angular velocity of a bevel gear suspension system can be determined using the principles of rotational motion. Bevel gears are used to transmit motion between non-parallel shafts, and the angular velocity relationship for such a system can be described using the gear ratio.

If we consider a setup where one bevel gear is located on the input shaft and the other on the output shaft, we can use a specific equation to determine the relationship between the angular velocity of the input gear and that of the output gear:

$$N_{in} \cdot \omega_{in} = N_{out} \cdot \omega_{out}, \tag{6}$$

where:

- N_{in} denotes the number of teeth present on the input bevel gear.
- ω_{in} signifies the angular velocity of the input shaft, measured in radians per second.
- N_{out} represents the number of teeth on the output bevel gear.
- ω_{out} represents the angular velocity of the output shaft, measured in radians per second.

Equation 6 is rooted in the principle of angular momentum conservation, which asserts that the product of the number of teeth and the angular velocity remains constant when gears are engaged with each other.

To determine either the angular velocity of the output gear (ω_{out}) or that of the input gear (ω_{in}), the equation can be rearranged as follows:

$$\omega_{in} = \frac{N_{out}}{N_{in}} \cdot \omega_{out} \tag{7}$$

Equation 7 allows for the determination of the angular velocity of either gear, given the number of teeth and the angular velocity of the other gear. In our particular scenario, where the number of teeth is identical across gears, an angular velocity counter-balance is achieved concerning the sides of the Rockerbot wheels allowing better stability concerning the irregular ground as highlighted by the test shown in Fig. 4b.

Sensors

Concerning perceptual capabilities, Rockerbot is equipped with a 32-plane LiDAR, supplemented by a 1-plane laser scan for crop mapping. The primary source of odometric information is derived from an Intel RealSense feature-based camera, which offers superior adaptability to changes in vegetation compared to approaches based on point clouds. Furthermore, the robot incorporates an OAK-D Pro camera, complete with a neural inference chip. This setup enables real-time object detection during navigation and facilitates the distribution of computational load.

Navigation method

The primary objective is to equip the robot with the ability to independently identify and follow crop rows. A crucial aspect of this process involves the robot's capability to detect the end of a row and subsequently execute a complete turn to continue its navigation in the next row. The navigation process is thus bifurcated into two distinct stages: row navigation and turning. The transition between these stages is facilitated by an end-of-row detector.

Our navigation method involves an inline process that partitions the surrounding point cloud of plants into two distinct groups through single-plane 2D clustering. These clusters are defined in real time, and we use the RANSAC algorithm to find the best-fitting line for each group. To ensure stability and address sudden changes in line slopes during the RANSAC convergence process, we use a sliding window of size 10, which includes a discount factor in the row direction.

With a well-defined line direction providing a local obstacle-free pathway, we calculate a series of control inputs to determine the next action, which could be either moving forward or retreating, depending on the situation. When navigation is active, a subprocess works to determine if the end of the maize row is approaching. If it is, a turning point is calculated based on the left or right direction, as indicated by the predefined path.

The turn is executed using the Nav2 framework, which considers a tuned cost map of the environment collected in real time during navigation. We retrieve the occupancy grid map with the help of a single-plane scan for close-range distances, and a multi-plane LiDAR for longer distances. The multi-plane LiDAR is preprocessed to merge a collection of planes slightly above the ground onto the same hypothetical plane. For computational efficiency, the ground is detected and removed.

Watering procedure

Rockerbot possesses the capability to detect nearby plants during its navigation and administer a liquid solution to them. This functionality is facilitated by the use of a mono-plane laser-scan sensor. Employing a predetermined threshold, we group the lateral laser points to ascertain the presence or absence of plants. Subsequently, the watering system is activated to irrigate the identified plants. It's worth noting that while the system was initially designed for water, it can also be adapted for the dispensing of fertilizers, pesticides, herbicides, or any other liquid solutions required to enhance crop quality in a maize field.

Object detection

Rockerbot is equipped with the OAK-D Pro camera, which enables efficient object detection through dedicated on-board neural network serialization and deployment capabilities. Unlike other affordable commercial RGB-D cameras like the Intel RealSense, which necessitates off-board computation, the OAK-D Pro comes with built-in memory. This memory is specifically engineered to house a compact deep learning model in inference mode. This feature allows for quicker computations on its integrated chip and more efficient distribution of the robot's computational load. We have deployed a fine-tuned YOLOv8 medium-size model (Redmon et al., 2016) to distinguish between deers and humans.

To mitigate the possibility of misclassifications at run-time, which may not have been avoidable during training time, we implemented a dynamic sliding prediction FIFO (First-In-First-Out) buffer with a predefined size of 10 predictions. If the majority of predictions within this buffer belong to the same class, the system issues an alert with the corresponding class-specific signal.

The adopted YOLO settings for training encompass a comprehensive set of data augmentation techniques aimed at enhancing the robustness and diversity of the training dataset, composed by us of $23,850$ images. Firstly, an "auto-orient" approach is applied, ensuring that objects in the images are correctly oriented, thus minimizing potential biases associated with object orientations. The images are then resized to a uniform 416×416 resolution using a "center crop" strategy, which maintains the most informative region while eliminating unnecessary background information. Contrast stretching is employed to further augment the dataset, enhancing the visibility of objects and patterns in the images.

Horizontal and vertical flipping is introduced as part of the data augmentation pipeline, expanding the dataset by creating mirrored versions of the original images. Additionally, rotations of 90 degrees in both clockwise and counter-clockwise directions, as well as flipping images upside down, are applied to introduce variations in object orientations. To simulate real-world scenarios and introduce randomness, rotations within a range of −45 to +45 degrees are incorporated.

Furthermore, a controlled degree of variability is introduced through small random rotations, up to ±15 degrees, in both horizontal and vertical directions. These settings collectively contribute to a training dataset that is more comprehensive, diverse, and representative of real-world conditions, ultimately enhancing the performance and generalization capabilities of the YOLO object detection model.

RESULTS

Kinematics

When assessing the skid-steering robot's performance, our initial validation test centered on its steering capabilities, specifically its ability to execute in-place turns. Our observations revealed a strong correlation between this ability and the robot's wheelbase dimension. To evaluate this behavior, we conducted a series of experiments in a controlled, level environment. Throughout these tests, we maintained a constant wheel separation (the distance between the left and right wheels) while varying the robot's wheelbase (the distance between its front and rear axles). We tested three different robot models with wheelbases of $0.15m$, $0.32m$, and $0.41m$.

The results unequivocally demonstrated that the size of the robot's wheelbase had a significant impact on its in-place turning capabilities. A larger wheelbase led to a diminished capacity for the robot to execute in-place turns effectively. Consequently, we faced a decision between opting for a shorter wheelbase, which improved turning capabilities and choosing a longer one that ensured greater overall stability. Ultimately, for the final robot design, we settled on a wheelbase of $0.32m$ to strike a balance between enhanced turning performance and overall stability.

Suspensions

A comprehensive validation process was undertaken to assess the efficacy of the robot's suspension mechanism. Initially, simulation tests were performed in Gazebo ROS2, where the robot navigated through a simulated flat terrain with strategically placed bumps to engage only the right front and rear wheels. Subsequently, real-world validation tests were conducted to corroborate the simulation results and evaluate the practical performance of the suspension system. A meticulous methodology was employed to ensure precise replication of simulated conditions, guaranteeing accuracy and consistency in the evaluation process. The test track was accurately designed to mirror the simulated environment, facilitating an accurate assessment of real-world scenarios. The primary evaluation metric utilized was the robot's pitch angle profile, enabling a comparative analysis between active suspension and immobilized scenarios.

In both simulated and real-world environments, the robot's suspension mechanism demonstrated significant effectiveness in mitigating pitch angles when encountering bumps. Simulation results showcased a peak-to-peak pitch angle reduction from 25.61 to 12.33 with an active suspension system, marking a notable 51.8% improvement compared to immobilized suspension. Real-world testing corroborated these findings, demonstrating consistent reductions in pitch angles with the suspension system enabled. Specifically, pitch angles decreased from

29.76 to 18.63, indicating a substantial 38.4% improvement in pitch angle mitigation. These results, illustrated in Fig. 4b, underscore the robustness and efficacy of the robot's suspension mechanism in real-world scenarios, validating its practical utility and performance.

Odometry

The critical element essential for enabling autonomous navigation is the provision of reliable odometry data to guide the robot. Traditionally, this data is calculated using wheel encoders. However, due to the significant wheel slippage experienced in rugged terrains, exacerbated by the inherent characteristics of our kinematic system, we have incorporated an additional sensor – a visual odometry camera (specifically, the Intel T265).

To assess the performance of both systems, we recorded odometry data from both the wheel encoders and the camera, comparing them against the data obtained from a high-precision motion capture system. Our evaluation involved computing the Absolute Position Error (APE) between the respective trajectories. The resulting Root Mean Squared Error (RMSE) for the APE is presented in Table 1, underscoring the necessity of an external odometry source, such as the T265 camera, to mitigate the substantial errors associated with encoder-based odometry in a skid-steering robot.

Table 1: RMSE error in meters of the T265 and wheel encoder concerning the OptiTrack trajectory

Method	RMSE
Encoder odometry T265	2.432022
odometry	0.596588

Object detection

Table 2: Average precision (AP) by class: deer, human, and all

	Validation	Testing
all	81%	87%
deer	88%	90%
human	74%	84%

The performance of the custom-trained YOLO model demonstrated effectiveness, as evidenced by the results presented. In Table 2, it can be observed that the model efficiently distinguished between deers and humans, achieving a higher Average Precision on the Testing Set compared to the Validation Set used for hyper-parameter adjustment.

This implies that the model avoided overfitting the training data, making it a dependable option for real-world usage. Furthermore, the high metric values in Table 3 emphasize the model's efficacy on the dataset.

Table 3: Deployment and performance evaluation of the proposed fine-tuned YOLO model

	mAP	Precision	Recall
Overall	81.3%	84.1%	74.4%

As depicted in Table 2, the testing set exhibited a higher mean Average Precision (mAP) score compared to the validation set, indicating the efficacy of fine-tuning without encountering overfitting issues. By delving into specific categories, particularly considering the balanced distribution of deers and humans in the training set, it becomes apparent from the data that the model became more adept at distinguishing between a deer and a human. This observation aligns with intuition, as deers typically maintain a consistent appearance across different habitats, whereas humans exhibit greater physical variability. This qualitative understanding elucidates why the mAP for humans is 84% and for deers is 90%. Nonetheless, both results are deemed excellent from a machine learning perspective on classification, thereby ensuring sufficient reliability for practical deployment.

The overall mAP of 81.3% reflects the model's comprehensive performance across all categories. This metric encapsulates both precision and recall, providing a holistic measure of the model's ability to correctly classify instances across various classes. The precision of 84.1% indicates the proportion of correctly identified instances among all instances classified as positive, highlighting the model's ability to minimize false positives. Conversely, the recall of 74.4% signifies the proportion of correctly identified instances among all actual positive instances, indicating the model's capacity to capture relevant instances without overlooking them. The balance between precision and recall is crucial in assessing the model's effectiveness in real-world scenarios, where both minimizing false positives and false negatives are essential for reliable decision- making. Therefore, the combination of these metrics offers valuable insights into the model's overall performance and its suitability for practical deployment in classification tasks.

DISCUSSION

The results presented provide valuable insights into the design and performance of Rockerbot.

In terms of kinematics, the findings highlight the trade-off between turning capabilities and overall stability in the context of the robot's wheelbase dimension. The decision to opt for a wheelbase of 0.32m represents a compromise between these two critical factors. This suggests that future designs might benefit from mechanisms that allow for adjustable wheelbase dimensions, enabling the robot to adapt to different operational requirements.

The research findings highlight the critical role of an active suspension system in augmenting the performance of robots, particularly in managing pitch angles. Both simulated and real-world tests demonstrated substantial enhancements, affirming the necessity of integrating such systems into robot designs. Further investigations could delve into the effects of varying suspension designs and configurations on overall robot performance, offering avenues for future research and development.

The odometry results highlight the challenges associated with obtaining reliable data in rugged terrains due to wheel slippage. The incorporation of a visual odometry camera (Intel T265) proved effective in mitigating these issues. This suggests that multi-modal sensor fusion, combining data from different types of sensors, could be a promising approach for improving odometry in skid-steering robots.

The performance of the custom-trained YOLO model in object detection tasks demonstrates the potential of deep learning techniques in enhancing the robot's autonomous navigation capabilities. The model's ability to generalize well to unseen data indicates its robustness and reliability, making it a promising choice for real-world deployment. Future research could explore the application of similar models to other object detection tasks, as well as the integration of these models into the robot's navigation system.

As future directions, enhancing the rotational curvature within a skid-steering model by advancing independent turning wheels offers a promising direction for future investigation. This endeavor entails refining kinematics to achieve the agility and precision observed in contemporary tractors. Additionally, there is a required emphasis on radar odometry, which represents a forefront technology in agriculture. Its robustness in adverse weather conditions, despite the RTK-DGPS, provides unmatched reliability for navigation (Frosi et al., 2023) and localization tasks (Usuelli et al., 2023). The integration of radar-based sensing systems holds significant potential for augmenting autonomous operations, especially in demanding environments such as maize fields.

In conclusion, the results presented provide a strong foundation for the ongoing development and refinement of skid-steering robots, with implications for their kinematics, suspension, odometry, and object detection capabilities. Future work in this area would do well to build on these findings, exploring the potential of adjustable wheelbase dimensions, multi-modal sensor fusion, and deep learning techniques in enhancing the performance and versatility of these robots.

Field Robot Event 2023

We have had the pleasure of deploying this research in the renowned annual international competition Field Robotics Event (FRE) in autonomous robotics agriculture. Despite successfully fine-tuning the autonomous navigation system and achieving highly positive results, we encountered a technical glitch on the day of the competition. A defect in the motor's encoders caused two out of the four wheels to become inoperative, which unfortunately hindered our participation in the navigation task. Nevertheless, Rockerbot managed to secure the third position in the Object Detection contest, thereby validating the superior quality of our research. As we look to the future, our goal is to further improve Rockerbot's overall system for next year FRE 2024.

CONCLUSION

In this study, we detailed the creation and refinement of a compact agricultural robot designed for autonomous navigation and surveillance of crop fields. The design decisions were initially tested and validated in a simulated environment before being applied in real-world conditions, effectively bridging the gap between theoretical design and practical application. This work was showcased at the esteemed Field Robotics Event 2023 in Maribor (Slovenia) where our proposed system secured third place in the Object Detection task. Looking ahead, we plan to further enhance the capabilities of Rockerbot, building on the success of this research and pushing the boundaries of autonomous agricultural technology.

Acknowledgments

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REFERENCES

1. Bakker, T., Van Asselt, K., Bontsema, J., & Van Henten, E. J. (2010). Robotic weeding of a maize field based on navigation data of the tractor that performed the seeding. *IFAC Proceedings Volumes, 43*, 157–159.
2. Chen, J., Qiang, H., Xu, G., Liu, X., Mo, R., & Huang, R. (2020). Extraction of navigation line based on improved

grayscale factor in corn field. *Ciencia Rural,* 50, e20190699.

3. Cudrano, P., Mentasti, S., Locatelli, E., Nicolò, M., Portanti, S., Romito, A., Stavrakopoulos, S., Topal, G., Usuelli, M., Zinzani, M., & Matteucci, M. (2022). Detection and mapping of crop weeds and litter for agricultural robots. In 2022 *AEIT International Annual Conference* (AEIT) (IEEE), 1–6.
4. Diffenbaugh, N. S., Krupke, C. H., White, M. A., & Alexander, C. E. (2008). Global warming presents new challenges for maize pest management. *Environmental Research Letters, 3*, 044007.
5. Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security: The Science, Sociology and Economics of Food Production and Access to Food, 14*, 1295–1319. https://doi.org/10.1007/s12571-022-01288-7
6. Fischler, M. A., & Bolles, R. C. (1981). Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. *Communications of the ACM* 24, 381–395.
7. Frosi, M., Usuelli, M., & Matteucci, M. (2023). Advancements in radar odometry. *arXiv preprint arXiv:2310.12729*.
8. Hiremath, S. A., Van Der Heijden, G. W., Van Evert, F. K., Stein, A., & Ter Braak, C. J. (2014). Laser range finder model for autonomous navigation of a robot in a maize field using a particle filter. *Computers and Electronics in Agriculture, 100*, 41–50.
9. Kozłowski, K., & Pazderski, D. (2004). Modeling and control of a 4-wheel skid-steering mobile robot. *International Journal of Applied Mathematics and Computer Science,* 14, 477–496.
10. Liu, L., Mei, T., Niu, R., Wang, J., Liu, Y., & Chu, S. (2016). Rbf-based monocular vision navigation for small vehicles in narrow space below maize canopy. *Applied Sciences,* 6, 182.
11. Redmon, J., Divvala, S., Girshick, R., & Farhadi, A. (2016). You only look once: Unified, real-time object detection. In *Proceedings of the IEEE conference on computer vision and pattern recognition*. 779–788.
12. Reiser, D., Miguel, G., Arellano, M. V., Griepentrog, H. W., & Paraforos, D. S. (2016). Crop row detection in maize for developing navigation algorithms under changing plant growth stages. In L. Reis, A. Moreira, P. Lima, L. Montano & V. Muñoz-Martinez (Eds.), *Robot 2015: Second Iberian Robotics Conference: Advances in Intelligent Systems and Computing*, vol 417 (pp 371–382). Springer, Cham.
13. Ritson, C. (2020). *Population Growth and Global Food Supplies*. In M. Rutland & A. Turner (Eds.), *Food Education and Food Technology in School Curricula. Contemporary Issues in Technology Education*. Springer, Cham. https://doi.org/10.1007/978-3-030-39339-7_17
14. Rubio, F., Valero, F., & Llopis-Albert, C. (2019). A review of mobile robots: Concepts, methods, theoretical framework, and applications. *International Journal of Advanced Robotic Systems*, 16(2). https://doi.org/10.1177/172988141983959
15. Sparrow, R. & Howard, M. (2021). Robots in agriculture: prospects, impacts, ethics, and policy. *Precision Agriculture, 22*, 818–833.
16. [Dataset] Statista (2021). Most grown crops in the world 2021. https://www.statista.com/ statistics/1003455/most-produced-crops-and-livestock-products -worldwide/
17. Usuelli, M., Frosi, M., Cudrano, P., Mentasti, S., & Matteucci, M. (2023). Radarlcd: Learnable radar-based loop closure detection pipeline. *arXiv preprint arXiv:2309.07094.*
18. Wang, T., Wu, Y., Liang, J., Han, C., Chen, J., & Zhao, Q. (2015). Analysis and experimental kinematics of a skid-steering wheeled robot based on a laser scanner sensor. *Sensors, 15*, 9681–9702.
19. Yang, S., Mei, S., & Zhang, Y. (2018). Detection of maize navigation centerline based on machine vision. *IFAC-PapersOnLine, 51*, 570–575.

Rockerbot: Kinematika robotske platforme za pridelavo koruze

IZVLEČEK

Pregledovanje in nadzor pridelka imata pomembno vlogo v sodobni kmetijski praksi, saj kmetom omogočata, da ocenijo stanje svojih njiv in na podlagih pravih informacij sprejemajo pravilne odločitve glede upravljanja s pridelki. Vendar so obstoječe metode pregledovanja pridelka pogosto računsko intenzivne, kar vodi do počasnih in dragih postopkov. Iz tega razloga obstaja zahteva po učinkovitejših in stroškovno dostopnejših pristopih za pregledovanje pridelkov, z namenom izboljšanja produktivnosti in trajnosti v kmetijstvu, kot tudi za reševanje težav glede pomanjkanja delovne sile. V tej raziskavi predstavljamo Rockerbot, nov kmetijski robot, ki je zasnovan kot kompaktni rover, sposoben krmariti in pregledovati koruzna polja v zgodnjih fazah rasti. Predstavljena tehnologija je bistvenega pomena za pravočasno prilagajanje spremembam, da se zagotovi optimalna pridelava pridelka. Delo ponuja celovit pregled korakov in odločitev, sprejetih v fazi razvoja strojne in programske opreme. Poglavje o strojni opremi je osredotočeno na dizajn robota, ki ga narekuje kinematika roverja, medtem ko poglavje o programski opremi opisuje naloge, ki jih lahko Rockerbot izvaja z uporabo mobilnega zaznavanja, kot so kartiranje, zaznavanje in odkrivanje.

