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Agricultural unmanned ground vehicles: A review from the stability point of view

Veículos agrícolas terrestres não tripulados: uma revisão sob o ponto de vista da estabilidade

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ABSTRACT - Agricultural ground vehicles often have to traverse unstructured terrain, i.e., terrain whose conditions cannot be precisely predicted during its displacement. Such characteristics restrict the use of robots in the agricultural field because their stability could be compromised by their interaction with the terrain. As it does not have a human operator capable of observing, predicting, and controlling the interaction of the vehicle with the terrain. Therefore, a robot must deal with the unpredictability caused by this interaction, a task that was previously performed by the human operator. Given the relevance of the topic, this study investigates the literature on agricultural unmanned ground vehicles from the stability point of view, and also presents relevant criteria for dealing with the stability of agricultural robots in terms of their design and selection.

Key words: Agricultural robots. Stability. UGV. Control. Review.

RESUMO - Máquinas agrícolas terrestres transitam em terrenos não estruturados, ou seja, um terreno cujas condições não se pode prever com exatidão ao longo de seu deslocamento. Tal característica restringe a aplicação de robôs em campo uma vez que a estabilidade pode ser comprometida por sua interação com o terreno. Por não contar com um operador capaz de observar, prever e controlar a interação do veículo com o terreno, um robô deve ser dotado da habilidade de lidar com as imprevisibilidades provocadas pela interação com o terreno, tarefa esta que era antes executada pelo operador. Dada a relevância do tema, o presente trabalho faz uma revisão da literatura sob o ponto de vista da estabilidade, além de apresentar critérios para o projeto e seleção de robôs agrícolas no que diz respeito à estabilidade.

Palavras-chave: Robôs agrícolas. Estabilidade. Controle. Revisão.

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INTRODUCTION

Machines that are used for agricultural field operations have to move on an unstructured terrain, that is, terrain whose conditions cannot be precisely predicted during its displacement. This characteristic restricts the application of robots in the field because their stability can be compromised during their interaction with the terrain. As it does not have a human operator capable of observing, predicting, and controlling the interaction of the vehicle with the terrain, the robot must deal with the unpredictability caused by this interaction, a task that was previously performed by the operator.

The literature presents works with a focus on tasks, such as pruning, weed control, harvesting (BACHCHE, 2015; FOUNTAS *et al.,* 2020), and generic tasks related to agricultural operations, such as navigation and location (MOISIADIS *et al.,* 2020; MOUSAZADEH, 2013), and specific cultures (FUE *et al.,* 2020; REN *et al.,* 2020). In general, with regard to the use of robots for agricultural activities, it is observed that the approaches prioritize the task and operation, and less attention is given to the stability of the vehicle, which implies a significant restriction of its applicability in the agricultural field. There are also studies that review agricultural robots considering their main activities for field operation (BECHAR; VIGNEAULT, 2016; ROSHANIANFARD *et al*., 2020; R SHAMSHIRI *et al.,* 2018), but also in this case stability is given less attention. However, to design an agricultural vehicle that is autonomous and capable of moving in a wide range of terrains, it is necessary to focus on the interaction between the terrain and the vehicle, in addition to guaranteeing its stability for the assigned operation.

Thus, this work reviews the agricultural robots from the stability point of view by classifying them according to their applicability in the field and their form of interaction with the terrain. Although the suspension and stability control system is not always detailed in the analysed studies, this article uses the information present in articles and other reference sources, such as patents, websites, photos, and videos, to classify them according to the criteria presented here. In addition, it is important to note that during the literature review process, only robots with wheels were considered, as there is no significant use of robots with legs in the agricultural context. An additional contribution of this study is the suggestion of criteria for the classification and analysis of agricultural robots regarding their stability and locomotion in agricultural fields, thereby providing a starting point for projects or selection of this type of vehicle.

The paper is organized as follows. In section 2, a brief description of the agricultural terrain and the characteristics that are relevant to its interaction with a robot and robot stability is presented. Section 3 classifies the types of suspension found in the literature, and Section 4 presents some stability criteria and explains how they can be applied for control. In section 5, the agricultural robots found in the literature are presented and classified, and some considerations concerning these robots from the stability point of view are presented. Finally, in Section 6, the need for stability control is briefly discussed and Section 7 outlines the conclusions.

AGRICULTURAL TERRAIN

The terrain is one of the primary challenges faced by mobile robots because this can cause its instability. Moreover, this interaction can jeopardize the execution of a task by the robot. Thus, the characterization of the terrain is crucial for the selection and design of mobile robots.

The terrain used for agricultural applications presents a wide variety of characteristics that make it difficult to build robots capable of simultaneously dealing with them. However, we can list some relevant factors that can contribute to the selection of characteristics and design of an agricultural robot. In particular, when considering the stability of a robot, one may can classify the agricultural terrain according to three main aspects: regularity of terrain, soil cohesion, and slope.

TERRAIN REGULARITY

The regularity of terrain concerns variations in its profile that directly impact vehicle locomotion and alter the force of contact between the wheels and the ground. Irregular terrains are those that present variations in their profiles, holes, stones, and large obstacles. In general, greenhouses, grain, or vegetable fields generally have a high regularity, whereas forestry or coffee fields may have a low regularity.

Traditionally, agricultural terrain is mechanically regularized to enable sowing. However, when this terrain is used by an autonomous system, any type of irregularity in the terrain profile can play a relevant role in causing robot instability, and may even lead to its rollover.

SOIL COHESION

Soil cohesion is the parameter related to its shear capacity by applying a load, such as the weight of the vehicle when traveling. Soils that are not very cohesive present a large deformation, which can cause the wheels to sink. The ASAE D497.7 standard (ASAE, 2011) refers to four types of soil surface conditions related to its cohesion. According to the standard, the soil can be hard, firm, tilled, or soft.

Due to the agricultural needs and the mechanical soil destructuring inherent to agricultural operations, agricultural soil usually presents low cohesion and can also be clayey, sandy, or have high humidity. Such parameters influence the traction capacity of the wheels and can cause skidding, lateral displacement, or even sinkage. Methods to mitigate the influence of low soil cohesion on the stability and locomotion of the robot in agricultural terrain include the adoption of features that reduce soil pressure and increase traction, such as wider wheels, tracks, or reduction of vehicle mass.

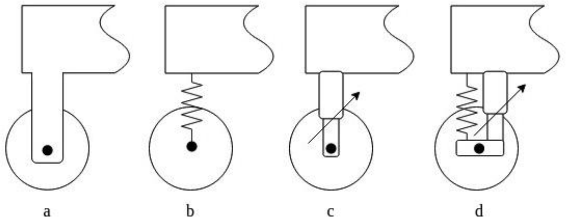
SLOPE

The slope of the terrain influences the distribution of the forces between the wheels and the position of the centre of mass of the robot in relation to its supporting polygon. The variation in the position of the centre of mass of the vehicle allied to the forces inherent to the interaction with the ground can cause overturning if these characteristics are not observed and controlled. Therefore, an agricultural robot must be able to deal with the slope of the terrain on which it moves. Low slopes require a structure, either mechanical or control, that is simpler than that required for higher slopes.

SUSPENSION TYPES

The robot suspension system can be defined as the set of mechanical and non-mechanical elements that allow the interaction of the chassis with the ground. For the purpose of this study, we classify the type of suspension in four distinct ways: rigid, passive or partially passive, active, and hybrid.

Figure 1 - Presents the diagram of each suspension type, all of which are briefly explained in the following sections



Description: (a) rigid (b) passive or partially passive (c) active (d) hybrid. Authors' own elaboration

RIGID SUSPENSION

Robots with rigid suspension have wheels that are rigidly connected to the chassis, so there is no possibility of movement between them (except the rotation of the wheel itself). Because there is no degree of freedom between the chassis and the wheels, these robots do not deal with ground irregularities in an optimal way, and any variations in the contact of the wheel with the ground reverberate to the chassis. Thus, robots with this type of suspension are more suitable for locomotion on regular and cohesive terrain, with low slopes, and at low speeds.

An example of this type of robot is the AgTracker, which uses a system composed of four wheels rigidly connected to the chassis for navigation between corn rows (XUE; ZHANG; GRIFT, 2012). Another example is the TERRA-MEEP, a platform used in the phenotyping of sorghum, which is inspired by rescue vehicles with a tracked locomotion system and has been tested on saturated soil after strong events of precipitation (YOUNG; KAYACAN; PESCHEL, 2019).

PASSIVE OR PARTIALLY PASSIVE SUSPENSION

This category includes robots that employ passive elements in their suspension system, such as springs, shock absorbers, or simply an articulated system. There may be variations in which a control system acts on the passive element, such as the shock absorbers with a variable damping coefficient. In this case, the suspension is considered partially passive despite the presence of a control system because it is performed on the passive element and not on the suspension.

This category includes a weed removal robot, an intelligent autonomous weeder (IAW), developed by the University of Wageningen in 2009, with articulated support on the front of the chassis to ensure the contact of the wheels with the soil (BAKKER *et al.*, 2010). Another example is TerraSentia, a robot that can navigate on a variety of field conditions and has been tested in corn, soybean, and wheat sorghum fields (ZHANG *et al.*, 2020).

ACTIVE SUSPENSION

Robots with active suspension have wheels and chassis that are connected by electric, hydraulic, or pneumatic actuators, and use some type of control system.