Ključne besede: kmetijska robotika, pametno kmetijstvo, avtonomna navigacija, zalivanje, kartiranje

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Genetic Background of Cattle Temperament: A Short Review

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ABSTRACT

Animal temperament describes behavioural differences between individuals that are consistent over time and across different circumstances. Knowledge of the animal's temperament has a major effect on the safety of handling and caring for the animals as well as on the adaptation of the animals to changing rearing conditions. To understand animal temperament, we need to know not only the genetic basis of temperament, but also the influence of the environment on its expression. Similarly the temperament of dairy cows can be defined as the animal's response to environmental or social stimuli. In this review article, chromosomes with genomic regions containing QTLs, genes and candidate genes responsible for the expression of temperament traits in cattle are presented. Knowledge of the genetic background of temperament expression in cattle and its variability in these traits allows temperament to be included in the selection index.

Keywords: cattle, temperament genetics, QTL, SNP, heritability, serotonin, dopamine

MOLECULAR GENETICS AND TEMPERAMENT TRAITS

QTL studies

Temperament is defined as a stable individual traits (Grandin, 1989), and in cattle, can also be defined as the response of animals to human behavior (Burrow, 1997; Ferguson and Warner, 2008; Cafe et al., 2011). Most economically important traits in dairy cows are related to the function of a large number of genes, and their expression is are influenced by the environment. These traits are longevity, fertility, calving ease, health, working ability and lactation performance. On the other hand, some genes play an important role in the inter-individual variability of aggressiveness, impulsive response and serotonergic responsiveness of the central nervous system, as well as in complex behavioral regulation. The dopamine and serotonin signaling systems are therefore central to behavioral phenotypes such as temperament. Due to the influence of behavioural trait genes, the transporters and receptors of the serotonin and dopamine signalling pathways have been considered to harbour genetic variations that may be associated with variable behavioural responses (Momozawa et al., 2005).

Breeding programs for dairy cows focus on production traits, carcass conformation and functional traits. The genes coding for the proteins responsible for the above traits are attempted to be identified by the method of *marker assisted selection* (MAS). This method is particularly interesting for traits with low heritability (temperament, fertility, health) that cannot be effectively improved by existing selection (Schrooten et al., 2000; Ball, 2003). Use of MAS to determine genetic markers is associated with quantitative trait loci (QTL) (Kolbehdari et al., 2008). Genome-wide association studies (GWAS), which use international data to identify genomic regions and candidate genes and their biological mechanisms, can be used as a very convenient method to identify genetic factors that influence complex traits in an

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individual breed of cattle (Guo et al., 2012; Valente et al., 2016). Similarly, the study showed differences in temperament between and within breeds. Using molecular approaches, QTLs were found to influence behavioral traits in a number of breeds (Haskel et al., 2014).

Understanding the biological background of bovine behavior is a relatively new area of research. To gain insight into the genetic background of cattle behavior, the genome of cattle must first be sequenced. When more than one percent of the population has a different nucleotide at a specific location in the genome. This difference is called a single nucleotide polymorphisms (SNP). They are different alleles at the same location of the DNA. SNP are used as markers to study regions or loci on one or more chromosomes where the record for a particular trait, i.e. phenotype, is located. This region is called a quantitative trait locus (QTL) and is associated with the variability of a particular quantitative trait in the population (Lander et al., 2001). These are often economically important traits. The fundamental question is whether phenotypic differences are the result of the effect of a few loci with a major effect or a larger number of them with a minor effect (Miles and Wayne, 2008).

Friedrich et al. (2015) studied the association of SNP with milk yield (MY) and animal behavior. They found that of 41 SNP studied, nine were associated with both behavioral traits and MY in different lactation periods. Only SNP that affect behavioral traits assessed in the novel object test affect milk production traits. These SNP are located on chromosomes BTA7, BTA10, BTA14, BTA19, and BTA29. Of these SNP, six are associated with more than one milk production trait. The results show an association between the active and exploratory behavior of the dairy cow and its milk yield for SNP significantly associated with the behavior and traits of milk production. Genotypes associated with greater inactivity were associated with higher milk yield and less response to rehousing.

The identification of QTL for behavioral traits in cattle enables the identification of candidate genes located near genetic markers that have the greatest impact on a given trait. So far, this procedure has not been shown to be efficient and reliable enough due to the high complexity of the expression of an individual animal's behavior and its interaction with the environment (Schmutz et al., 2001; Gutierrez-Gil et al., 2008). Among the results of studies on the identification of QTL for behavioral traits in cattle, the study by Hiendlerer et al. (2003) is noteworthy. They investigated QTL related to conformation and behavior of dairy cows, especially those loci whose recording includes nervous/aggressive and "obedient" behavior during milking. A QTL for temperament was found on chromosome 29 (The Linkage mapping was performed with the Canadian Beef Reference Herd (http://skyway.usask.ca~sch-mutz)). As part of a larger QTL study of 162 microsatellites, four of these were located on bovine chromosome 29 and were used to genotype all 18 parents and 136 progeny. Tyrosinase was mapped 9 cM from ILSTS015 (LOD score of a 5.65) and 15 cM from BMC8012 (LOD score of a 3.68). Microsatellites on chromosome 29 and tyrosinase were linked to CRI -MAP, resulting in the map ILSTS015 ± TYR ± BMC8012 ± BMC1206 ± BMC3224).

On chromosome 29, the tyrosinase gene (*TYR*) was found to be associated with the QTL region for temperament and milking speed (Schmidtz et al., 2001). *Tyrosinase* is a multifunctional enzyme involved in the metabolism of the neurotransmitter dopamine. It catalyzes the conversion of tyrosine to dihydroxyphenylalanine (DOPA is the catecholcontaining precursor of dopamine) and oxidizes DOPA to dopaquinone. Tyrosinase also oxidizes dopamine to form melanin via dopamine quinone, which has been shown to inactivate tyrosine hydroxylase, the rate-limiting enzyme for dopamine synthesis (Xu et al., 1998; Higashi et al., 2002). It follows that the tyrosinase gene QTL is a candidate for temperament in cattle. In addition, Gutiérrez-Gil et al. (2008) identified 29 QTL regions carrying a record for temperament traits distributed across 17 chromosomes in Holstein x Charolais (Table 2). Of them, 5 QTL were associated with FF traits (flight from feeder - animal moves away when approached by an observer), and 24 influenced SS test traits (social separation – activities the animal engages in when removed from its barn mates). No overlap of QTL markers was found for traits measured by two different tests (FF and SS). Wegenhoft (2005) reported QTL on 10 chromosomes and all but one QTL region carried candidate genes affecting behavior and temperament (Table 1). Boldt (2008) determined QTL for aggressiveness mapped to BTA3, BTA6, BTA12 and BTA29. QTL for nervousness and running speed were also identified at locations on BTA22 and BTA29. A QTL for sociability was detected on BTA22 and a QTL for running speed was detected on BTA12.

In cattle behavioral traits, researchers have generally focused on barn and milking parlor temperament and habituation ability. For example, Kolbehdari et al. (2008) studied temperaments during milking in 462 Canadian Holstein bulls. They found that 10 SNP significantly affected milking temperament. The chromosomes affecting milking temperament were BTA4, BTA13, BTA19, BTA22, BTA23, BTA26, and BTA29. Riley et al. (2016) also examined the associations of SNP on multiple chromosomes with temperament (nervousness and running speed with values ranging from 1 to 9). They found that five SNP on chromosomes BTA1, BTA24, and BTA29 had indirect associations with aggressiveness, nervousness, or flightiness at weaning. Aggressiveness was defined as the animal's willingness to intentionally attack the evaluator by hitting it with any part of the body, but especially with the head or foot. Nervousness and running speed were indicators of the calf's relaxation during the evaluation. Sociability was a measure of the animals'

willingness to separate from their group and feel comfortable in isolation from other cattle.

Table 1: Quantitative trait loci for temperament[a] in cattle (according to Adamczyk et al., 2013)

BTA chromosome	Trait-associated marker	Chromosome position (cM)	Genotype	References
1	DIK70-PIT17B7	37	BT (Angus) × BI (Brahman, Nellore)	Wegenhoft (2005)
3	BM7225-ILSTS64	45	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
4	TEXAN17-MAF50	28–51	BT (Angus) × BI (Brahman, Nellore)	Wegenhoft (2005)
6	CSSM22-CSM34	1	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
8	BMS1864-BM3419	0	BT (Angus) × BI (Brahman, Nellore)	Wegenhoft (2005)
9	BM6436-BM4208	72	BT (Angus) × BI (Brahman, Nellore)	Wegenhoft (2005)
9	BM2504-UWCA9	30.92–49.99	CHA × HF	Gutierrez-Gil et al. (2008)
12	BMS2252-RM094	20 I 22	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
16	INRA013-BMS462	79	BT (Angus) × BI (Brahman, Nellore)	Wegenhoft (2005)
16	INRA48-BM3509	70	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
16	HUJ625	100.2	CHA × HF	Gutierrez-Gil et al. (2008)
16	ETH11-BM719	54.07–77.57	CHA × HF	Gutierrez-Gil et al. (2008)
18	BL1016-BM8151	18	BT (Angus) BI (Brahman, Nellore)	Wegenhoft (2005)
18	IDVGA-31-ABS013	0–15.75	Charolais × Holstein–Friesian	Gutierrez-Gil et al. (2008)
19	CSSM065–ETH3	69.83–90.04	Charolais × Holstein–Friesian	Gutierrez-Gil et al. (2008)
20	DIK015-BM5004	52.49–71.80	Charolais × Holstein–Friesian	Gutierrez-Gil et al. (2008)
25	BM737-INRA222	31.59–53.37	Charolais × Holstein–Friesian	Gutierrez-Gil et al. (2008)
26	ABS012-HEL11	9.9	Charolais × Holstein–Friesian	Gutierrez-Gil et al. (2008)
26	IDVGA59-HEL11	33	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
28	BP23	10,89	CHA × HF	Gutierrez-Gil et al. (2008)
29	BMS764-BMC8012	11.29–21.11	HF cows	Hiendlederetal (2003)
29	DIK094-MNB101	40.16–69.73	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)
29	BMC3224-BMS764	21	BT (Angus) × BI (Brahman, Nellore)	Boldt (2008)

[a]Temperament was measured once by the degree of animal nervousness in changed/new environmental conditions for the animal, with the assessed animal being most often separated. BT – *Bos taurus*; BI – *Bos indicus*; CHA – Charolais; HF – Holstein–Friesian

In cattle behavioral traits, researchers have generally focused on barn and milking parlor temperament and habituation ability. For example, Kolbehdari et al. (2008) studied temperaments during milking in 462 Canadian Holstein bulls. They found that 10 SNP significantly affected milking temperament. The chromosomes affecting milking temperament were BTA4, BTA13, BTA19, BTA22, BTA23, BTA26, and BTA29. Riley et al. (2016) also examined the associations of SNP on multiple chromosomes with temperament (nervousness and running speed with values ranging from 1 to 9). They found that five SNP on chromosomes BTA1, BTA24, and BTA29 had indirect associations with aggressiveness, nervousness, or flightiness at weaning. Aggressiveness was defined as the animal's willingness to intentionally attack the evaluator by hitting it with any part of the body, but especially with the head or foot. Nervousness and running speed were indicators of the calf's relaxation during the evaluation. Sociability was a measure of the animals' willingness to separate from their group and feel comfortable in isolation from other cattle.

The temperament of cattle can also be evaluated as a result of the action of various metabolites. Such a complex study was carried out on 25 Charolais x Holstain cows based on the new object test (NO). Subsequently, the NO was replaced by an unknown person (Brand et al., 2015). The study showed that they can classify four temperaments of the tested cows, namely: fearful/neophobic-alert, interested-stressed, subdued/uninterested-calm, and outgoing/neophilic-alert temperament. These four types of temperament may also be due to the specific regulation of molecular signaling pathways that are activated in response to fear in stressful situations. Cows with a temperament characterized as fearful/neophobic-alert and interested-stressed have lower levels of glutamic acid, aspartic acid, and Gamma-Aminobutyric Acid (GABA), whereas cows with a temperament, of uninterested-calm, sociable, and indifferent, have higher levels of the aforementioned excitatory (glutamic- and aspartic acid) and higher levels of the inhibitory neurotransmitter GABA.

Common genomic regions

The considerable variation in the areas of cattle genetics associated with behavior can largely be attributed to the use of different research methods. Bailey et al. (2015) found associations between land use indices and genetic markers near candidate genes, demonstrating that grazing distribution is heritable and providing a new approach for linking genetic variation to grazing behavior in beef cattle. They identified QTL regions on chromosomes BTA17 and BTA29 that contain genes responsible for locomotion, motivation and spatial memory. In the study, 770,000 genetic SNP markers were examined on 30 bovine chromosomes. They were used to genotype these cows to examine the genetic association with cattle distribution on pasture (selecting cattle with favorable phenotypes for pasture distribution can reduce the number of cattle in riparian areas and improve grazing uniformity in mountainous terrain). They concluded that associations between land use indices and genetic markers near candidate genes prove that it is possible to genetically determine the specific movement of cattle on pasture and that this is a heritable trait.

Table 2: Quantitative trait loci for habituation ability in cattle (Adamczyk et al., 2013)

Trait	BTA chromosome	Trait-associated marker	Chromosome position (cM)	Genotype	References
Habituation[a]	1	BM6438	1.78	CHA × HF	Gutierrez-Gil et al. (2008)
	1	BMS4044	141	CHA × HF	Gutierrez-Gil et al. (2008)
	4	MAF50-DIK026	51.21–86.23	CHA × HF	Gutierrez-Gil et al. (2008)
	6	DIK5076-BM1329	4.51–35.39	CHA × HF	Gutierrez-Gil et al. (2008)
	7	RM006-BM1853	25.39–85.32	CHA × HF	Gutierrez-Gil et al. (2008)
	8	CSSM047	115.2	CHA × HF	Gutierrez-Gil et al. (2008)
	9	BM888-CSRM60	59,98–77,81	CHA × HF	Gutierrez-Gil et al. (2008)
	10	BMS528-TGLA378	24,01–43,65	CHA × HF	Gutierrez-Gil et al. (2008)
	11	ILSTS100-IDVGA-3	59,11–81,8	CHA × HF	Gutierrez-Gil et al. (2008)
	16	BM121	26.4	CHA × HF	Gutierrez-Gil et al. (2008)
	19	BMS2142-CSSM065	43.31–69.83	CHA × HF	Gutierrez-Gil et al. (2008)
	21	HEL10-TGLA337	65	CHA × HF	Gutierrez-Gil et al. (2008)
	29	RM044-MNB166	24.48–33.51	CHA × HF	Gutierrez-Gil et al. (2008)
Habituation[a] + Temperament[b]	1	BMS574	15.42	BB cattle from ET	Schmutz et al. (2001)
	5	RM103	29.42	BB cattle from ET	Schmutz et al. (2001)
	9	ILSTS013	48.73	BB cattle from ET	Schmutz et al. (2001)
	11	LISTS036	61,57	BB cattle from ET	Schmutz et al. (2001)
	14	RM180-ILSTS008	33.31–50.91	BB cattle from ET	Schmutz et al. (2001)
	15	ADCY2	22.67	BB cattle from ET	Schmutz et al. (2001)

[a]Habituation was defined by the authors as adaptability of animals to novel environmental conditions in a given time period. [b]Temperament was measured once by the degree of animal nervousness in changed/new environmental conditions for the animal, with the assessed animal being most often separated. ET = embriotransfer; CHA – Charolais; HF – Holstein–Friesian; BB – beef breed

Most genes identified in cattle (*Bos taurus*), pigs (*Sus scrofa*), and sheep (*Ovis aries*) that are associated with a range of behavioral traits (e.g., temperament, indexes of terrain use, milking speed, tail biting, and suckling) likely control stimulus reception (e.g., olfaction), internal recognition of stimuli, and body response to stimuli. In a review article, Alvarenga et al. (2021) examined genomic regions associated with behavior in livestock such as cattle, pigs and sheep. In cattle, 383 such markers were identified. Six genes (*NR3C2, PITPNM3, RERG, SPNS3, U6*, and *ZFAT*) were identified in both cattle and pigs. About half of the genes associated with behavior in livestock (cattle, sheep, and pigs) are also responsible for various behavioral, psychological, and neurological disorders in humans. For example, *NCOA7, GAD2, PDGFD, TMPRSS5, DRD2, IQSEC1, MAOB, PTPRF, SLC25A16, TMCO5A*, and *SNRPB2*, which are associated with temperament in dairy cows, have already been linked to neuropsychiatric disorders in humans. Identifying the molecular mechanisms of behavior may contribute to a better understanding of behavioral problems that are widespread in many areas of animal husbandry, such as animal handling, susceptibility to stress, or adaptation to different production conditions. On the other hand, research has shown that the influence of genetic differences on behavior is not direct but manifests at other levels, including transcripts, proteins, metabolites, and through complex networks of neurophysiological and structural factors (Johnston and Edwards, 2002).

CANDIDATE GENES

Identification of candidate genes and functional analyses

The creation of genetic maps for various domestic animal species and efforts to improve animal welfare in different production systems have increased the number of studies on the genetic background of animal temperament. In the past, the selection of animals in livestock production was based mostly on their adaptability to the environment and their responsiveness to humans. However, differences between breeds of animals quickly appeared. For example, *Bos indicus* were found to be more restless than *Bos taurus* and heifers were found to have more lively temperaments than bulls (animals with a lively temperament pose a considerable risk to the stockperson and other animals). It has also been found that animals exhibiting calmer temperaments grow faster than those that are agitated during normal husbandry routines (Voisinet et al., 1997).

In order to reveal the functional consequences of the discovered candidate genes, the researchers analyzed the biological processes, cellular components, and molecular functions of the genes in their study. Among other things, the researchers focused on the serotonergic and catecholaminergic systems and their interplay for the synthesis and metabolism of important neurotransmitters such as serotonin and dopamine. The gene encoding dopamine receptor D4 (*DRD4*) has been associated with behavioral traits such as finding new objects and curiosity in humans and various animals such as cattle (Bailey et al., 2007) and Great tits (Korsten et al., 2010). In cattle, *DRD4* is possibly located in the distal part of chromosome BTA29 (Glenske et al., 2011). The latter analyzed ten microsatellites in German Angus calves. The candidate gene for the D4 dopamine receptor was analyzed and included in a quantitative trait loci (QTL) study based on three different behavioral tests in cattle (score tethering test, weighing test, separation and restraint test). A *DRD4* fragment was mapped to the distal region of BTA29. The results showed that BTA29, with a putative QTL in the proximal part and a *DRD4* candidate gene in the distal part, plays an important role in regulating temperament (Glenske et al., 2011).

The next frequently discussed functional candidate gene is the monoamine oxidase A (*MAOA*) gene. The enzyme monoamine oxidase A (*MAOA*) breaks down monoamines such as the neurotransmitter serotonin. The *MAOA* gene is assigned to the X- chromosome in all mammals analyzed so far, including humans and cattle. The *MAOA* gene and its product play an important role in the complex regulation of behavior in cattle. The *MAOA* gene of humans, mice, and monkeys is thought to determine the trait aggressiveness. Lühken et al. (2010) also analyzed the coding region of the MAOA gene with the aim of detecting the genetic variability of behavior using four tests (I, behavior after two minutes of enthering, IIa, behavior when entering the scale, IIb, behavior during weighing, III, behavior during the separation test which classifies the different activities carried out by cattle, when they are removed from their familiar environment). They identified five SNP in the coding region, three of which were in the coding region of the gene (exons III and XV). One of the SNP in exon XV (NC_007331.3:g.80340C>T) was a nonsynonymous mutation. In a nonsynonymous mutation, there is usually an insertion or deletion of a single nucleotide in the sequence during transcription when the mRNA copies the DNA. This single missing or added nucleotide results in codon shuffling and mutation of the amino acid sequence.