In order to use a control system, it is also necessary that a stability criterion is established and measured through sensors so that the controller sends the command signal to the actuators.

In general, this type of suspension presents great mechanical rigidity, as any compliance can significantly affect the stability of the robot. For this reason, such robots move at low speeds and on partially structured terrains. In this category, the robot by Fernandes and Garcia (2018) uses a double-actuated wheeled leg to move in rough terrains.

HYBRID SUSPENSION

When the suspension system of a robot contains both passive elements, such as springs and shock absorbers, and active elements, such as actuators, and their stability is controlled, one can say that such a robot has a hybrid suspension system because it contains both elements. Robots in this category exhibit greater mobility because they combine the advantages of both previous categories and are able to transit through unstructured terrain at higher speeds. However, they require a more elaborate control system that is capable of dealing with the ground reaction forces during motion.

An example of a robot with hybrid suspension is the Agri.q (QUAGLIA *et al.*, 2020), which has eight wheels connected two by two by a rocker arm and a platform actively controlled by electric actuators.

STABILITY CRITERIA

The interaction of an agricultural robot with the environment can be affected by a series of agents that can make it unstable in situations that were previously stable. The higher the locomotion speed, the greater the contribution of the dynamic effects of the reaction of the soil to the instability of the vehicle. Furthermore, the presence of external forces, such as those caused by seeding or ploughing tools that interact with the robot can also make it unstable.

Figure 2 - Displays some examples of robots with rigid suspension

Description: (a) BoniRob (FLECKENSTEIN; DORNHEGE; BURGARD, 2017), (b) AgTracker (XUE; ZHANG; GRIFT, 2012), (c) Asterix (UTSTUMO *et al*., 2018) (d) Grape project (ROURE *et al*., 2018) (e) TERRA-MEEP (YOUNG; KAYACAN; PESCHEL, 2019) (f) Xaver (FENDT, 2020). Authors' own elaboration

Figure 3 - Presents some examples of robots with passive suspension

Description: (a) Agbot II (BAWDEN; KULK *et al*., 2017) (b) IAW (BAKKER; ASSELT *et al*., 2010), (c) Kiwi Harvester (JONES *et al*., 2019); (d) Vinbot (LOPES *et al*., 2016), (e) Thorvald II (GRIMSTAD; FROM, 2017) (f) Agribot (TABILE *et al*., 2013). Authors' own elaboration

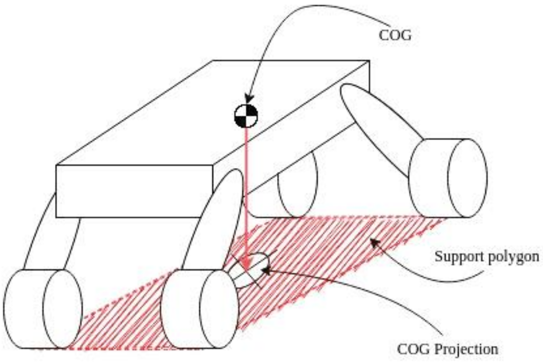
Therefore, the simple determination and control of the static stability of the robot may not be sufficient to guarantee the success of the operation. It is necessary to evaluate the operating conditions, such as speed, possibility of shock with external agents, and interaction with agents that apply some external force to the robot in order to guarantee its stability.

The stability of a vehicle can be classified in two distinct ways: statically or dynamically. The first disregards the action of external forces and the acceleration of the vehicle, whereas the second uses this information to measure stability.

STATIC STABILITY

The concept of static stability was first defined by McGhee and Frank (1968) for quadrupeds and is based on the projection of the centre of gravity (COG) of a robot over its supporting polygon (projection of the robot's support points in the horizontal plane), as illustrated in Figure 4. If the COG is inside the supporting polygon, the robot is statically stable. Therefore, to measure the degree of instability, it is possible to calculate the shortest distance from the projection point of the COG to the border of the nearest supporting polygon (S_{SM}). The shorter this distance, the greater the instability of the vehicle (SANTOS; GARCIA; ESTREMERA, 2007).

Figure 4 - Robot scheme with the projection of the centre of gravity inside the support polygon



Source: Authors' own elaboration

In addition, the supporting polygon must be formed by considering at least three points of contact with the soil (SIEGWART; NOURBAKHSH; SCARAMUZZA, 2011). However, the static stability on a horizontal surface may become unstable in the presence of other conditions, such as slopes, manoeuvre, and advancement on uneven terrain or steps (VIDONI; BIETRESATO *et al.*, 2015).