For decades, selection has exerted selection pressure on a specific phenotype of animal behavior, such as aggressiveness, thus altering the specific frequencies of alleles for this trait in the cattle population. Eusebi et al. (2019) studied the Lidia breed of cattle, which has been selected for aggressiveness, ferocity, and fast movements since the 18th century because it is used in bullfights. They focused on mapping selection markers associated with aggression on the X chromosome and compared samples of Lidia cattle with two Spanish breeds that show the opposite, calm behavior. The most important markers appeared in the vicinity of monoamine oxidase A (*MAOA*). A polymorphism consisting of a variable number of tandem repeats of nucleotide "C" was detected. The lower number of repeats in the Lidia breed compared to the other cattle breeds suggests that the lower number of these repeats is associated with aggressive behavior, rapid response and fast movement of the animal.

Among published research identifying novel genes for behavioral traits in cattle is the study by Garza-Brenner et al. (2016), which examined an interaction network approach to identifying novel genes (interacting genes) and evaluated their effects and the effects of 19 dopamine- and serotonin-related genes on temperament. Their potential to be associated with temperament was evaluated based on their reported biological activities, which included interactions with neuronal activity, receptor function, targeting or synthesis of neurotransmitters, and association with behavior. Results from Charolais cows in the Pen Score (PS) and Exit Velocity (EV) tests were used to calculate temperament. Results of single marker association analysis between genotypes and temperament measurements (EV, PS and/or TS Temperament Score) showed significant associations of six SNP from four candidate genes. Markers rs109576799 and rs43696138, located in the *DRD3* and *HTR2A* genes, respectively, were significantly associated with EV and TS traits. Four markers, rs110365063 and rs137756569 from the *POMC* gene and rs110365063 and rs135155082, located in *SLC18A2* and *DRD2*, were associated with PS.

In addition, Garza-Brenner et al. (2020) studied a group of molecular markers previously associated with temperament and their influence on growth traits. Phenotypic data were sorted and used to determine correlations between birth weight (BW), weaning weight (WW), yearling weight (YW), and temperament traits measured as exit velocity (EV is defined as the rate (m/s) at which an animal traverses a specific distance after exiting a squeeze chute) and temperament score (TS values were calculated by averaging the PS and EV). Pen score (PS) is a subjective measure, based on individual visual assessments of animals behavior while confined to a pen in groups of five animals, where a score of 1 is calm and 5 is aggressive. Significant correlations between BW and WW and both temperament scores (EV and TS) were observed only in the young cow group. The study showed that markers rs109576799 (*DRD3*), rs134604468, rs137756569 (*POMC*), and rs43696138 (*HTR2A*), previously associated with temperament traits in cattle, were also associated with weight traits (BW and WW). Four markers located on candidate genes for temperament traits also influenced BW and WW in Charolais cows, suggesting that both traits may be influenced by the same genes.

The propiomelanocortin (*POMC*) gene associated with temperament is located on chromosome BTA11. The *POMC* gene is a posttranslationally processed precursor of peptide hormones, some of which are involved in energy homeostasis, including α-melanocyte-stimulating hormone (MSH), adrenocorticotropic hormone (ACTH), and β-endorphin. Another gene of interest is neuropeptide Y (*NPY)*, which regulates appetite, feeding behavior, and hormonal function. Because of its role in feeding, some SNP of this gene have been associated with growth traits in cattle. Both the *POMC* and *NPY* genes are important regulatory factors in the leptin/melanocortin pathway, which is considered one of the most important pathways regulating energy metabolism. Both are involved in hypothalamic function – the pituitary-adrenal axis – which plays an important role in regulating numerous physiological processes, including reproduction, anxiety, stress response (fight-or-flight), learning and memory, and the cardiovascular system.

There are still no studies in the literature comparing the behavior of different breeds, especially animals raised under similar housing conditions. A study by Paredes-Sanchez et al. (2020) identified genomic regions and genes associated with temperament in Brahman cattle. In testing the cattle, they used three different tests: EV – exit velocity, PS – pen score, and TS – temperament score. Fourteen bovine temperament SNP were associated with the above tests, all with EV and few with PS and TS. They identified about 21 candidate genes for temperament in Brahman breed of cattle. Studies on the influence of breed on temperament specificity in cattle were also conducted on a sample of Nellore breed cattle, where they also investigated which candidate genes shape temperament in cattle. Valente et al. (2016) conducted a study to uncover genomic regions, potential candidate genes, and their biological mechanisms underlying temperament as measured by the running speed test (FS). In this study, nine regions associated with temperament were identified. Among them were six known genes *NCKAP5*, *PARK2*, *ANTXR1*, *GUCY1A2*, CPE and *DOCK1*. Of these genes, *PARK2*, *GUCY1A2*, *CPE* and *DOCK1* are related to the dopaminergic system, memory formation, biosynthesis of peptide hormones and neurotransmitters, or brain development.

Hiendleder et al. (2003) performed a genome scan for quantitative trait loci (QTL) in Holstein animals. They found 60 QTL that were significant at the 5% chromosome level for 22 body shape and behavior traits, with estimated heritabilities of 0.07–0.41, indicating that a substantial number of loci influence body conformation and behavior. Mapping QTL for body conformation and behavior in cattle on multiple chromosomes revealed that QTL for correlated traits are present in the same chromosomal regions. An example is a QTL for temperament and milking speed (rG = 0.53) on chromosome 5 at 136/136 cM, on chromosome 18 at 105/109 cM, on chromosome 29 at 20/20 cM, and on chromosome X/Y at 9/9 cM.

On the other hand, researchers have not detected any biological functions of the *DRD3* gene in cattle. However, in humans, genetic variants of dopamine receptor D3 (*DRD3*) have been linked to schizophrenia and autism. The gene has also been associated with emotional reactivity, executive functions, and stress responses. The bovine rs109576799 *DRD3* marker, located in the intron of the *DRD3* gene, suggests that this variation has no obvious functional effects on gene expression. However, its effect on temperament traits could be explained by the gene's role in emotional reactivity and the sensitivity of the dopamine system to environmental stressors, which in turn could be explained by its association with behavior (National Library of Medicine, 2024).

The results of previous studies have proven the genetic orientation of behavior and, moreover, have confirmed the assumption that certain behavioral traits are influenced by different genomic regions. Research by Dos Santos et al. (2017) examined genome-wide association studies for reactivity assessed by the REATEST® (this test uses an electronic device with an accelerometer positioned under the chute record of Guzerat (*Bos indicus*) cow movement for 20 seconds during routine weighing) (Table 3). They examined reactivity to humans, which is mainly influenced by past experience. They identified QTL for bovine reactivity on chromosomes BTA1, BTA5, BTA14, and BTA25. The candidate gene on the first chromosome is *ZBTB20* (zinc finger and *BTB* domain containing 20). The *ZBTB20* directly affects the development of different parts of the hippocampus and influences behavioral traits such as memory and anxiety. A candidate gene *KIAA1429* was identified on chromosome BTA14. Two associated genes were discovered on chromosome BTA25.

The first is the *ABCC1* gene, a membrane-associated protein belonging to the ATP superfamily, and the von Willebrand factor domain-containing gene 3A (*vWA3A*). Proteins containing von Willebrand domains are involved in basement membrane formation, cell migration, cell differentiation, adhesion, hemostasis, signal transduction, chromosome stability, malignant transformation, and immune defense. Although *vWA3A* is differentially expressed in blood, brain, lung, ovary, and testis, there is still no evidence for the function of this gene in cattle.

Bos indicus cattle often have a reputation for poor or dangerous temperament. For example, Riley et al. (2016) studied subjective temperament scores (1 to 9; higher scores indicate less favorable temperament) for aggressiveness, nervousness, flight, sociability and overall temperament in one-year-old *Bos indicus* crossbred cattle and weaned calves. *Bos indicus* cattle are characterized by a more stress response temperament and are also more aggressive than *Bos taurus* cattle. Therefore, they are of particular interest for the study of aggressiveness. Chen et al. (2020) found a total of five SNP on BTA1, BTA24, and BTA29 that we believe are associated with aggression, nervousness, or run/run speed when assessed after weaning, and 13 SNP on 11 chromosomes that are likely associated with aggression, nervousness, run or total temperament score of bulls at 1 year of age.

Milking speed (MS is mainly associated with the required milking time in relation to milk yield) and milking temperament (MT reflects behavioral responses to human or equipment during the milking process and can be subjectively scored on a linear scale of 1–5 points from very nervous to very calm animals) are important traits in breeding dairy cows. These two traits are of global importance because the intensification of farming, the introduction of modern devices that reduces contact with humans, e.g. automatic milking machines require properly adapted animals. This is important both from a breeding point of view and from the point of view of introducing both hereditary traits into selection. Genomic selection represents a potential method to increase the genetic progress of both traits. From this point of view, Chen et al. (2020) studied the associations of >5.7 million whole genome sequence variants with MT and MS in 4,381 and milk flow rate in 4,219 Holstein cattle. They found 40 and 35 significant SNP independently associated with MT and MS, respectively, distributed across 26 chromosomes (Table 3). Eight candidate genes *GRIN3A*, *KCNJ3*, *BOSTAUV1R417*, *BOSTAUV1R419*, *MAP2K5*, *KCTD3*, *GAP43*, and *LSAMP* are thought to play an important role in the expression of MT traits because they are involved in biologically important signaling pathways such as the glutamatergic synapse, vomeronasal receptor, and oxytocin signaling. Since production traits in animal breeding are usually polygenic, this is also true in our case. MT and MS are traits regulated by a large number of genes. The SNP for both traits were located on 19 chromosomes. Important biological pathways have also been identified in relation to the expression of this trait, such as glutamatergic synapse function and oxytocin signaling. Knowledge of the biological mechanisms underlying the phenotypic expression of MT and MS in dairy cows is useful for optimizing genomic prediction of breeding value.

Table 3: Chromosomes and genes responsible for temperament traits in cattle

Chromosome	Temperament characteristic	Peak markers	Gen	Reference
1	Reactivity	rs41965198		Dos Santos et al. (2017)
1	Reactivity	rs109007595	POU1F1 (POU class 1 homeobox 1)	Dos Santos et al. (2017)
1	Milking temperament	rs109576799	*DRD3* (dopamine receptor D3)	Garza-Brenner et al. (2016)
1	Milking temperament	rs211042818		Chen et al. (2020)
1	Milking temperament	rs42810614		Chen et al. (2020)
1	Milking temperament Reactivity	rs108944043	*ZBTB20* (zinc finger and BTB domain containing 20)	Dos Santos et al. (2017)
2	Milking temperament	rs383768960		Chen et al. (2020)
3	Temperament	rs110572929	*OR6P1* (olfactory receptor, family 6, subfamily P, member 1)	Riley et al. (2016)
3	Temperament	rs110358340		Riley et al. (2016)

Chromosome	Temperament characteristic	Peak markers	Gen	Reference
3	Milking temperament	rs208423467		Chen et al. (2020)
3	Milking temperament	rs132650029		Chen et al. (2020)
3	Milking temperament	rs446551565		Chen et al. (2020)
3	Milking temperament	rs110358340		Chen et al. (2020)
4	Milking temperament	rs41587635	*NRCAM* (neuronal cell adhesion molecule)	Kolbehdari et al. (2008)
5	Reactivity	rs29002595		Dos Santos et al. (2017)
6	Milking temperament	rs211661579		Chen et al. (2020)
6	Milking temperament	rs381423005		Chen et al. (2020)
8	Milking temperament	rs43695372		Chen et al. (2020)
8	Milking temperament	rs382298735		Chen et al. (2020)
9	Milking temperament	rs210732867		Chen et al. (2020)
9	Milking temperament	rs109147749	*SFT2D1* (SFT2 domain containing 1)	Chen et al. (2020)
9	Milking temperament	rs377930383	*TBC1D32* (TBC1 domain family member 32)	Chen et al. (2020)
9	Milking temperament	rs110768750		Chen et al. (2020)
9	Milking temperament	rs383164349	CFAP206 (cilia and flagella associated protein 206)	Chen et al. (2020)
9	Milking temperament	rs385265013	*TBC1D32* (TBC1 domain family member 32)	Chen et al. (2020)
10	Milking temperament	rs385815295	*MAP2K5* (mitogen-activated protein kinase kinase 5)	Chen et al. (2020)
10	Milking temperament	rs442437054	*REC114* (REC114 meiotic recombination protein)	Chen et al. (2020)
11	Pen score	rs134604486	*POMC* (proopiomelanocortin)	Garza-Brenner et al. (2016)
11	Pen score	rs137756569	*POMC* (proopiomelanocortin)	Garza-Brenner et al. (2016)
11	Milking temperament	rs461599895		Chen et al. (2020)
12	Temperament	rs43696138	*HTR2A* (5-hydroxytryptamine receptor 2A)	Garza-Brenner in sod. (2016)
12	Milking temperament	rs207744310		Chen et al. (2020)
12	Milking temperament	rs133939404		Chen et al. (2020)
13	Milking temperament	rs41601522	*CSTF1* (cleavage stimulation factor subunit 1)	Kolbehdari et al. (2008)

Chromosome	Temperament characteristic	Peak markers	Gen	Reference
14	Reactivity	rs110729726	*KIAA1429* (KIAA1429 ortholog)	Dos Santos et al. (2017)
14	Milking temperament	rs433044051		Chen et al. (2020)
15	Pen score	rs135155082	*DRD2* (dopamine receptor D2)	Garza-Brenner et al. (2016)
16	Milking temperament	rs381220479		Chen et al. (2020)
16	Milking temperament	rs385094052		Chen et al. (2020)
16	Milking temperament	rs380118891		Chen et al. (2020)
17	Milking temperament	rs457419900		Chen et al. (2020)
18	Milking temperament	rs209543233		Chen et al. (2020)
21	Milking temperament	rs109756761	*ADAMTS7* (ADAM metallopeptidase with thrombospondin type 1 motif 7)	Chen et al. (2020)
22	Milking temperament	rs29024274	*CACNA1D* (calcium channel, voltage-dependent, L type, alpha 1D subunit)	Kolbehdari et al. (2008)
22	Milking temperament	rs134284583	EEFSEC (eukaryotic elongation factor, selenocysteine-tRNA specific)	Chen et al. (2020)
22	Milking temperament	rs383977582	*KBTBD12 (kelch repeat and BTB domain containing 12)*	Chen et al. (2020)
23	Milking temperament	rs41667511	*BYSL* (bystin like)	Kolbehdari et al. (2008)
23	Temperament	rs42037482	*RREB1* (ras responsive element binding protein 1)	Riley et al. (2016)
23	Milking temperament	rs383925248		Chen et al. (2020)
24	Milking temperament	rs208988018		Chen et al. (2020)
25	Reactivity	rs42063418	*ABCC1* (ATP binding cassette subfamily C member 1)	Dos Santos et al. (2017)
25	Reactivity	rs109589165	*VWA3A* (von Willebrand factor A domain containing 3A)	Dos Santos et al. (2017)
26	Milking temperament	rs1606777	SLC18A2 (solute carrier family 18 (vesicular monoamine transporter), member 2) *SLC18A2* (solute carrier family 18 (vesicular monoamine transporter), member 2)	Kolbehdari et al. (2008)
26	Pen score	rs110365063	SLC18A2 (solute carrier family 18 (vesicular monoamine transporter), member 2)	Garza-Brenner et al. (2016)
27	Milking temperament	rs207974554	ZMAT4 (zinc finger matrin-type 4)	Chen et al. (2020)
27	Milking temperament	rs211354263		Chen et al. (2020)
27	Milking temperament	rs433573094	*ZMAT4* (zinc finger matrin-type 4)	
27	Milking temperament	rs109526335		Chen et al. (2020)
27	Milking temperament	rs109475419	ZNF385D (zinc finger protein 385D)	Chen et al. (2020)

Chromosome	Temperament characteristic	Peak markers	Gen	Reference
27	Milking temperament	rs385056921	ZMAT4 (zinc finger matrin-type 4)	Chen et al. (2020)
27	Milking temperament	rs42891178		Chen et al. (2020)
29	Milking temperament	rs466626658		Chen et al. (2020)
29	Temperament	Up:BMS764 Low:BMC8012		Hiendleder et al. (2003)
29	Temperament	BMS764		Glenske et al. (2011)
29	Milking temperament	rs41652321	CCDC88B (coiled-coil domain containing 88B)	Kolbehdari et al. (2008)
29	Miking temperament	rs41584970		Kolbehdari et al. (2008)
29	Milking temperament	rs43706181	*DPP3* (dipeptidyl peptidase 3)	Kolbehdari et al. (2008)
29	Milking temperament	rs29024010	*NTM* (neurotrimin)	Kolbehdari et al. (2008)

CONCLUSIONS

To date, there have been many findings on behavioral genetics, from candidate genes to the effects of SNPs and QTLs to research on associations between SNPs and QTLs. Research confirms that phenotypic differences are the result of the influence of a few loci with a strong effect or a larger number of them with a small effect. The influence of genetic variants on behavior is not direct, but results from a complex feedback network of neurophysiological and structural factors such as hormones and proteins, which in turn are products of indirect genetic effects. Due to environmental influences, genes that influence temperament in cattle are less heritable compared to genetic loci associated with production traits. Future research on behavioral traits in cattle will likely focus on further exploring the genetic background and how variations in genes influence the expression of temperament in individual animals. This will make it possible to include temperament traits in selection indices. The main challenges for a more comprehensive integration of temperament in dairy cattle breeding programs are the definition of individual traits and large-scale monitoring of temperament. On the other hand, there is still a lack of understanding of the genetic background of traits and the availability of economic values for temperament.

REFERENCES

1. Adamczyk, K., Pokorska, J., Makulska, J., Earley, B., & Mazurek, M. (2013). Genetic analysis and evaluation of behavioural traits in cattle. *Livestock Science*, *154*, 1-12. Retrieved from: https://dx.doi.org/10.1016/j.livsci.2013.01.016
2. Alvarenga, A. B., Oliveira, H. R., Chen, S. Y., Miller, S. P., Marchant-Forde, J. N., Grigoletto, L., & Brito, L. F. (2021). A systematic review of genomic regions and candidate genes underlying behavioral traits in farmed mammals and their link with human disorders. *Animals*, *11*(3), 715. Retrieved from: https://doi.org/10.3390/ani11030715
3. Ball, N. (2003). T*emperament traits in cattle: Measurement and pre-liminary genetic analysis* (Doctoral dissertaion). The University of Edinburgh, pp. 80-86. Retrieved from: https://era.ed.ac.uk/handle/1842/10716
4. Bailey, J. N., Breidenthal, S. E., Jorgensen, M. J., McCracken, J. T., & Fairbanks, L. A. (2007). The association of DRD4 and novelty seeking is found in a nonhuman primate model. *Psychiatric Genetics*, *17*(1), 23-27. Retrieved from: https://doi10.1097/YPG.0b013e32801140f2
5. Bailey, D. W., Lunt, S., Lipka, A., Thomas, M. G., Medrano, J. F., Cánovas, A., Rincon, G., Stephenson, M. B., & Jensen, D. (2015). Genetic influences on cattle grazing distribution: Association of genetic markers with terrain use in cattle. *Rangeland Ecology & Management*, *68*, 142-149. Retrieved from: https://doi.org/10.1016/j.rama.2015.02.001
6. Bendesky, A., & Bargmann, C. (2011). Genetic contributions to behavioural diversity at the gene-environment interface. *Nature Reviews Genetics*, *12*, 809-820. Retrieved from: https://doi.org/10.1038/nrg3065
7. Brand, B., Hadlich, F., Schauer, N., Graunke, K. L., Langbein, J., Repsilber, D., Ponsuksili, S., & Schwerin, M. (2015). Temperament type specific metabolite profiles of the prefrontal cortex and serum in cattle. *PLoS ONE*, *10*, e0125044. Retrieved from: https://doi.org/10.1371/journal.pone.0125044

8. Boldt, C. R., (2008). *A study of cattle disposition: Exploring QTL associated with temperament*. A Senior Honors Thesis. University Undergraduate Research Fellows, Texas A&M University.
9. Burrow, H. M. (1997). Measurement of temperament and their relationship with performance traits of beef cattle. *Animal Breeding Abstract*s, *65*, 477-495.
10. Cafe, L. M., Robinson, D. L., Ferguson, D. M., McIntyre, B. L., Geesink, G. H., & Greenwood, P. L. (2011). Cattle temperament: persistence of assessments and associations with productivity, efficiency, carcass and meat quality traits. *Journal of Animal Science*, *89*(5), 1452-1465. Retrieved from: https://doi.org/10.2527/jas.2010-3304
11. Chen, S. Y., Oliveira, H. R., Schenkel, F. S., Pedrosa, V. B., Melka, M. G., & Brito, L. F. (2020). Using imputed whole-genome sequence variants to uncover candidate mutations and genes affecting milking speed and temperament in Holstein cattle. *Journal of Animal Science*, *103*(11), 10383-10398. Retrieved from: https://doi.org/10.3168/jds.2020-18897
12. Dos Santos, L. V., Peixota, M. G. C. D., Fonseca, P. A. S., Pires, M. F. A., Ventura, R. V., Rosse, I. C., Bruneli, F. A. T., Machado, M. A., & Carvalho, R. S. (2017). Identification of candidate genes for reactivity in guzerat (*Bos indicus*) cattle: A genome-wide association study. *PLoS ONE*, *12*(1), e0169163. Retrieved from: https://doi.org/10.1371/journal.pone.0169163
13. Eusebi, P. G., Sevane, N., Cortés, O., Contreras, E., Cañon, J., & Dunner, S. (2019). Aggressive behavior in cattle is associated with a polymorphism in the MAOA gene promoter. *Animal Genetics*, *51*(1), 14-21. Retrieved from: https://doi.org/10.1111/age.12867
14. Ferguson, D., & Warner, R. (2008). Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? *Meat Science*, *80*, 12-19. Retrieved from: https://doi.org/10.1016/j.meatsci.2008.05.004
15. Friedrich, J., Brand, B., Ponsuksili, S., Graunke, K. L., Langbein, J., Knaust, J., Kuehn, C., & Schwerin, M. (2015.) Detection of genetic variants affecting cattle behaviour and their impact on milk production: a genome-wide association study. *Animal Genetics*, *47*(1), 12-18. Retrieved from: https://doi.org/10.1111/age.12371
16. Garza-Brenner, E., Sifuentes-Rincón, A. M., Randel, R. D., Paredes-Sánchez, F. A., Parra-Bracamonte, G. M., Vera, W. A., Rodríguez Almeida, F. A., & Segura Cabrera, A. (2016). Association of SNPs in dopamine and serotonin pathway genes and their interacting genes with temperament traits in Charolais cows. *Journal of Applied Genetics*, *58*(3), 363-371. Retrieved from: https://doi.org/10.1007/s13353-016-0383-0
17. Garza-Brenner, E., Sifuentes-Rincón, A. M., Rodríguez-Almeida, F. A., Randel, R. D., Parra-Bracamonte, G. M., & Arellano-Vera, W. (2020). Influence of temperament-related genes on live weight traits of Charolais cows. *Revista Brasileira de Zootecnia*, *49*, e20180121. Retrieved from: https://doi.org/10.37496/rbz4920180121
18. Glenske, K., Prinzenberg, E. M., Brandt, H., Gauly, M., & Erhardt, G. (2011). A chromosome-wide QTL study on BTA29 affecting temperament traits in German Angus beef cattle and mapping of DRD4. *Animal*, *5*(2), 195-197. Retrieved from: https://doi.org/10.1017/S1751731110001801
19. Grandin, T. (1989). Behavioral principles of livestock handling. *The Professional Animal Scientist*, *5*(2), 1-11. Retrieved from: https://doi.org/10.15232/S1080-7446(15)32304-4
20. Guo, J., Jorjani, H., & Carlborg, Ö. (2012). A genome-wide association study using international breeding-evaluation data identifies major loci affecting production traits and stature in the Brown Swiss cattle breed. *BMC Genetics*, *13*, 82. Retrieved from: https://doi.org/10.1186/1471-2156-13-82
21. Gutiérrez-Gil, B., Ball, N., Burton, D., Haskell, M., Williams, J. L., & Wiener, P. (2008). Identification of quantitative trait loci affecting cattle temperament. *Journal of Heredity*, *99*(6), 629-638. Retrieved from: https://doi.org/10.1093/jhered/esn060
22. Haskell, M. J., Simm, G., & Turner, S. P. (2014). Genetic selection for temperament traits in dairy and beef cattle. *Frontiers in Genetics*, *5*(368), 1-18. Retrieved from: https://doi.org/10.3389/fgene.2014.00368
23. Hiendleder, S., Thomsen, H., Reinsch, N., Bennewitz, J., Leyhe-Horn, B., Looft, C., Xu, N., Medjugorac, I., Russ, I., Kühn, C., Brockmann, G. A., Blümel, J., Brenig, B., Reinhardt, F., Reents, R., Averdunk, G., Schwerin, M., Förster, M., Kalm, E., & Erhardt, G. (2003). Mapping of QTL for body conformation and behavior in cattle. *Journal of Heredity*, *94*(6), 496-506. Retrieved from: https://doi.org/10.1093/jhered/esg090
24. Higashi, Y., Asanuma, M., Miyazaki, I., & Norio Ogawa, N. (2000). Inhibition of tyrosinase reduces cell viability in catecholaminergic neuronal cells. *Journal of Neurochemistry*, *75*, 1771-1774. Retrieved from: https://doi.org/10.1046/j.1471-4159.2000.0751771.x
25. Johnston, T. D., & Edwards, L. (2002). Genes, interactions, and the development of behavior. *Psychological Review*, *109*(1), 26. Retrieved from: https://doi.org/10.1037/0033-295X.109.1.26
26. Kolbehdari, D., Wang, Z., Grant, J. R., Murdoch, B., Prasad, A., Xiu, Z., Marques, E., Stothard, P., & Moore, S. S. (2008). A whole-genome scan to map quantitative trait loci for conformation and functional traits in Canadian Holstein bulls. *Journal of Dairy Science*, *91*(7), 2844-2856. Retrieved from: https://doi.org/10.3168/jds.2007-0585
27. Korsten, P., Mueller, J. C., Hermannstädter, C., Bouwman, K. M., Dingemanse, N. J., Drent, P. J., Liedvogel, M., Matthysen, E., van Oers, K., van Overveld, T., Patrick, S. C., Quinn, J. L., Sheldon, B. C., Tinbergen, J. M., & Kempenaers, B. (2010). Association between DRD4 gene polymorphism and personality variation in great tits: a test across four wild populations. *Molecular Ecology*,

19(4), 832-843. Retrieved from: https://doi.org/10.1111/j.1365-294X.2009.04518.x

28. Lander, E. S., Linton, L. M., Birren, B., Nusbaum, C., Zody, M. C., Baldwin, J., Devon, K., Dewar, K., Doyle, M., FitzHugh, W., Funke, R., Gage, D., Harris, K., Heaford, A., Howland, J., Kann, L., Lehoczky, J., LeVine, R., McEwan, P., McKernan, K., Meldrim, J., Mesirov, J. P., Miranda, C., Morris, W., Naylor, J., Raymond, C., Rosetti, M., ...& Morgan, M. J. (2001). Initial sequencing and analysis of the human genome. *Nature*, *409*, 860–921. Retrieved from: https://doi.org/10.1038/35057062
29. Lühken, G., Glenske, K., Brandt, H., & Erhardt, G. (2010). Genetic variation in monoamine oxidase A and analysis of association with behaviour traits in beef cattle. *Journal of Animal Breeding and Genetics*, *127*(5), 411-418. Retrieved from: https://doi.org/10.1111/j.1439-0388.2010.00855.x
30. Martin, P., & Bateson, P. (1993). *Measuring behaviour: An introductory guide*, 2nd ed. Cambridge: Cambridge University Press.
31. Miles, C. M., & Wayne, M. (2008). Quantitative trait locus (QTL) analysis. *Nature Education*, *1*(1), 208.
32. Momozawa, Y., Takeuchi, Y., Kusunose, R., Kikusui, T., & Mori, Y. (2005). Association between equine temperament and polymorphisms in dopamine D4 receptor gene. *Mammalian Genome*, *16*, 538–544. Retrieved from: https://doi.org/10.1007/s00335-005-0021-3
33. NIH. National Library of Medicine. (2024) Retrieved from: https://www.ncbi.nlm.nih.gov/gene/1814
34. Paredes-Sanchez, F. A. P., Rincon, A. M. S., Casas, E., Vera, W. A., Bracamonte, G. M. P., Riley, D. G., Welsh Jr, T. H., & Randel, R. D. (2020). Novel genes involved in the genetic architecture of temperament in Brahman cattle. *PLoS ONE*, *15*(8), e0237825. Retrieved from: https://doi.org/10.1371/journal.pone.0237825
35. Riley, D. G., Gill, C. Bold, C., R., Funkhouser, R. R., Herring, A. D., Riggs, P. K., Sawyer, J. E., Lunt, D. K., & Sanders, J. O. (2016). Crossbred steer temperament as yearlings and whole genome association of steer temperament as yearlings and calf temperament post-weaning. *Journal of Animal Science*, *94*(4), 1408-1414. Retrieved from: https://doi.org/10.2527/jas.2015-0041
36. Schmidtz, B. H., Buchanan, F. C., Plante, Y., & Schmutz, S. M. (2001). Linkage mapping of the tyrosinase gene to bovine chromosome 29. *Animal Genetics*, *32*, 119-120. Retrieved from: https://doi.org/10.1046/j.1365-2052.2001.0700j.x
37. Schmutz, S. M., Stookey, J. M., Winkelman-Sim, D. C., Waltz, C. S., Plante, Y., & Buchanan, F. C. (2001). A QTL study of cattle behavioral traits in embryo transfer families. *Journal of Heredity*, *92*(3), 290-292. Retrieved from: https://doi.org/10.1093/jhered/92.3.290
38. Schrooten, C., Bovenhuis, H., Coppieters, W., & Van Arendonk, J. A. M. (2000). Whole genome scan to detect quantitative trait loci for conformation and functional traits in dairy cattle. *Journal of Dairy Science*, *83*, 795-806. Retrieved from: https://doi.org/10.3168/jds.S0022-0302(00)74942-3
39. Valente, T. S., Baldi, F., Sant'Anna, A. C., Albuquerque, L. G., & Paranhos da Costa, M. J. R. (2016). Genome-wide association study between single nucleotide polymorphisms and flight speed in Nellore cattle. *PloS ONE*, *11*(6), e0156956. Retrieved from: https://doi.org/10.1371/journal.pone.0156956
40. Voisinet, B. D., Grandin, T., Tatum, J. D., O'connor, S. F., & Struthers, J. J. (1997). Feedlot cattle with calm temperaments have higher average daily gains than cattle with excitable temperaments. *Journal of Animal Science*, *75*(4), 892-896. Retrieved from: https://doi.org/10.2527/1997.754892x
41. Wegenhoft, M. A. (2005). *Locating quantitative trait loci associated with disposition in cattl*e. A Senior Honors Thesis. University Under-graduate Research Fellows, Texas A&M University.
42. Xu, Y., Stokes, A. H., Roskoski, R., Jr., & Kent, E. V. (1998). Dopamine, in the presence of tyrosinase, covalently modifies and inactivates tyrosine hydroxylase. *Journal of Neuroscience Research*, *54*, 691-697. Retrieved from: https://doi.org/10.1002/(SICI)1097-4547(19981201)54:5<691::AID-JNR14>3.0.CO;2-F

Genetsko ozadje temperamenta goveda: kratek pregled

IZVLEČEK

Temperament živali opisuje vedenjske razlike med posamezniki, ki so stalne skozi čas in v različnih okoliščinah. Poznavanje temperamenta živali pomembno vpliva na varnost pri ravnanju z živalmi in skrbi zanje ter na prilagajanje živali spreminjajočim se pogojem reje. Da bi razumeli temperament živali, moramo poleg genetske osnove temperamenta poznati tudi vpliv okolja na njegovo izražanje. Podobno lahko temperament krav molznic opredelimo kot odziv živali na okoljske ali socialne dražljaje. V tem preglednem članku so predstavljeni kromosomi z genomskimi območji, ki vsebujejo QTL, gene in kandidatne gene, odgovorne za izražanje lastnosti temperamenta pri govedu. Poznavanje genetskega ozadja izražanja temperamenta pri govedu in njegove spremenljivosti pri teh lastnostih omogoča vključitev temperamenta v selekcijske indekse.

Ključne besede: govedo, genetika temperamenta, QTL, SNP, dednost, serotonin, dopamin

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Supplemental Role of Fodder Tree Legumes in Dwarf Sheep and Goats Feeding Systems – A Review

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ABSTRACT

The potential of fodder tree legumes (FTL) as a promising and nutritional strategy to minimize the problem of insufficient supply of forages, especially during the dry season, in West African dwarf sheep and goats' production systems was reviewed. For more sustainable agricultural systems, including expanding the use of locally produced available feedstuffs, FTL species with a focus on *Leucaena leucocephala*, *Gliricidia sepium,* and *Enterolobium cyclocarpum* represent an interesting strategy to provide dietary nitrogen and improve feed digestibility, weight gain, and nitrogen retention, thus enhancing dwarf sheep and goats' productivity. They also contain concentrations of biologically active compounds with nutraceutical value that assist in slowing down the infections with parasitic nematodes of the gastrointestinal tract and mitigating enteric methane emissions from these animals. The dietary crude protein and tannin content ranged from 16.20 to 26.79% and 0.95 to 2.92%, respectively across the FTL species. Mean weight gain (g/day) of 43.23 to 48.59 and 32.46 to 40.87, respectively were reviewed for dwarf sheep and goats fed FTL supplementary diets. Haematological and serum biochemical variables monitored were within the permissible range for healthy animals and showed the adequacy of nutrient supply from FTL species with nutrient utilization to improve productivity. The review concluded that the combination of excellent nutritive value reported for FTL provides important opportunities for sustainable dwarf sheep and goat feeding systems.

Keywords: sheep, goats, performance, tree legumes, tannins, anthelminthic, methane mitigation

INTRODUCTION

The dwarf breeds of sheep and goats are widely distributed throughout the humid savannah zones of Nigeria where they have been part of rural livelihoods for eras, playing a significant role in the food chain and being instrumental in poverty reduction in resource-poor communities (Lebbie, 2004; Fasae et al., 2012; Adebayo et al., 2022). These animals with an average weight of 20-30kg and 25-40kg for goats and sheep, respectively have immense contributions to rural livelihoods within the West African subregion (NRC, 1991; Odeyinka, 2001; Odusanya et al., 2017). Despite the valuable contributions of these animals to farmers' livelihoods, inadequate nutrition through prolonged dry season droughts and infections with gastrointestinal parasites pose a threat and represent a major constraint to their sustainable production (Lamidi and Ologbose, 2014). During this dry period, the natural pasture does not only have low dry matter yield but is also poor in quality with low crude protein content. Hence, the nutrient bioavailability to livestock production from such feed resources is very poor to fulfill the energy requirement to maintain their body weight, resulting in low digestibility, severe drop in body condition, and poor productivity of the animals (Odusanya et al., 2017).

This has however necessitated the exploration of drought resistance fodder tree legumes (FTL) which are of good quality to meet the nutritional requirements of these animals for year-round feeding, so as to attain their genetic potential. FTL are important evergreen strategic feed resources in ruminant production systems and serve as a potential source of readily available high-quality fodder with relatively low feeding costs, to many smallholders. They have remained to complement the dry season feed supply, as they possess the potential for vigorous growth, re-growth, and palatability, serving as an integral part of farming systems that have significant promise for ruminant production in

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the tropics (Kebede et al., 2016; Getachew et al., 2022). FTL has been widely used as a source of supplemental nitrogen for ruminants. The leaves have high crude protein, minerals, and degradability when used as a supplement to low-quality roughages. (Abdulrazak et al., 1997; Reynolds and Atta-Krah, 2006; Fasae and Bello, 2023).

The presence of tannins in FTL leaves which account for up to 20% of the dry matter (Harvey et al., 2019) have likewise demonstrated noteworthy benefits for ruminants when consumed moderately. Tannins have been found to serve as a bioactive substance that significantly improves productive performance, serving as a practical and realistic alternative to non-drug gastro-intestinal parasite control strategies as well as supporting the manipulation of rumen fermentation to induce methane mitigation in ruminant production systems (Jerónimo et al., 2016; Jafari et al., 2019; Besharati et al., 2022).

This paper reviews the supplemental role of *Leucaena leucocephala*, *Gliricidia sepium,* and *Enterolobium cyclocarpum* fodder tree legumes, based on their availability, high nutritive value, and inclusion in diets as one of the many ways of improving the utilization of poor-quality roughages in dwarf sheep and goat feeding systems.

CHEMICAL CONSTITUENTS OF FODDER TREE LEGUMES

Wide variation was observed in the crude protein (CP) contents of the leaves of FTL species (Table 1). Values obtained were within 16.20 to 25.76% which were above the threshold level of 7% CP required by the microbes in the rumen to support the metabolic functions of their host (NRC, 2000). The high dietary protein content of FTL species demonstrates their ability to correct nitrogen deficiency in augmenting the quality of local forages for sheep and goat production. Thus, assists in maintaining seasonal and yearly feed stability and also ensures sustainable rural livelihoods, when compared to ruminant systems based on grass or cereals, especially during dry periods. The dietary NDF contents across the FTL species were within the permissible limit guaranteed as optimal intake of tropical feeds by ruminant animals (Van Soest, 1994). These levels have been attributable to the better influence of dry matter intake and time of rumination by these animals. Nutritional models have predicted dietary NDF to be an important driver of rumen digesta load and therefore feed intake (Ellis et al., 1999). NDF lower than 30% can result in possible rumen health issues such as acidosis, while values higher than 60% are negatively correlated with lower consumption, which means the animal fills up faster.

The detection of trace amounts of tannins, a group of "secondary" plant metabolites described to account for up to 20% of the dry matter in forage legumes have been observed to form complexes with protein, carbohydrate, alkaloids, vitamins, and minerals. Mean moderate values obtained for tannins in FTL forages fed to dwarf sheep and goats were within the bearable range which was attributed mostly to the effect of air and sun-drying of the leaves. This supports the assertions in many reports that air and sun-drying reduce or inhibit tannin concentration in forages (Stewart and Mould, 2000; Mohamed et al., 2015). Moderate dietary tannin concentrations (<3 % dry matter-DM) in ruminant diets have been confirmed to be bloat-free with more rumen undegradable protein, and a beneficial role as antioxidants that can supply satisfactory dietary protein for post-ruminal digestion and absorption in the small intestine to significantly enhance ruminant productive performance (Lowry et al., 1996; Serra et al., 2021).

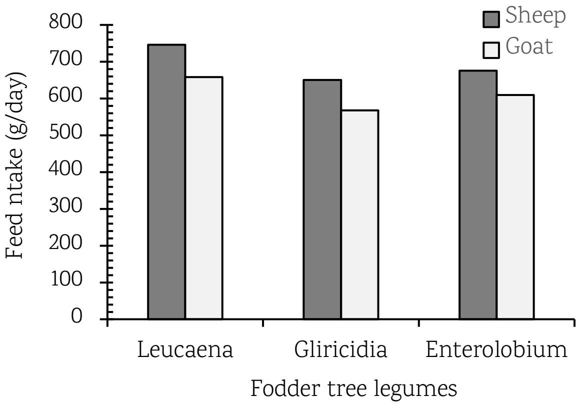
Table 1: Chemical composition range of some fodder tree legumes fed to dwarf sheep and goats

Nutrients	*Leucaena*	*Enterolobium*	*Gliricidia*
Dry matter (%)	92.93–94.56	88.82–93.77	89.54–95.32
Crude protein (%)	19.60–26.79	16.20–23.42	18.52–24.73
Ether extract (%)	2.04–6.57	4.03–10.34	2.77–7.02
Neutral detergent fibre (%)	44.67–58.70	40.42–59.00	45.89–52.65
Acid detergent fibre (%)	33.55–41.20	28.45–38.25	29.95–35.78
Acid detergent lignin (%)	10.95–14.67	13.78–14.92	9.75–13.50
Tannin (%)	1.45–2.52	1.24–2.11	0.95–1.94
Gross energy (MJ/kg dry matter)	18.01–23.60	19.21–23.07	19.23–22.72

Data summarized from: Devendra, 1982; Odeyinka et al., 2001; Oduguwa et al., 2008; Fadiyimu et al., 2012; Fasae and Omosun, 2013; Ekanem et al., 2023.

FEED INTAKE OF FODDER TREE LEGUMES IN DWARF SHEEP AND GOATS

The feed intake (% DM) of FTL by dwarf sheep and goats was considerably high with both species of animals consuming an average of 3 to 4 % of their body weight (Figure 1). The high crude protein (CP) content observed in FTL species has been an important factor that enables high feed consumption by these animals. These reportedly promote a favorable rumen environment ensuing enhanced fermentation of low-quality forages, thus increasing microbial protein synthesis, rate, and extent of digestion which prompted an increase in DM intakes (Bonsi et al., 1994; Abdulrazak et al., 1996; Jabbar et al.,1997; Fasae et al., 2011; Kang et al., 2015).



Data summarized from: Smith et al., 1995; Odeyinka, 2001; Fasae et al., 2010; Oduguwa et al., 2013; Ekanem et al., 2022.

Figure 1: Mean dry matter feed intake (g/day) of supplementary fodder tree legume diets by Dwarf sheep and goats

Feeding FTL levels of less than 30% as supplemental diets to dwarf sheep and goats significantly improved dry matter intake and performance (Smith et al., 1995; Fasae et al., 2011; Ekanem et al., 2022). Low to moderate dietary tannin concentrations have been found to possess minimal bitter and astringent taste, thus increasing palatability, preference, and eventually voluntary feed intake in ruminants (Fasae and Omosun, 2013; Tseu et al., 2020). However, low DM intake observed in some FTL forages like Gliricidia, supports few studies that recognized its feeding value to an odour adduced to the volatile compounds released from its leaves surface which has been implicated in this initial reluctance of animals to eat Gliricidia (Odeyinka et al., 2001; Fasae et al., 2010). Besides, wilting and a short period of adaptation have been found to overcome these palatability problems associated with Gliricidia forage, with no long-term detrimental effects on the animals, once adapted.

NUTRIENT DIGESTIBILITY, NITROGEN UTILIZATION AND METHANE PRODUCTION BY DWARF SHEEP AND GOATS FED FODDER TREE LEGUMES SUPPLEMENTARY DIETS

The mean values for nutrient digestibility (%), nitrogen retention, and methane production of FTL diets fed to Dwarf sheep and goats are presented in Table 2. The dry matter and crude protein digestibility values were reasonably high across animal species reportedly attributed to the high dietary protein content in FTL plants (Ikyume et al., 2018; Garba Bala and Rabiu Hassan, 2023). This assertion corroborates other studies that have shown the influence of increasing dietary protein levels from forage legumes to have improved the apparent nutrient digestibility of low-quality forages. Different outputs from research demonstrated a linear increase in CP digestibility with increasing levels of FTL leaf meal supplementation and established their advantages in the process of digestibility improvements (Tolera and Sundstøl, 2000; McDonald et al., 2002).

Table 2: Mean nutrient digestibility, nitrogen retention, and methane production of fodder tree legumes supplementary diets fed to Dwarf sheep and goats

Nutrients	Sheep	Goats
Dry matter digestibility (%)	74.92	73.40
Crude protein digestibility (%)	77.48	75.68
Neutral detergent fibre digestibility (%)	62.69	64.32
Nitrogen retention (%)	71.81	69.68
Methane (g CH_4 kg/DMI)	20.12	19.72

Data summarized from: Osakwe and Steingass, 2006; Fasae et al., 2010; Oyedele et al., 2016; Ikyume et al., 2018.

Moreover, the influence of moderate concentrations of dietary tannins was described to improve the digestive utilization of feed mainly due to a reduction in protein degradation in the rumen and a subsequent increase in amino acid flow to the small intestine (Frutos et al., 2004; Wen et al., 2020; Besharati et al., 2022), with effects reflected in animal performance. Cabral Filho et al. (2013) investigated three levels of tannin in the diet of sheep and reported a different DM digestibility between high- and low-tannin plants. The low tannin content diet had a higher CP digestibility, and there were no significant differences between the medium tannin content and high tannin content diets.

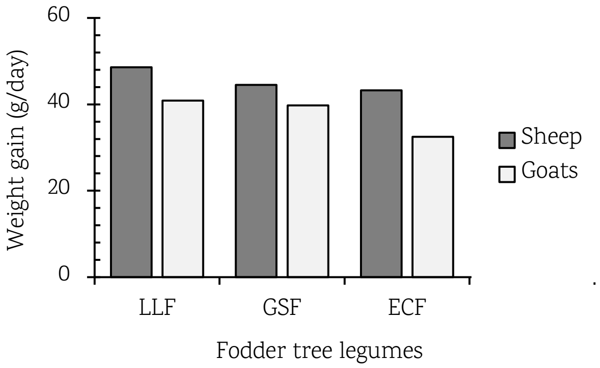
The positive nitrogen retention values demonstrated that the FTL-supplemented diets were well utilized and efficiently used as fermentable nitrogen sources for microbial growth in the rumen. Nitrogen balance has been described as a good indicator of the protein value of a diet when the amino acid supply is balanced with the energy supply (Babayemi and Bamikole, 2006). McSweeney et al. (2001) reviewed the effects of decreasing dietary tannin to have increased nitrogen digestibility and excretory nitrogen in sheep faeces.

Feeding FTL as supplementary diets to dwarf sheep and goats shows its capability in methane mitigation. The quantity and rate of fermentability of tannin contained FTL diets were reported to affect ruminal pH, volatile fatty acids production, incorporation and stimulation of the ruminal ammonia nitrogen into microbial protein for adequate utilization in the rumen of sheep and goats (Osakwe and Steingass, 2006; Olafadehan et al., 2016). Tannins have ample biological activity in ruminal fermentation processes as they somehow affect the growth rate of the rumen microbial population to irritate changes that induce mitigation of enteric methane emissions in ruminants. They support the manipulation of rumen fermentation and induce a reduction in methane synthesis in the rumen (Jafari et al., 2019), directly or indirectly by either impeding methanogens or protozoal population and nitrogen-producing microbes. with several possible hypotheses to describe the mechanisms of action of tannins on enteric methane mitigation (Newbold et al., 1997; Jayanegara et al., 2015; Naumann et al., 2017; Adejoro, 2019). Tenzin Tseten (2022) acknowledged that feed manipulation remains the most cost-effective approach, attaining a substantial 60% reduction in methane by meticulously opting for the type or quality of forage and optimizing the concentrate-to-forage ratio in feed. A review by Eckard et al. (2010) noted a 13–16% methane reduction per kg DM intake with tannin-containing forages across a number of studies. Reduced methane emissions from ruminants fed on legume-based forage diets tend to have less negative environmental impact on biodiversity, nitrogen losses to water, as well as greenhouse gas emissions (Phelan et al., 2015). Economically, apart from its environmental benefits, FTL used as feed supplements has the primary advantage of improving farmers' income by reducing protein costs and improving the efficiency of productive ruminants.

FODDER TREE LEGUMES' SUPPLEMENTARY EFFECT ON WEIGHT GAIN OF DWARF SHEEP AND GOATS

The trend in weight change of dwarf sheep and goats fed supplementary diets of FTL is depicted in Figure 2. The responses of these animals to the high dietary CP levels from FTL could have initiated the trend for greater weight gain which is consistent with several studies that have proved the advantageous effects of FTL in improving weight gain in various breeds of sheep and goats (Srivastavam and Sharma, 1998; Helal et al., 2018, Dana et al., 2000). FTL are rapidly degradable, initiating higher fractional outflow rates of particulate matter from the rumen, so assisting in meeting the requirements of rumen microorganisms for efficient degradation of low-quality roughages (Adu et al., 1990). These further boosts the production of protein by ruminal microbes and the efficiency of microbial nitrogen production, providing a productive balanced diet that improves animal weight gain (Mupangwa et al., 2000). Moreso, better weight gains of dwarf sheep and goats were

also attributed to their beneficial responses to moderate dietary tannin in enhancing their performance by augmenting urea recycling and activating microbial efficiency. This further protects plant protein from excessive degradation in the rumen (Norton and Poppi, 1995; Hidosa, 2016) by providing the host animal with a significant source of additional protein for absorption and utilization with an improvement in weight gain.



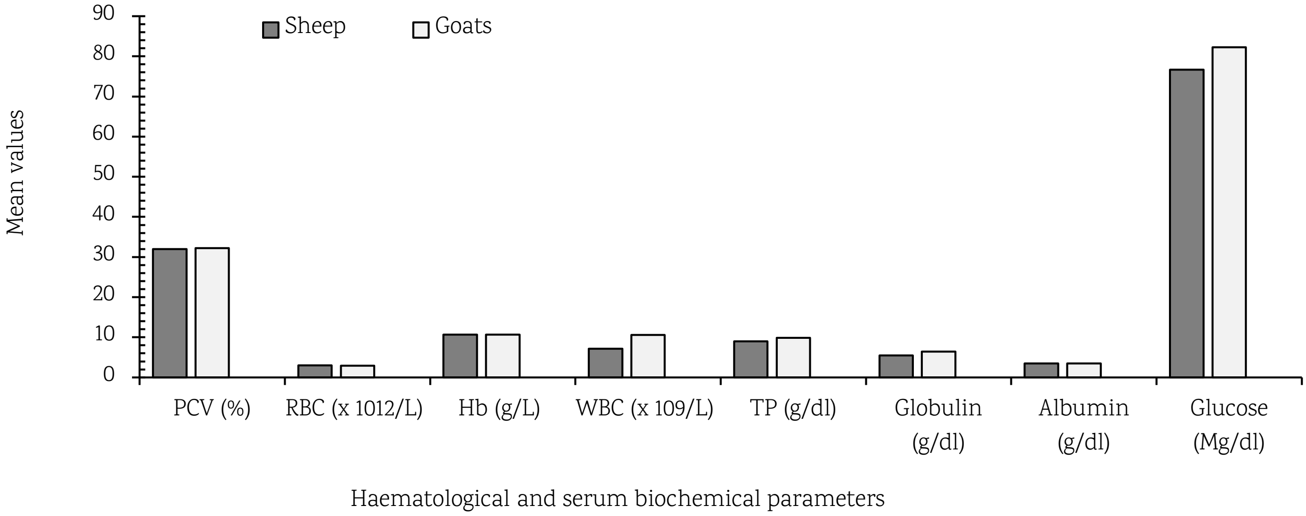
Data summarized from: Smith et al., 1995; Odeyinka, 2001; Fasae et al., 2011; Oduguwa et al., 2013; Ikyume, 2018. LLF – *Leucaena leucocephala*, GSF – *Gliricidia sepium*, ECF – *Enterolobium cyclocarpum*

Figure 2: Mean weight gain (g/day) of Dwarf sheep and goats fed supplementary fodder tree legumes

HAEMATOLOGICAL AND SERUM BIOCHEMICAL OF DWARF SHEEP AND GOATS FED FODDER TREE LEGUME SUPPLEMENTED DIETS

Haematological and biochemical parameters of Dwarf sheep and goats fed FTL-supplemented diets (Figure 3) showed values within the permissible range for healthy animals (Daramola et al., 2005; Carlos et al., 2015), which point to the non-adverse effects of these diets on the animals. These blood variables have often been suggested when evaluating the effects of a diet on animal performance in the short to medium term (Pambu-Gollah et al., 2000). They signify an integrated index of the adequacy of nutrient supply and give an immediate indication of the nutritional status of an animal at that point in time. They are also used to monitor the health and immunity status as well as an index of transportation stress in ruminants (Ambore, 2009; Mohammed et al., 2016).

In the reviewed studies, the experimental animals did not show any major clinical signs of ill health or toxicity credited to the moderate inclusion levels of FTL as supplementary diets. The PCV values show no dehydration or anemia deficiency in the animals, while the red blood cell and hemoglobin indices indicated the absence of haemolytic anaemia and the oxygen-carrying capacity of the blood, respectively (Daramola et al., 2005). The glucose concentrations suggest that the FTL supplementary diets were sufficient to maintain blood glucose homeostasis in the animals. Mean normal WBC counts showed that the concentration of FTL in the diets was below the level that could cause adverse effects. Though, indigenous goats possess a protective system that provides a rapid potent defense against infectious agents (Belewu and Ojo-Alokomaro, 2007).



Data summarized from: Ukanwoko and Ironkwe, 2012; Mohammed et al., 2016; Odusanya et al., 2017.

Figure 3: Mean haematological and serum biochemical parameters of dwarf sheep and goats fed fodder tree legume supplemented diets

FORAGE TREE LEGUMES AND THEIR ANTHELMINTHIC EFFECTS ON DWARF SHEEP AND GOATS

The mechanisms involved in gastrointestinal parasites' response to the diets containing FTL fed to dwarf sheep and goats demonstrate the potential of the tannin-rich FTL as a bioactive substance that has been proven to play an important role in animal health, especially as an anthelminthic in reducing the level of gastrointestinal nematodes in animals (Fasae and Omosun, 2013). For decades, plants containing bioactive compounds have been employed in worm control, which is still in practice today. Some *in vivo* and *in vitro* studies have made known that bioactive plants containing diverse types of secondary metabolites, such as condensed tannins are a capable option for nematode control in livestock production systems (Garcia-Bustos, 2019; Rodríguez-Hernández, 2023).

The reduction in faecal egg count across studies confirms the efficacy of tannins in FTL to improve animals' ability to control the biology of parasite worm populations, as well as their ability to tolerate the detrimental pathophysiological effects of nematode infections (Hoste et al., 2005). The positive effect of tannins on animal resilience has similarly been underlined in different animal species. The consumption of certain tannin-contained plants has host-mediated effects that influence animal biology and improve the immune response to decrease larval migration and development, thereby directly reducing abomasal and intestinal infections (Athanasiadou et al., 2000; Valderrábano et al., 2010). Van Houtert et al. (1995) equally observed that the increase in protein availability to the host through protein supplementation via forage during the course of a parasitic infestation could lead to a reduction in the number of nematodes in sheep due to the improvement of their immunity to parasites.

Parasitism imposes a considerable nutritional disadvantage on ruminants, and therefore controlling the parasite burden will indirectly assist the nutritional status of animals. The potential of FTL having a combined beneficial action as regards nutritional and antiparasitic could further support the issues of increased societal demands to reduce the use of chemical compounds in livestock production, thereby enhancing sustainable agriculture systems.

CONCLUSION

The review illustrates the valuable role of FTL in Dwarf sheep and goat production systems through their unique contributions as a high-quality supplementary protein source in improving animal productivity in terms of promoting weight gain, enhancing feed digestibility, anthelminthic as well as in methane mitigation, especially during the critical dry season period. The capacity of Dwarf sheep and goats to utilize and produce valuable food products from low-value feedstuffs will help retain their niches and the optimization of the productivity of these animals. This would hence improve the economic, nutritional, and social status of the resource-poor smallholder farmers with the potential to benefit the wider society through improved ecosystem services and reduced negative environmental impacts.

REFERENCES

1. Abdulrazak, S. A., Muinga, R. W., Thorpe, W., & Ørskov, E. R. (1996) The effects of supplementation with *Gliricidia sepium* or *Leucaena leucocephala* on forage intake, digestion and liveweight gains of *Bos taurus x Bos indicus* steers offered Napier grass. *Animal Science, 63*, 381-388.
2. Adebayo, A. A, Adewuyi, P. L., Akewusola, O. G., & Babayemi, O. J. (2022). Grazing behaviour of West African dwarf sheep and goats co-grazed on natural pasture in the humid zone of Nigeria *Nigerian Journal of Animal Production*, *49*(2), 299-306.
3. Adejoro, F. A. (2019). *The use of condensed tannins and nitrate to reduce enteric methane emission and enhance utilization of high forage diets in sheep* (Doctoral Dissertation) submitted to the Faculty of Natural and Agricultural Sciences at the University of Pretoria, Pretoria.
4. Adu, I. F., Fajemisin, B. A., & Adamu, A. M. (1990). The utilization of sorghum fed to sheep as influenced by urea or graded levels of lablab supplementation, In: Proceedings of the First Biennial Conference of the African Small Ruminant Research Network, ILRAD, Nairobi, Kenya 10-14 December 1990.
5. Ambore, B., Ravikanth, K., Maini, S., & Rekhe, D. S. (2009). Haematological profile and growth performance of goats under transportation stress. *Veterinary World, 2*(5),195-198.
6. Athanasiadou, S. L., Kyriazakis, I., Jackson, F., & Coop, R. L. (2000). Consequences of long-term feeding with condensed tannins on sheep parasitized with *Trichostrongylus colubriformis*. *International Journal for Parasitology*, *30*, 1025-1033.
7. Babayemi, O. J., & Bamikole, M. A. (2006). Nutritive value of *Tephrosia candida* seed in West African dwarf goats. *Journal Central European Agriculture, 7*(4), 731-738.
8. Garba Bala, A., & Rabiu Hassan, M. (2023) *Feeding Forage Cowpea: Goats Performed Well with High Nutrient Digestibility and Nitrogen Retention*. IntechOpen. DOI: https://doi.org/10.5772/intechopen.1001085
9. Belewu, M. A., & Ojo-Alokomaro, K.O. (2007). Haematological indices of West African dwarf goat fed leaf meal-based diets. *Bulgarian Journal of Agricultural Science, 13*, 601-606.
10. Besharati, M., Maggiolino, A., Palangi, V., Kaya, A., Jabbar, M., Eseceli, H., De Palo, P., & Lorenzo, J. M. (2022). Tannin in ruminant nutrition: *Review. Molecules, 27*(23), 8273.
11. Bonsi, M. L. K., Osuji, P. O., Nsahlai, V. I., & Tuah, K. A. (1994) Graded levels of *Sesbania sesban* and *Leucaena leucocephala* as supplements to tef straw given to Ethiopian Menz sheep. *Journal of Animal Production, 59*, 235-244.
12. Cabral Filho, S., Abdalla, A., Bueno, I., & Oliveira, A. (2013) Effect of sorghum tannins in sheep fed with high-concentrate diets. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 65*, 1759-1766.
13. Carlos, M. M. L., Leite, J. H. G. M, Chaves, D. F, Vale, A. M., Façanha, D. A. E., & Melo, M. M. (2015). Blood parameters in the morada nova sheep: Influence of age, sex, and body condition score. *Journal of Animal and Plant Science*, *25*, 950-955.
14. Dana, N., Shenkoru, T., & Azage, T. (2000). Growth rates and testicular characteristics of Ethiopian highland sheep offered chickpea haulm supplemented with incremental levels of *Leucaena leucocephala* leaf hay. *Livestock Production Science; 65*(3), 209-217.
15. Daramola, J. O., Adeloye, A. A., Fatoba, T., & Soladoye, A. O. (2005). Haematological and biochemical parameters of West African dwarf goats. *Livestock Research Rural Development, 17*(8), 5. http://www.lrrd.org/lrrd17/8/dara17095.htm
16. Devendra, C. (1982). The nutritive value of *Leucaena leucocephala* cy. peru in balance and growth studies with goats and sheep. *MARDI Research Bulletin*, *10*(2), 138-150.
17. Eckard, R. J., Grainger, C., & de Klein, C. A. M. (2010). Options for the abatement of methane and nitrous oxide from ruminant production: A review. *Livestock Science, 130*(1-3), 47-56. https://doi.org/10.1016/j.livsci.2010.02.010
18. Ekanem, N. J., Inyang, U. A., & Ikwunze, K. (2023). Chemical composition, secondary metabolites and nutritive value of elephant-ear tree (*Enterolobium cyclocarpum* (Jacq.) Griseb): A review. *Nigeria Journal Animal Production, 49*(2), 277-286. https://doi.org/10.51791/njap.v49i2.3489
19. Ellis, W. C., Poppi, D. P., Matis, J. H., Lippke, H., Hill, T. M., & Rouquette, F. M. (1999). Dietary-digestive-metabolic interactions determining the nutritive potential of ruminant diets. *Proceedings of the Vth International Symposium on the Nutrition of Herbivores*, *5*, 423-481. San Antonio, Texas, USA, 11-17 April 1999.
20. Fadiyimu, A. A., Fajemisin, A. N., Arigbede, M. O., & Alokan, J. A. (2012). Rumen dry matter degradability and preference by West African Dwarf goats for selected multipurpose trees in Nigeria. *Livestock Research for Rural Development, 24*(1), 3.
21. Fasae, O. A. Akintola, O. S. Sorunke, A. O., & Adu, I. F. (2010). The effects of feeding varying levels of cassava foliage on the performance of West African Dwarf goat. *Applied Tropical Agriculture, 15*(2), 97-102.
22. Fasae, O. A., Adesope, A. I., & Ojo, V. O. A. (2011). The effect of Leucaena leaf meal supplementation to maize residues on village goat performance. *Journal of Animal and Plant Sciences,* 2, 1276-1282.
23. Fasae, O. A., Iposu, S. O., & Badejo, O. O. (2012). Assessment of smallholder sheep and goat production in the humid zone of Nigeria. *Botswana Journal of Agriculture and Applied Sciences, 8*(1), 19-26.

24. Fasae, O. A., & Omosun, J. E. O. (2013). Influence of tannin in selected forages on the growth performance and faecal egg count of semi-intensively managed sheep. *Bulletin of Animal Health and Production in Africa, 61*, 247-252.
25. Fasae, O. A., & Bello, R. A. (2023). Natural anthelminthic effects of supplementary forage legume diets on grazing calves. *Proceedings of the 16th National Conference of Organic Agriculture Project in Tertiary Institution in Nigeria (OAPTIN), 16*, 48-51. Held at the Federal University of Agriculture, Abeokuta, Nigeria, 21-23 March 2023.
26. Frutos, P., Hervás, G., Giráldez, F. J., & Mantecón, A. R. (2004). Review. Tannins and ruminant nutrition. *Spanish Journal of Agricultural Research*, *2*(2), 191-202.
27. Garcia-Bustos, J. F., Sleebs, B. E., & Gasser, R. B. (2019). An appraisal of natural products active against parasitic nematodes of animals. *Parasites Vectors*, *12*, 306.
28. Getachew, A., Yisehak, K., Dereje, A., & Temessgen, D. (2022). Indigenous legume fodder trees and shrubs with emphasis on land use and agroecological zones: Identification, diversity, and distribution in semi-humid condition of southern Ethiopia. *Veterinary Medicine and Science*, *9*, 5
29. Harvey, I. M., Bee, G., Dohme-Meier, F., Hoste, H., Karonen, M., Kölliker, R., Lüscher, A., Niderkorn, V., Pellikaan, W. F, Salminen, J., Skøt, L., Smith, L.M.J., et al. (2019). Benefits of condensed tannins in forage legumes fed to ruminants: the importance of structure, concentration, and diet composition. *Crop Science, 59*(3), 861-885.
30. Helal, H. G., Nassar, M. S., Badawy, H. S., Eid, E. Y., & El Shaer, H. M. (2018). Comparative nutritional studies of sheep and goats fed cultivated tree legumes mixture under desert condition *American-Eurasian Journal of Sustainable Agriculture, 12*(1), 10-21.
31. Hidosa, D. (2016). Review on: Bioactive substance of legume forages and their feeding effect on nutrient intake, growth performance, and nutrient digestibility of livestock. *Journal of Natural Sciences Research, 6*(21), 51-57.
32. Hoste, H., Torres-Acosta, J. F., Paolini, V., Aguilar-Caballero, A., Etter, E., Lefrileux, Y., Chartier, C., & Broqua, C. (2005). Interactions between nutrition and gastrointestinal infections with parasitic nematodes in goats. *Small Ruminant Research*, *60*, 141-151.
33. Ikyume, T., Okwori, A., & Tsewua, A. (2018). Nutrient utilization by West African Dwarf (WAD) goats fed selected tree forages and legumes. *Journal Translational Research, 2*(1), 19-23.
34. Jabbar, M. A., Reynolds, L., & Larbi, A. (1997). Nutritional and economic benefits of *Leucaena* and *Gliricidia* as feed supplements for small ruminants in humid West Africa. *Tropical Animal Health Production, 29*, 35-47.
35. Jafari, S., Ebrahimi, M., Goh, Y. M., Rajion, M. A., Jahromi, M. F., & Al-Jumaili, W.S. (2019). Manipulation of rumen fermentation and methane gas production by plant secondary metabolites (saponin, tannin, and essential oil) – A review of ten-year studies. *Annals of Animal Science, 19*, 3-29.
36. Jerónimo, E., Pinheiro, C., Lamy, E., Dentinho, M. T., Sales-Baptista, E., Lopes, O., & Silva, F. (2016). Impact on animal performance and quality of edible products. In Combs, C. A. (Ed.), *Tannins in ruminant nutrition* (pp. 121-168). Hauppauge, NY, USA: Nova Science Publisher Inc.
37. Kang, S., Wanapat, M., Phesatcha, K., & Norrapoke, T. (2015). Effect of protein level and urea in concentrate mixture on feed intake and rumen fermentation in swamp buffaloes fed rice straw-based diet. *Tropical Animal Health and Production*, *47*, 671-679.
38. Kebede, G., Assefa, G., Feyissa, F., & Mengistu, A. (2016). Forage legumes in crop-livestock mixed farming systems – A review. *International Journal of Livestock Research*, *6*, 1-18.
39. Lamidi, A. A., & Ologbose, F. I. (2014). Dry season feeds and feeding: a threat to sustainable ruminant animal production in Nigeria. *Journal of Agriculture and Social Research, 14*(1), 17-30.
40. Lowry, J. B., McSweeney, C. S., & Palmer, B. (1996). Changing perceptions of the effect of plant phenolics on nutrient supply in the ruminant. *Australian Journal of Agricultural Research, 47*, 829-842.
41. McDonald, P., Edwards, R., Greenhalgh, J. C., Sinclair, L., & Wilkinson, R. (2010). *Animal Nutrition*, 7th edition. Harlow, England: Prentice Hall.
42. McSweeney, C. S., Palmer, B., McNeill, D. M., & Krause, D. O. (2001). Microbial interactions with tannins: Nutritional consequences for ruminants. *Animal Feed Science Technology*, *91*, 83-93.
43. Mohamed, K. E., Salih, A. M., Zomrawi, W. B., Hamza, M. M., Elamin, K. M., & Dousa, B. M. (2015). The effect of drying methods on chemical composition and digestibility of *Leucaena leucocephala* Leaves. *Global Journal of Animal Scientific Research, 3*(2), 419-422.
44. Mohammed, S. A., Razzaque, M. A., Omar, A. E., Albert, S., & Al-Gallaf, W. M. (2016). Biochemical and haematological profile of different breeds of goat maintained under intensive production system. *African Journal of Biotechnology*, 15, 1253-1257.
45. Mupangwa, J., Ngongoni, N., Topps, J., & Hamudikuwanda, H. (2000). Effects of supplementing a basal diet of *Chloris gayana* hay with one of three protein-rich legume hays of *Cassia rotundifolia*, *Lablab purpureus* and *Macroptilium atropurpureum* forage on some nutritional parameters in

goats. *Tropical Animal Health and Production, 32*, 245-256.

46. Naumann, H. D, Tedeschi, L. O, Zeller, W. E., & Huntley, N. F. (2017). The role of condensed tannins in ruminant animal production: advances, limitations and future directions. *Revista Brasileira de Zootecnia,* 46, 929-49.
47. Newbold, C. J, El Hassan, S. M, Wang, J., Ortega, M. E, & Wallace, R. J. (1997). Influence of foliage from African multipurpose trees on the activity of rumen protozoa and bacteria. *British Journal of Nutrition,* 78, 237-249.
48. Norton, B. W., & Poppi, D. P. (1995). Composition and attributes of pasture legumes. In J. P. F. D'Mello, C. Devendra (Eds.), *Tropical legumes in animal nutrition (23 p)*. Wallingford, Oxon, UK: CAB International.
49. NRC. (2000). *Nutrient requirements of beef cattle*. 7th rev. ed. Washington, DC: National Academies Press.
50. NRC (NCR) (1991) Micro*livestock: Little-known small animals with a promising economic future*. Washington DC: National Academies Press.
51. Odeyinka, S. M. (2001). Effects of feeding varying levels of *Leucaena leucocephala* and *Gliricidia sepium* on the intake and digestibility of West African Dwarf goats. *Nigerian Journal of Animal Production, 28*(1), 61-65.
52. Oduguwa, B. O., Adebayo Olusoji Oni, O. A., Arigbede, O. M., Adesunbola, J. O., & Sudekum, K. H. (2013). Feeding potential of cassava (*Manihot esculenta crantz*) peels ensiled with *Leucaena leucocephala* and *Gliricidia sepium* assessed with West African dwarf goats. *Tropical Animal Health Production, 45*, 1363-1368.
53. Odusanya, L. Q., Fasae, O. A., Adewumi, O. O., & James, I. J. (2017). Effect of cassava leaf meal concentrates diets on the performance, haematology, and carcass characteristics of West African Dwarf lambs. *Archivos de Zootecnia, 66*(256), 601-607.
54. Olafadehan, O. A., Njidda, A. A., Okunade, S. A., Adewumi, M. K., Awosanmi, K. J., Ijanmi, T., & Raymond, A. (2016). Effects of feeding *Ficus polita* foliage-based complete rations with varying forage concentrate ratio on performance and ruminal fermentation in growing goats. *Animal Nutrition and Feed Technology*, 16, 373-382.
55. Osakwe, I. I. & Steingass, H. (2006) Ruminal fermentation and nutrient digestion in West African Dwarf Sheep Fed *Leucaena leucocephala* Supplemental Diets. *Agroforestry Systems, 67*, 129-133.
56. Oyedele, O. J., Asaolu, V. O., & Odeyinka, S. M. (2016). Nutrient digestibility and growth performance of West African Dwarf goats fed foliage combinations of *Moringa oleifera and Gliricidia sepium* with equal proportions of a low-cost concentrate. *Journal of Natural Sciences Research, 6*(18), 20-29.
57. Pambu-Gollah, R., Cronjé, P. B., & Casey, N. H. (2000). An evaluation of the use of blood metabolite concentrations as indicators of nutritional status in free-ranging indigenous goats. *South African Journal of Animal Science, 30*(2), 115-120.
58. Phelan, P., Moloney, A. P., McGeough, E. J, Humphreys, J., Bertilsson, J., O'Riordan, E. G., & O'Kiely, P. (2015) Forage legumes for grazing and conserving in ruminant production systems. *Critical Reviews in Plant Sciences*, *34*(1-3), 281-326.
59. Pilachai, R., Schonewille, J. T., Thamrongyoswittayakul, C., Aiumlamai, S., Wachirapakorn, C., Everts, H., & Hendriks, W. H. (2012). The effects of high levels of rumen degradable protein on rumen pH and histamine concentrations in dairy cows. *Journal Animal Physiology and Animal Nutrition; 96* 206-213.
60. Reynolds, L., & Atta-Krah, A. W. (2006). Alley farming with livestock. International Workshop on Alley Farming for Sub-humid Region of Tropical Africa, IITA, Ibadan, Nigeria.
61. Rodríguez-Hernández, P., Reyes-Palomo, C., Sanz-Fernández, S., José Rufino-Moya, P., Zafra, R., Martínez-Moreno, F. J., Rodríguez-Estévez, V., & Díaz-Gaona, C. (2023). Antiparasitic tannin-rich plants from the south of Europe for grazing livestock: A Review. *Animals*, *13*(2), 201.
62. Ropiak, H. M., Lachmann, P., Ramsay, A., Green, R. J., & Mueller-Harvey, I. (2017). Identification of structural features of condensed tannins that affect protein aggregation. PLoS ONE, *12*, e0170768.
63. Santra, A., Karim, S. A., Mishra, A. S., Chaturvedi, O. H., & Prasad, R. (1998). Rumen ciliate protozoa and fibre utilization in sheep and goats. *Small Ruminant Research, 30*, 13-18.
64. Serra, V., Salvatori, G., & Pastorelli, G. (2021). Dietary polyphenol supplementation in food-producing animals: Effects on the quality of derived products. *Animals, 11*, 401.
65. Smith, J. W., Larbi, A., Jabbar, M. A., & Akinlade, J. (1995). Voluntary intake by sheep and goats of *Gliricidia sepium* fed in three states and at three levels of supplementation to a basal diet of *Panicum maximum*. *Agroforestry Systems, 32*(3), 287-295.
66. Srivastavam, S. N. L., & Sharma, K. (1998). Response of goats to pelleted diets containing different proportions of sun-dried *Leucaena leucocephala. Small Ruminant Research*, *28*, 139-148.
67. Stewart, J. L., & Mould, F. (2000) The effect of drying treatment on fodder quality and tannin content of two provenances of *Calliandra calothyrsus*, *Journal of the Science of Food and Agriculture, 80*(10), 1461-1468.
68. Tseten, T., Sanjorjo, R. A., Kwon, M., & Kim, S.W. (2022). Strategies to mitigate enteric methane emissions from ruminant animals. *Journal Microbiology Biotechnology, 32*(3), 269-277.
69. Tolera, A., & Sundstøl, F. (2000). Supplementation of

graded levels of *Desmodium intortum* hay to sheep feeding on maize stover harvested at three stages of maturity. 2. Rumen fermentation and nitrogen metabolism. *Animal Feed Science and Technology, 87*(3/4), 215-229.

70. Tseu, R. J., Junior, F. P, Carvalho, R. F., Sene, G. A., Tropaldi, C. B., Peres, A. H., & Rodrigues, P. H. M. (2020). Effect of tannins and monensin on feeding behaviour, feed intake, digestive parameters and microbial efficiency of Nellore cows. *Italian Journal of Animal Science, 19*(1), 262-273.
71. Ukanwoko, A. I., & Ironkwe, M. O. (2012). Growth performance and haematological values of West African Dwarf (WAD) goats fed *Leucaena*, *Gliricidia*, and cassava leaf meal-cassava peel-based diets. *International Research Journal of Agricultural Science and Soil Science, 2*, 98-101.
72. Valderrábano, J., Calvete, C., & Uriarte, J. (2010). Effect of feeding bioactive forages on infection and subsequent development of *Haemonchus contortus* in lamb faeces. *Veterinary Parasitology, 172*, 89-94.
73. Van Houtert, M. F. J., Barger, I. A., & Steel, J. W. (1995) Dietary protein for young grazing sheep: Interactions with gastrointestinal parasitism. *Veterinary Parasitology, 60*, 283-295.
74. Van Soest, P. J. (1994). *Nutritional Ecology of the Ruminant*, 2nd ed. Ithaca, NY, USA: Cornell University Press.
75. Waghorn, G. C., Shelton, I. D., McNabb, W. C., & McCutcheon, S. N. (1994). Effects of condensed tannins in *Lotus pedunculatus* on its nutritive value for sheep. 2. Nitrogenous aspects. *Journal Agricultural Science, 123*, 109-119.
76. Wen, Z., Xu, W., Wei, C., Zhang, Z., Jiang, C., & Chen, X. (2020). Effects of decreasing dietary crude protein level on growth performance, nutrient digestion, serum metabolites, and nitrogen utilization in growing goat kids (*Capra hircus*). *Animals*, *10*(1), 151.

Vloga krmnih stročnic kot dopolnilnega krmila pri krmljenju pritlikavih ovc in koz – pregled

IZVLEČEK

Članek obravnava pregled literature na temo potenciala krmnih stročnic kot obetavne in prehranske strategije za zmanjšanje problema nezadostne oskrbe s krmo v proizvodnih sistemih zahodnoafriških pritlikavih ovac in koz, zlasti v sušnem obdobju. Za bolj trajnostne kmetijske sisteme, vključno s širjenjem uporabe lokalno pridelane razpoložljive krme, predstavljajo krmne stročnice predvsem vrste *Leucaena leucocephala*, *Gliricidia sepium* in *Enterolobium cyclocarpum* zanimivo strategijo za zagotavljanje dušika v prehrani in izboljšanje prebavljivosti krme, za povečanje telesne mase in zadrževanje dušika, s čimer se poveča produktivnost pritlikavih ovac in koz. Vsebujejo tudi biološko aktivne spojine, ki pomagajo pri upočasnitvi okužb s parazitskimi ogorčicami v prebavnem traktu in zmanjšujejo emisije črevesnega metana pri teh živalih. Vsebnost surovih beljakovin se je v različnih vrstah krmnih stročnic gibala med 16,20 do 26,79 %, vsebnost taninov pa med 0,95 do 2,92 %. Pri pritlikavih ovcah, ki so jih dokrmljevali s krmnimi stročnicami, se je glede na objavljene raziskave prirast telesne mase povprečno povečal za 43,23 do 48,59 g/dan, pri pritlikavih kozah pa za 32,46 do 40,87 g/dan. Analizirane hematološke in serumske biokemične spremenljivke so bile v dovoljenem območju za zdrave živali in so pokazale ustrezno oskrbo s hranili iz različnih vrst krmnih stročnic in izboljšanje produktivnosti živali. Na osnovi pregledane literature lahko zaključimo, da imajo krmne stročnice odlično hranilno vrednost ter predstavljajo pomemben prehranski potencial za trajnostne sisteme krmljenja pritlikavih ovc in koz.

Ključne besede: ovce, koze, uspešnost, drevesne metuljnice, tanini, anthelmintik, blažitev izpustov metana

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Robot for Navigation in Maize Crops for the Field Robot Event 2023

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ABSTRACT

Navigation in a maize crop is a crucial task for the development of autonomous robots in agriculture, with numerous applications such as spraying, monitoring plant growth and health, and detecting weeds and pests. The Field Robot Event 2023 (FRE) continued to challenge universities and other research teams to push the development of algorithms for agricultural robots further. The Universidad Autónoma Chapingo has been developing a robot for various agricultural tasks, aiming to provide a low-cost alternative to work with Mexican farmers in the future. For this edition of the FRE, a navigation algorithm was created using an encoder, an IMU (Inertial Measurement Unit), an RPLIDAR (Rotating Platform Light Detection and Ranging), and cameras to collect data for decision-making. The algorithm was developed in ROS Melodic, dividing the task into steps that were tested to determine the robot's actual movements. The system navigates by using ROIs (regions of interest) and the mass center to guide the robot between maize rows. It calculates the mean of the final orientation values before reaching the end of a row, which is detected using an RPLIDAR. For turns and straight-line movements to reach the next row, the orientation is used as a guide. To detect plants for spraying, lasers located on each side of the vehicle are employed. Obstacle detection relies on a YOLOv5 (You Only Look Once) trained model and a laser, while reverse navigation uses a rear camera. During the competition, the robot faced challenges such as dealing with grass, the small size of the plants, and the need to use a different power source, which affected its performance.

Keywords: machine vision, convolutional neural network (CNN), regions of interest (ROI), autonomous navigation

INTRODUCTION

Corn is an essential crop for farmers and is grown on more than 150 million hectares worldwide (Kannan et al., 2018). Corn is a cereal of great economic and social importance worldwide because corn is critical for human food, industrial use, domestic animal feeding, security of food supply, biodiesel and biofuels, agricultural exports and income, crop rotation, adaptation to climate change, and income sources for farmers (Monteiro et al., 2021).

Currently, agricultural demand is being surpassed by the growing number of inhabitants worldwide, either due to the migration of youth to large cities or the decrease in available land for cultivation. This need has sparked significant interest globally in the development of new technologies and advancements in the field of agricultural robots to aid in achieving better food production.

According to FAO (2009) and Calicioglu et al. (2019) a significant challenge in agriculture is to produce more food because of the increase in the global population, aiming for long-term equilibrium. On the other hand, Subeesh and Mehta (2021) emphasize that traditional agriculture requires a lot of labor, with limitations in crop monitoring tasks. Additionally, there is a significant decrease in skilled labor, which is why traditional agricultural methods are not sufficient to achieve maximum productivity (Bai et al., 2023). Agricultural robots present an opportunity to strengthen agrifood systems by addressing labor shortages and reduce CO_2 emissions (Orum et al., 2023).

Many agricultural operations require machinery operators to have great skill to achieve good trajectories and configure technical parameters in real-time (Fujita et al., 2020). As an alternative solution, modern agriculture introduces agricultural robots and intelligent equipment, gradually replacing human operations as the direction for future agricultural development (Xie et al., 2022). Interest in agricultural robotic systems has surged in recent years, promoting the development of more autonomous and intelligent vehicles in agriculture.

Autonomous agricultural robots have the potential to increase agricultural production efficiency and reduce the consumption of natural resources (Khadatkar et al., 2021). In

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agricultural environments, agricultural robots have been used for various tasks such as plowing, transplanting, pruning, weeding, harvesting, planting, spraying, fertilizing, and more (Mao et al., 2020).

An essential aspect to enable a robot to work autonomously in the field is autonomous navigation. With this goal in mind, research is being conducted in the field of navigation. In these environments, there are sensors capable of detecting crop lines, with the most common ones being known as LIDAR (light detection and ranging), which are laser-based sensors that measures distances, and cameras. Although LIDAR has certain advantages over cameras due to the characteristics of the environments where agricultural robots must navigate (typically open environments with frequent changes in lighting conditions) it is at this point where cameras present disadvantages related to the variability in color shades that can result in different contrast levels (Nehme et al., 2021).

Another group of sensors used for navigation in combination with the above mentioned are integrated in the inertial measurement unit (IMU), which is used to correct position errors (Feng et al., 2023).

For all the reasons mentioned above, Chapingo Autonomous University pioneered the development of a farm robot in Mexico, with the aim of designing, constructing, and evaluating an unmanned mobile vehicle for agricultural tasks. Additionally, in this work, an algorithm using affordable sensors and machine vision is proposed to navigate automatically between maize rows.

MATERIALS AND METHODS

For the development of the vehicle, the following methodology based on the mechatronics design was followed:

1) Mechanical design and construction of the vehicle.
2) Instrumentation of the vehicle and electrical system.
3) Development of the navigation system.
4) Design and construction of the sprayer.
5) Development of the artificial vision system.
6) Functional testing for FRE 2023 tasks.

The main components of the robot are mentioned next.

Mechanical components

For the construction of the multitask agricultural robot "Voltan", 0.125-inch (3.175 mm) aluminum was used for the body and chassis shown in Figure 1 to achieve a lightweight design resulting in lower battery consumption (Reyes and Velázquez, 2019). Steel bushings were placed in the chassis, where 24 ball bearings were installed to position the drive axles that transmit the motion generated by the motors.

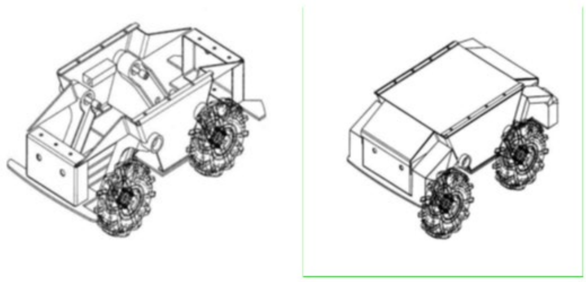

Figure 1: Body and chassis diagrams

The movement of the vehicle is of the skid-steer type, which means it executes turns by adjusting the velocities of the two sides of the robot. To achieve this, each of the two electrical motors is used to control two wheels on each side.

The transmission system consists of a pinion at the top and a sprocket at the bottom, connected by a chain. This design is replicated to drive all 4 tires, and the components have a pitch of 35. The pinions have 9 teeth, while the sprockets have 27 teeth. This configuration generates motion in agricultural tires sized 3.50-4, mounted on rims with a diameter of 4 inches (101.6mm). The components are shown in the Figure 2.

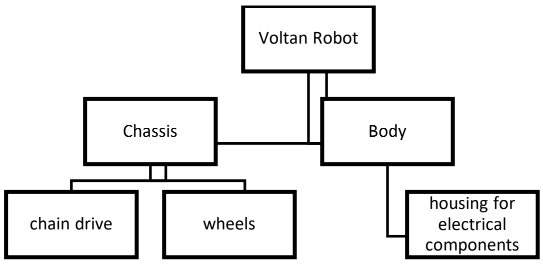

Figure 2: Mechanical diagram

For the connection between the chassis and the wheels, a steel arm was used, constructed with a rectangular tubular profile of 1.75 inches × 0.75 inches (44.45 mm × 19.05 mm) for each wheel.

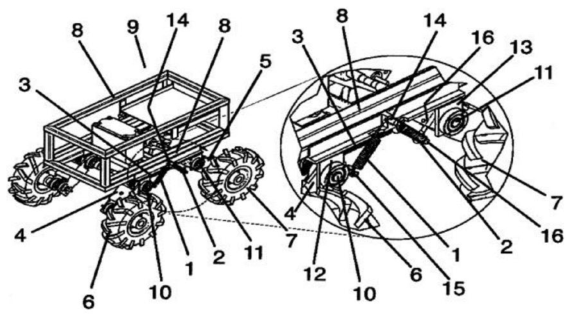

Figure 3: Suspension system

With the aim of ensuring proper performance on uneven terrains, a suspension system was designed and built for ground vehicles shown in Figure 3, whether autonomous or not (Reyes & Velázquez, 2020). This system is characterized by the use of a triangular arrangement consisting of three tension-operated helical springs. Another important component is the tires, which are designed for agricultural use and have a special tread pattern for better grip on the soil.

Electronic components

Electrical system

The electrical power components of the robot were selected with the consideration that the robot would be able to work in tilled soil without excessive skidding while dragging a furrow opener. This electrical system is designed to provide power and control to the DC motors, allowing them to drive the vehicle or machinery to which they are connected. The motor controllers play a crucial role in managing the speed and direction of the motors, while the battery serves as the primary power source. The electrical system in this setup includes the following components:

1. DC Motors: There are two 250 W DC gear reduction motors operating at 12 V each.
2. Sabertooth 2×60 Motor drive. Each motor is equipped with a Sabertooth 2×60 dual motor driver module with a capacity of 60 A. These controllers allow for independent management of motor speed and direction.
3. Battery: The system is powered by a 12 V sealed lead-acid battery from MHB. It has a capacity of 26 Ah, which indicates its energy storage capacity.
4. Wiring: Wiring is used to connect the various components of the electrical system, allowing for the flow of power from the battery to the motors and controllers.
5. Sensors. Cameras, IMU, RPLIDAR are used to obtain information of the environment and the orientation of the robot.

Encoder

The robot was equipped with an encoder model E50S8-5000-3-T-5, which is an optical sensor that emits 5000 pulses per revolution of the wheel axis through an infrared emitter and receiver. The algorithm programming was done in the Arduino IDE, and it calculated the encoder's degrees of advancement (Gr), allowing for the determination of the distance traveled by the robot. To achieve this, the encoder's resolution (5000 pulses per revolution) was used, and, along with the wheel's circumference, the real-time distance traveled by the robot was determined using the following expressions 1 and 2, respectively.

$$Gr = \left(\frac{360}{ppr}\right)(pr) \quad (1)$$

Where:
- Gr = number of degrees of advancement of the encoder shaft, [°]
- ppr = total number of pulses per revolution of the encoder (5000), [Pulses/revolution]
- pr = pulses recorded by the Arduino, [Pulses/meter]

$$lr = \left(\frac{p}{360}\right)(Gr) \quad (2)$$

This is an incremental encoder, so for better data capture and to prevent pulse loss, the encoder and IMU were connected to an Arduino MEGA, which publishes the readings to ROS on a computer via Serial communication.

RPLIDAR

An RPLIDAR is a Rotating Platform LIDAR which uses this platform to provide a 360-degree scan of the surroundings with laser sensors.

The lidar used for the detection of the plants works knowing the next turn direction, this is written as text in a file using the same coding as the FRE 2023 examples (1R, 3L, etc.), a node of ROS looks for spaces of more than a meter long around the vehicle, so it is subscribed to a topic that publishes the measurements of the encoder, its located in the front part of the robot centered, at a low height of the soil level.

In the robot the RPLIDAR A1 was used, which is a low-cost 2D (360-degree) laser scanner (LIDAR) solution developed by SLAMTEC. The device can perform a 360-degree scan, has dimensions of 98.5 mm × 70 mm × 60 mm and a weight of 170 g. It features a distance range of 0.15 to 6 meters for white objects, and an angular range of 0 to 360 degrees. The distance resolution is less than 0.5 mm, with an angular resolution of 1 degree. The sampling duration is 0.5 ms, and the sampling frequency ranges from 2000 to 2010 Hz. The scanning speed ranges from 1 to 10 Hz, with a typical speed of 5.5 Hz.

This device showed problems with days with high solar illumination outdoors, which is because of the limited lasers in the sensor, better models include multiple rings of lasers which can improve the data obtained.

IMU (Inertial Measurement Unit)

IMUs are essential components for applications requiring precise motion tracking, orientation sensing, and environmental awareness. By combining data from accelerometers, gyroscopes, and magnetometers, IMU sensors can provide a comprehensive view of an object's 3D motion and orientation in real-time. These sensors are widely used in robotics for navigation and control, in augmented reality for accurate head tracking, in drones for stable flight, and in many other applications where motion and orientation data are critical (Kurniawan, 2021).

Voltan have an IMU GPU6050 which is composed of a 3-axis accelerometer and a 3-axis gyroscope. Together, these sensors can provide the information to determine the heading, pitch, and orientation of an object. An inertial measurement unit (IMU) can be used for measuring acceleration and angular velocity (Cizmic et al., 2023).

The MPU-6050 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000 dps (degrees per second) and a user-programmable accelerometer full-scale range of ±2 g, ±4 g, ±8 g, and ±16 g.

The main data used from this sensor was the orientation of the robot with respect to the plane of the soil, it was used to calculate turns. To do this the IMU is connected to an Arduino mega that is connected to the computer, the data is published in a ROS topic.

Navigation system

It is important to consider that agricultural autonomous navigation is a complex system engineering, which consists of four key technologies: environmental perception, precise positioning, decision-making and planning, and execution control (Binbin et al., 2023). The Voltan robot from the Universidad Autónoma Chapingo uses for its navigation data from an imu, an encoder, two LIDAR, a RPLIDAR, and cameras, then a program running on a laptop computer make the decision for the correct movements.

Main software in ROS

Voltan operates with code developed in ROS (Robot Operating System) due to its numerous advantages, as noted by Saavedra et al. (2023). These advantages include hardware abstraction, inter-process communication, package management, development tools, distributed computing, software reuse, and rapid testing. ROS enables encapsulating nodes in different programming languages, facilitating system growth and prototyping. The navigation of Voltan is divided into different phases to be performed sequentially.

First the movement between the rows, for this part the machine vision system sends values to adjust the trajectory of the vehicle, at the same time in a different ROS node the RPLidar combined with encoder data detects the plants and look for spaces without plants to determinate the end of the row and stop the vision system control when its necessary. Second the movement of the final part its guided for the mean of the final 50 orientations of the robot. The third part is the turn, for this part the robot uses the gyroscope to perform 90 degrees turn over its own axis calculated using a mean of the latest orientations when the robot was navigating using the machine vision system. Fourth, it moves to the direction of the next row measuring the displacement with an encoder, once the desired distance is reached the robot stops and performs another 90 degrees turn. Fifth, finally navigates using the gyroscope and the machine vision control start again. All the process can be seen in Figure 4.

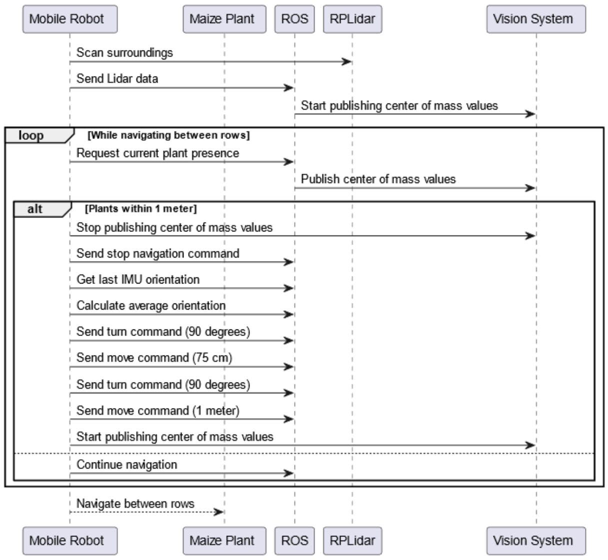

Figure 4: Steps of the navigation

Machine vision system

For the detection of the plants, machine vision was used. The advantages of this approach are the cheap cost of cameras, and the open resources like OpenCV, short for Open Source Computer Vision Library. This is a widely used open-source software library that focuses on computer vision and machine learning.

Recognition and detection of crop rows is one of the key technologies for automatic navigation in the field. Jiang et al. (2015) combined geometric features of crop rows and robot active zones by using several regions of interest (ROI) and extracted crop rows center of mass by clustering methods to obtain crop row centerlines. In a similar way, the Voltan robot use a segmentation algorithm in real time to detect the rows.

To develop this part, the program ignores the color space values that are not important and that includes sky, soil, and other elements. The system developed uses the mass center and the coordinate in the x axis of the image captured for the camera, for this the camera is positioned in the front and to the center of the robot so this can use the values of the x coordinates in pixels of center of mass of the ROIs to guide its movement.

If the center of mass is allocated to the right or left the robot moves to maintain the point between the rows, it was necessary to limit the vision using masks when the camera is not seeing the rows correctly and this way don't allow other rows enter to the frame of interest. To reduce the compute resources, it was necessary to use a resolution of image smaller than the original raw information of the camera (640 × 480 pixels). The system has been developed to be useful even in different light conditions present in the outside on different time hours of day. For the code OpenCV was used along with ROS Melodic.

Movement algorithm

All the sensors and actuators are communicated to ROS Melodic in a laptop, which do the control and make decisions. All the sensors publish its data in ROS topics. Other node is used for the detection of the end of the row, this use information from the RPLIDAR and encoder, and when there is a space of more than a meter publish an "end of the row" message to stop the navigation using machine vision.

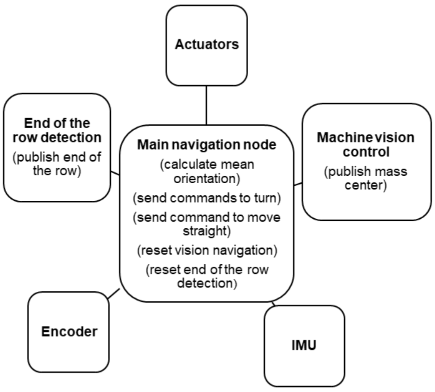

Figure 5: Nodes used for the navigation of Voltan

The main nodes shown in Figure 5 are:

1. Navigation node. This node follows the sequence used to navigate in the field, calculates orientation of the robot for the turns and straight movements, and reset other nodes when they're not necessary. It also reads the route of a text in a file with instructions for the next turn and next number of rows to be traverse.
2. End of the row detection. Detects the areas with no plants and determines if the distance of the row has been covered and the side of the next turn have the space for the turns.
3. Machine vision control. Segments the plants, calculates the mass center and publish the coordinates of the point to guide the robot.
4. Encoder. It's connected to an Arduino that publish the data to ROS.
5. IMU. It is connected to an Arduino that publish the data to ROS.
6. RPLIDAR. It is connected to the computer and publish readings of the laser to ROS.

Sprinkler System

For the localized sprinkler system, the robot was equipped with two Tf-Lidar Plus sensors, with one sensor placed on each rear side of the robot. The algorithm was programmed using Arduino IDE. Only one sensor can be read per microcontroller, for this reason, a slave microcontroller was used for each sensor, and the reading from each sensor was sent via serial communication to a master microcontroller where decision-making was performed.

The algorithm of the slave microcontrollers was programmed so that when an object is at a distance equal to or less than 40 cm, a signal is sent to the microcontroller equal to 1; otherwise, a value equal to 0 is sent. In the master microcontroller, the forward distance of the vehicle was measured, and it also received signals from the two slaves.

The algorithm is divided into two routines, with the first routine used when the robot enters between plants rows and is executed once.

The slave Arduinos have the function of monitoring the sides of the robot for the presence or absence of plants. The Lidar sensors detect objects once the vehicle begins to navigate. When an object appears at a distance equal to or less than 40 cm, a status value of 1 is sent via serial communication. Conversely, if there is no object within that range, a value of 0 is sent.

Using the data received by the master Arduino, actions are determined to activate or deactivate relays that control the sprinklers. Before executing any action, the flag value is checked to determine whether it is in the rows entry routine or already within it.

If both Lidar sensors detect the presence of an object on both sides of the sprinkler system and the flag has a value of 1, a 5-second delay is executed. This delay compensates for the time difference since the sensors and sprinklers are not located in the same position. With this compensation, there is time for the sprinkler to reach the plant that the sensor has monitored.

The activation or deactivation of the sprinklers depends on the detection or non-detection by the Lidar sensors. The sprinkler turns on 2 seconds before reaching the plant and continues spraying for an additional 2 seconds. When this routine is completed, it indicates that the robot is now between rows, so the flag value is updated to 2. When the flag takes on this value, the algorithm begins executing the routine in which the delay is 3 seconds, and this routine continues throughout the navigation.

Detection of images system

To detect the obstacles represented for images of 3 categories: human, deer, and another category selected for every team in the competition a convolutional neural network architecture was used, YOLO (You Only Look Once) V5, which is a state-of-the-art, real-time object detection system that frame object detection as a single regression problem, straight from image pixels to bounding box coordinates and class probabilities (Redmon and Farhadi, 2016).

Object detection involves creating features from input images. These features are then fed through a prediction system to draw boxes around objects and predict their classes. The YOLO model was the first object detector to connect the procedure of predicting bounding boxes with class labels in an end-to-end differentiable network.

The YOLO network consists of three main pieces. Backbone: A convolutional neural network that aggregates and forms image features at different granularities. Neck: A series of layers to mix and combine image features to pass them forward to prediction. Head: Consumes features from the neck and takes box and class prediction steps (Solawetz, 2020).

For start the training is mandatory to have a dataset of images and label the dataset. The dataset was labeled using (Makesense, 2023), a free-to-use online tool for labeling photos that do not require installation, it makes suggestions and automate repetitive parts in the labelling process. During this task it was marked into a box the object of interest and put a label with the category of this object.

For the task, 'four categories were used: human, deer, goat and rooster, a dataset of images with these objects was created for the training of the neural network, the size of this is 1085 images between the three categories, each photo contains the corresponding label for the object that contains.

For the validation set, 84 images were set aside with this three categories and objects that no correspond to any of the four categories. The image processing was done in Google Collab, using and preexisting model of YOLO v5 programed in Python 3. A 100-epoch training process was established.

When the training was completed, a file containing the corresponding values for each category was obtained and, then this file was imported into a python program where is possible to obtain data from a camera and make the boxes to point the objects that are part of one of the categories of interest.

When an object appears in the image, the software recognizes it and try to classify in one of the categories of interest, if the object is part of them, it appears into a box with a text with the name of the category to which it belongs. During the task, a Logitech C920 web camera, connected to a portable computer mounted on the robot, was used, and the signals of object detection were the labels and the boxes around each object as can be seen in Figure 6.

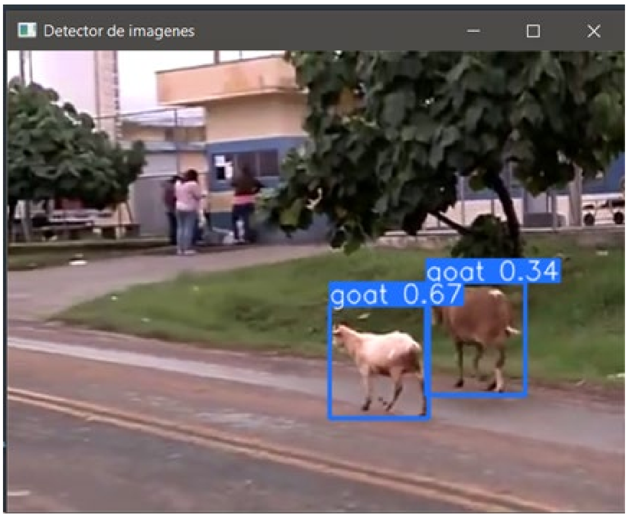

Figure 6: Detection of a goat using the code developed

RESULTS

This section includes a description of the performance of the robot Voltan in the Field Robot Event 2023 competition in the 4 different tasks but also includes data from testing of the steps used for the navigation in the simulated maize field.

Tests

Turns using the IMU

One of the steps in the navigation system involves making 90-degree turns. To test this aspect, actual turning angles were measured on a solid floor using a metal square and a protractor. The wheels on one side of the robot were aligned with reference marks, and the robot was then rotated using the data of the IMU to stop after 90 degrees. The actual degrees of rotation were recorded. This process was repeated 20 times for both left and right turns. The results are shown in the Table 1.

Table 1: Angles measured for turns to the left of the robot

Repetition	Actual angle	Sensor final angle	Angle objective	Sensor angle	Error
1	93	90.14	90	90.14	2.86
2	96	180.15	180.14	90.01	5.99
3	93	270.22	270.15	90.07	2.93
4	94	360.29	360.22	90.07	3.93
5	96	450.37	450.29	90.08	5.92
6	95	540.39	540.37	90.02	4.98
7	95	630.47	630.39	90.08	4.92
8	94	720.55	720.47	90.08	3.92
9	94	810.57	810.55	90.02	3.98
10	95	900.61	900.57	90.04	4.96
11	96	990.66	990.61	90.05	5.95
12	95	1080.78	1080.66	90.12	4.88
13	95	1170.87	1170.78	90.09	4.91
14	94	1260.89	1260.87	90.02	3.98
15	96	1351	1530.89	90.11	5.89
16	95	1441.01	1441	90.01	4.99
17	95	1531.1	1531.01	90.09	4.91
18	94	1621.22	1621.1	90.12	3.88
19	96	1711.32	1711.22	90.1	5.9
20	96	1801.41	1801.32	90.09	5.91
Mean	94.85			90.0705	
SD	0.98808693			0.039666372	
MAE					4.7795

SD – standard deviation; MAE – mean absolute error

Table 2: Angles measured for turns to the right of the robot

Repetition	Actual angle	Sensor final angle	Angle objective	Sensor angle	Error
1	92	90.03	90	90.03	1.97
2	93	180.11	180.03	90.08	2.92
3	92	270.12	270.11	90.01	1.99
4	93	360.26	360.12	90.14	2.86
5	92	450.31	450.26	90.05	1.95
6	92	540.33	540.31	90.02	1.98
7	93	630.52	630.33	90.19	2.81
8	92	720.62	720.52	90.1	1.9
9	93	810.71	810.62	90.09	2.91
10	93	900.72	900.71	90.01	2.99
11	92	990.78	990.72	90.06	1.94
12	92	1080.82	1080.78	90.04	1.96
13	93	1170.91	1170.82	90.09	2.91
14	94	1260.99	1260.91	90.08	3.92
15	92	1351.05	1350.99	90.06	1.94
16	91	1441.12	1441.05	90.07	0.93
17	93	1531.21	1531.12	90.09	2.91
18	92	1621.29	1621.21	90.08	1.92
19	92	1711.33	1711.29	90.04	1.96
20	94	1801.37	1801.33	90.04	3.96
Mean	92.5			90.0685	
SD	0.76088591			0.04368247	
MAE					2.4315

SD – standard deviation; MAE – mean absolute error

It can be inferred that the error is between 2 and 6 degrees more than the turn desired, so it was taken in consideration to calculate an objective angle more adequately. Using the mean average error, an objective angle of 85 degrees was included in the code for turns to the left. For the measurements recorded for the turns to the right the data is shown in the table 2.

It can be inferred that the error is between 0.9 and 4 degrees more than the turn desired, so it was taken in consideration to calculate an objective angle more adequately. Using the mean average error, an objective angle of 87 degrees was included in the code for turns to the left.

Test of displacement from row to row

To test the code for straight movement at the end of the row the movements were measured at the end of the row and until the robot is in the new row to restart the navigation using machine vision. For the robot to finish in a good final position its necessary that the calculation of the orientation angle mean that is in the final part of the row is done well, because this angle is the reference to finish in a parallel position in a new row. This part was divided into 5 movements as can be seen in the Figure 7.

To know the actual displacement after every turn at the end of the row a model was constructed using green paper rectangles that simulated the plants, attached to a 5-meter string with a 40 cm spacing between them. The robot had the objective to navigate using the machine vision system for 5 meters and then start the turns routine, first a displacement of 0.6 meters between rows was used.

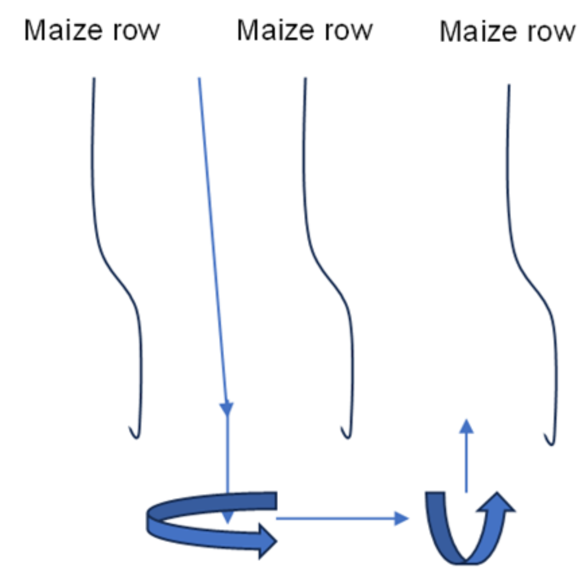

Figure 7: Movements of the robot to reach the next row

From these results the mean distance the robot moves after the turns of 90 degrees is 0.305 m for the first one and 0.262 for the second one as can be seen in table 3. These values were used to set the necessary straight displacement to move to the next rows. This experiment was repeated with a different distance for the sd2 the results are showed in the table 4.

The same was repeated a third time but just considering the last 5 movements the results are in the Table 5.

Table 3: Robot displacements measured in motion

Repetition	dbr	sd1	dat1	sd2	dat2	sd3
1	5.5	1.06	0.33	0.61	nd	0.52
2	5.2	1.01	0.28	0.57	0.34	0.5
3	5.14	1.01	0.4	0.68	0.26	0.63
4	4.98	1.05	0.27	0.6	0.25	0.55
5	4.3	1.08	0.28	0.59	0.23	0.57
6	4.64	1.1	0.27	0.56	0.23	0.55
Mean	4.96	1.051667	0.305	0.601667	0.262	0.553333
SD	0.391578	0.033375	0.04717	0.038909	0.040694	0.041096

dbr – displacement between rows, sd – straight displacement, dat – displacement after turn, SD – Standard deviation, nd – no data

Table 4: Robot displacements measured in motion

Repetition	dbr	dat1	sd2	dat2	sd3
1	5.03	0.47	1.6	0.38	0.5
2	5.3	0.38	1.49	0.34	0.49
3	5.27	0.32	1.69	0.27	0.5
4	4.85	nd	1.56	0.35	0.5
5	4.56	0.45	1.63	0.4	0.6
6	5.25	0.29	1.46	0.41	0.51
7	4.62	0.42	1.54	nd	0.53
Mean	4.982857	0.388333	1.567143	0.358333333	0.518571
SD	0.312181	0.358608	0.071949	0.07994	0.051153

dbr – displacement between rows, sd – straight displacement, dat – displacement after turn, SD – standard deviation, nd – no data

Table 5: Robot displacements measured in motion

Repetition	dat1	sd2	dat2	sd3
1	0.22	0.55	0.37	0.51
2	0.28	0.48	0.3	0.53
3	0.34	0.6	0.33	0.57
4	0.37	0.53	0.23	0.52
5	0.28	0.54	0.4	0.5
Mean	0.298	0.54	0.326	0.526
SD	0.058481	0.043012	0.065803	0.027019

sd – straight displacement, dat – displacement after turn, SD – standard deviation

Using the total number of dat1 and dat2 the mean displacements were obtained, shown in Table 6.

Table 6: Mean of the distances after turn 1 and 2

	dat1	dat2
Mean	0.33235294	0.318125
SD	0.07163531	0.06554579

dat – displacement after turn, SD – standard deviation

This is a better data of the real movements of the robot.

Test of detection of plants

Table 7: Results of the detection with lasers

Number of papers	Papers sprinkled	Success rate
36	36	100 %

The sprinkler made for the competition can be seen in Figure 8. In this test the same model using paper to represent the plants was used, it was annotated the plants where water was applied. The distance between the lines with plants was of 0.8 m. In the table 7 it can be seen that the system detected all the papers while the robot was navigating.

As it can be seen the lasers worked fine with a detection distance of 0.4 m.

Figure 8: Voltan with the sprinkler for the competition

Metrics of CNN

The results after training the YOLOv5 network are shown in Table 8. These results highlight the performance metrics and effectiveness of the model on the test dataset.

The results show that the CNN have problems with goats and deer, with a low precision, the person can be detected better than the rest of the classes and the roaster was a better option to propose for class. Well, these issues come from the low number of images used to train the network.

Table 8: Metrics of the trained YOLOv5 model

Class	Images	Instances	P	R	mAP50	mAP50-95
All	84	93	0.46	0.49	0.523	0.352
Person	84	27	0.967	1	0.995	0.682
Goat	84	21	0.0231	0.022	0.187	0.143
Deere	84	16	0.152	0.25	0.207	0.142
roaster	84	29	0.696	0.69	0.702	0.442

P – precision, R – recall, mAP50 - mean average precision calculated with an IoU (intersection over union) threshold of 50%, mAP50-95 - mean average precision calculated with an IoU (intersection over union) threshold range from 50% to 95%

Results on the Field Robot Event 2023 competition

Task 1: navigation

For this task, the robot had problems with the size of the plants, which were too small for the camera and RPLIDAR to detect using the positions of the sensors and the programmed codes, so the team changed the sensors' location. Another challenge was the presence of grass in the field, which created noise during the segmentation of the plant rows. The batteries had to be bought in Europe due to the restriction of the airline for this kind of devices.

At the moment of the task, the robot had problems following the curved sections of the rows because of the noise in the segmentation system and the different power source, causing it to deviate from the track. The final position for the task was the 11th place.

Task 2: treating (spraying) the plants

To address the issue with the presence of grass and trees, the vision of the camera was restricted by using masks in the OpenCV code, it only utilized data from the camera's lower left and right sections. But the use of just one battery changed the power provided for the driver to the motors causing problems to the movement and correction of the position.

During the test of task 2, the robot could not enter the field to initiate navigation due to low values of PWM and battery power. As a result, the final outcome was recorded as 'DNS' (Did Not Start).

Task 3: sensing and recognizing possible obstacles.

For this task, the YOLOv5 model, trained as mentioned in the materials and methods section, was used. The system encountered issues with the size of the images, making it unable to detect image categories at a distance. Consequently, the robot achieved the 7th position.

Task 4: static and dynamic obstacles.

For this task, a backward navigation camera was added. It operates by using an inverted version of the main machine vision system, allowing the robot to reverse when encountering obstacles and then enter the next row. Additionally, a laser was integrated to detect obstacles in the field within a distance of 0.4 m, halting the robot's movement for camera-based detection.

Despite these enhancements, the robot continued to experience issues related to low PWM values and battery power, which affected the accuracy of its movements. As a result, the robot finished in the 8th position.

CONCLUSION

The machine vision system for navigation is a good cheap alternative to the use instead of RPLIDAR, but it needs a more powerful computer. The inclusion of the IMU to guide the straight movements works fine. The navigation in the real test was poor and posed challenges to consider for future editions of the competition and work in a real agricultural field. The use of masks to limit the frame was a good addition to the system. The measurements of the real displacements show a possible loss of data of the encoder. The system, as it currently stands, is not reliable and requires several improvements. Firstly, it needs at least one more encoder and an updated version of ROS (Robot Operating System). The algorithms should be enhanced to combine data from multiple sensors (RPLIDAR, camera, and encoder) for detecting the end of the row and navigating between plants. Additionally, the system should calculate the speed of movement, make necessary corrections, and determine current position values. Other improvements to be considered include adding an embedded computer, calculating position using odometry, implementing fuzzy logic control for movement.

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REFERENCES

1. Bai, Y., Zhang, B., Xu, N., Zhou, J., Shi, J., & Diao, Z. (2023). Vision-based navigation and guidance for agricultural autonomous vehicles and robots: A review. *Computers and Electronics in Agriculture*, *205*, 107584.
2. Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., & Sims, R. (2019). The future challenges of food and Agriculture: An Integrated analysis of trends and solutions. *Sustainability*, *11*(1), 222. Retrieved from: https://doi.org/10.3390/su11010222
3. Cizmic, D., Hoelbling, D., Baranyi, R., Breiteneder, R., & Grechenig, T. (2023). Smart boxing glove "RD a": IMU combined with force sensor for highly accurate technique and target recognition using machine learning. *Applied Sciences*, *13*(16), 1-16. Retrieved from: https://doi.org/10.3390/app13169073
4. Food and Agriculture Organization (FAO). (2009). *How to feed the world in 2050*. Retrieved from: https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/Issues_papers_SP/La_agricultura_mundial.pdf
5. Feng, X., Liang, W. J., Chen, H. Z., Liu, X. Y., & Yan, F. (2023). Autonomous localization and navigation for agricultural robots in greenhouse. *Wireless Personal Communications*, *131*, 2039-2053. Retrieved from: https://doi.org/10.1007/s11277-023-10531-z
6. Fujita, S., Emaru, T., Ravankar, A. A., & Kobayashi, Y. (2020). Development of robust ridge detection method and control system for autonomous navigation of mobile robot in agricultural farm. In Symposium on Robot Design, Dynamics and Control (pp. 16-23). Cham: Springer International Publishing.
7. Jiang, G., Wang, Z., & Liu, H. (2015). Automatic detection of crop rows based on multi-ROIs. *Expert Systems with Applications*, *42*(5), 2429-2441. Retrieved from: https://doi.org/10.1016/j.eswa.2014.10.033
8. Khadatkar, A., Mathur, S. M., Dubey, K., & BhusanaBabu, V. (2021). Development of embedded automatic transplanting

system in seedling transplanters for precision agriculture. *Artificial Intelligence in Agriculture*, *5*, 175-184. Retrieved from: https://doi.org/10.1016/j.aiia.2021.08.001

9. Kannan, M., Ismail, I., & Bunawan, H. (2018). Maize dwarf mosaic virus: From genome to disease management. *Viruses*, *10*(9), 492. Retrieved from: https://doi.org/10.3390/v10090492
10. Kurniawan, A. (2021). IMU sensor: Accelerometer and gyroscope. In: Beginning Arduino Nano 33 IoT. Apress, Berkeley, CA. Retrieved from: https://doi.org/10.1007/978-1-4842-6446-1_3
11. Makesense (2023). Makesense for Labeling [Software platform]. Retrieved from: https://www.makesense.ai/
12. Mao, S., Li, Y., Ma, Y., Zhang, B., Zhou, J., & Wang, K. (2020). Automatic cucumber recognition algorithm for harvesting robots in the natural environment using deep learning and multi-feature fusion. *Computers and Electronics in Agriculture*, *170*, 105254. Retrieved from: https://doi.org/10.1016/j.compag.2020.105254
13. Monteiro, N., Alencar, E., Souza, N., & Leao, T. (2021). Ozonized water in the preconditioning of corn seeds: physiological quality and field performance. *Ozone Science and Engineering*, *43*(5), 436-450. Retrieved from: https://doi.org/10.1080/01919512.2020.1836472
14. Nehme, H., Aubry, C., Solatges, T., Savatier, X., Rossi, R., & Boutteau, R. (2021). Lidar-based structure tracking for agricultural robots: Application to autonomous navigation in vineyards. *Journal of Intelligent & Robotic Systems*, *103*, 1-16. Retrieved from: https://doi.org/10.1007/s10846-021-01519-7
15. Orum, J., Wubale, T., Marcus, S., Harold, A., Veldhuisen, B., & Hildrands, H. (2023). Optimal use of agricultural robot in arable crop rotation: A case study from the Netherlands. *Smart Agricultural Technology*, *5*, 1-8. Retrieved from: https://doi.org/10.1016/j.atech.2023.100261
16. Redmon, J., & Farhadi, A. (2016). YOLO9000: Better, faster, stronger. IEEE Conference on Computer Vision and Pattern Recognition (CVPR). Retrieved from: https://arxiv.org/abs/1612.08242
17. Reyes-Amador, A., & Velázquez-López, N. (2019). Modelo industrial de carrocería para vehículo de cuatro ruedas (No. de solicitud MX/f/2018/003352). IMPI. Retrieved from: https://siga.impi.gob.mx/
18. Reyes-Amador, A., & Velázquez-López, N. (2020). Sistema de suspensión para vehículos terrestres autónomos o no autónomos (Patente No. MX 4369 B). IMPI. Retrieved from: https://siga.impi.gob.mx/
19. Saavedra Sueldo, C., Perez Colo, I., De Paula, M., Villar, S. A., & Acosta, G. G. (2023). ROS-based architecture for fast digital twin development of smart manufacturing robotized systems. *Annals of Operations Research*, *322*(1), 75-99. Retrieved from: https://doi.org/10.1007/s10479-022-04759-4 Solawetz, J. (2020). What is YOLOv5? A Guide for Beginners.
20. Roboflow. Retrieved from:https://blog.roboflow.com/yolov5-improvements-and-evaluation/
21. Subeesh, A., & Mehta, C. R. (2021). Automation and digitization of agriculture using artificial intelligence and internet of things. *Artificial Intelligence in Agriculture*, *5*, 278-291. Retrieved from: https://doi.org/10.1016/j.aiia.2021.11.004
22. Xie, D., Chen, L., Liu, L., Chen, L., & Wang, H. (2022). Actuators and sensors for application in agricultural robots: A review. *Machines*, *10*(10), 913. Retrieved from: https://doi.org/10.3390/machines10100913

Robot za navigacijo v posevkih koruze za dogodek »Field Robot 2023«

IZVLEČEK

Operacije, kot je avtonomna navigacija robotov med vrstami rastlin na koruznem polju, so ključne za razvoj robotov v kmetijstvu. Takšne operacije so lahko del številnih nalog, kot so škropljenje, spremljanje rasti in zdravja rastlin ter odkrivanje plevela in škodljivcev. Na dogodku »Field Robot Event 2023« (FRE) so univerze in raziskovalne skupine izzvane k razvoju naprednih algoritmov za kmetijske robote. Universidad Autónoma Chapingo razvija robota za različna kmetijska opravila, s ciljem zagotoviti cenovno dostopno rešitev za mehiške kmete v prihodnosti. Za dogodek FRE so ustvarili navigacijski algoritem, ki uporablja podatke iz odometrije, inercialne merilne enote (IMU), RPLIDAR (nizkocenovno LiDARsko tipalo) in kamer, kar omogoča avtonomno odločanje. Algoritem je bil razvit v Robotskem Operacijskem Sistemu (ROS Melodic) in je nalogo razdelil na več korakov, ki so bili preizkušeni za določitev dejanskih premikov robota. Navigacijski sistem upošteva interesna področja (ROI) in masno središče robota, kar omogoča krmiljenje robota med vrstami koruze. Za premikanje med vrstami uporablja meritve RPLIDAR, medtem ko za zavoje uporablja orientacijo robota prek IMU. Za zaznavanje rastlin za škropljenje so na vsaki strani vozila nameščeni laserski merilniki. Zaznavanje ovir temelji na algoritmu YOLOv5 (You Only Look Once) in laserju, medtem ko za vzvratno navigacijo robot uporablja zadnjo kamero. Med tekmovanjem se je robot soočal z izzivi, kot so ravnanje s travo, majhne rastline in potrebe po drugačnih energetskih virih, kar je vplivalo na njegovo delovanje.

Ključne besede: strojni vid, konvolucijske nevronske mreže (CNN), interesna področja (ROI), avtonomna navigacija

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