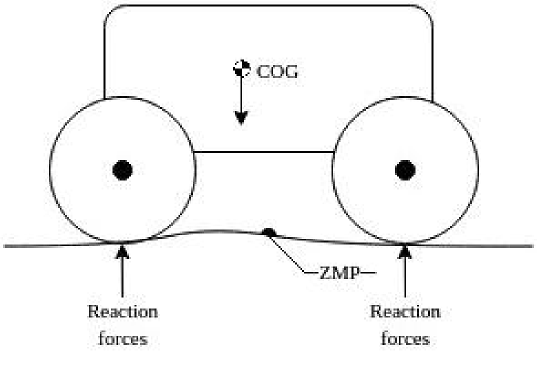
Some studies have defined the stability of agricultural machinery (PREVIATI; GOBBI; MASTINU, 2014; VIDONI *et al.*, 2015). However, these definitions are based on the static stability criterion, which does not account for the inertial characteristics of the robot and, hence, may be insufficient when the vehicle moves at higher speeds (above $1ms^{-1}$). In these cases, it is necessary to establish a criterion that allows the vehicle to remain dynamically stable.

DYNAMIC STABILITY

When the dynamic effects present in the system are considerable, it is necessary to apply a stability criterion capable of dealing with such effects. Therefore, several stability criteria have been developed to consider the dynamics of the robot and the acceleration involved in the system. The first stability criterion based on the moment was developed by Orin (1976) and Vukobratovic and Stepanenko (1972). The concept of dynamic stability margin (S_{ZMP}) was defined based on the projection of the pressure centre (COP) on the supporting polygon, as depicted in (Figure 5).

In addition to the moment-based stability criterion, some authors have proposed an energy-based stability concept. We can highlight the model presented by Ghasempoor and Sepehri (1998), and later extended by Garcia and Santos (2005), as they consider the dynamics of the vehicle. Such concepts are more significant for application in the agricultural environment because they allow the evaluation of the dynamic stability of vehicles in unstructured terrain and in the presence of external forces, such as the forces caused by the use of tools attached to the robot.

Figure 5 - Zero moment point concept



Source: Authors' own elaboration

AGRICULTURAL GROUND ROBOTS

Based on the parameters presented in Sections 2, 3, and 4, we classified the robots found in the literature and qualitatively evaluated their stability and capacity to deal with the irregular terrain.

We analysed 52 papers published since 2010. Among the robots mentioned in these, 31 have a rigid suspension (Table 1), 18 have a passive or semi-passive suspension system (Table 2), one uses active suspension (Table 3), and two robots have a hybrid suspension (Table 3).

It is observed that most of the analysed robots contain a rigid suspension and, therefore, they do not have any kind of stability control. Such robots have good performance in regular terrain, with high cohesion and low slopes. However, they are not suitable for working conditions that require their locomotion in different conditions, at higher speeds, or even when the operation requires chassis alignment, such as in spraying or cargo transport.

In addition, all the robots presented in Table 1 travel on regular terrain, which has a high cohesion and low slope, except for the TERRA-MEPP (YOUNG; KAYACAN; PESCHEL, 2019) and ByeLab (VIDONI *et al.*, 2017), which have a system of tracks and can therefore travel on terrains with low cohesion. The limitation of locomotion while traversing this type of terrain is due to the fact that vehicles with rigid suspension are unable to control their stability because they cannot vary the position of the centre of mass in relation to the wheels and are unable to ensure the contact of the wheels with the ground. Some robots use commercial Husky platforms, such as Levin Robot (LEVIN; DEGANI, 2016) and Grape-Project (ROURE *et al.*, 2018), which allows greater agility in the development of algorithms but is restricted to the concept of suspension offered by a commercial platform.

In this type of suspension, the tire plays a pivotal role because it can be considered as the first level of damping, providing the robots a minimum adaptability to the terrain. Therefore, most of the observed robots have wheels with a tire.

When one wants to travel on slightly less cohesive and steeper terrain, it is necessary to use a passive suspension system, such as the robots presented in (Table 2).

Owing to the suspension system, such robots can travel on less cohesive terrain and even with higher slopes. However, most of the analysed robots travel on regular terrains with little variation in their profile. The only exceptions among the analysed vehicles are the Vinbot (LOPES *et al.*, 2016), which presents a more robust suspension system because it is based on the commercial platform SUMMIT XL (ROBOTNIK, 2020), and Swagbot (WALLACE *et al.*, 2019), which uses a rocker type suspension, similar to that used by space exploration robots. It is important to note that, although they can travel in considerably uneven terrain, no vehicle in this category has a system capable of ensuring that the chassis is able to perform an agricultural operation, and the suspension system is used to maintain contact between the wheels and the ground.

Table 1 - Rigid Suspension Robots

Name	Suspension Type	Terrain characteristics			Cited work
		Regularity	Cohesion	Slope	
BoniRob (V2)	Rigid	Regular	Firm	Low	(BIBER *et al.*, 2012; FLECKENSTEIN; DORNHEGE; BURGARD, 2017)
TERRA-MEPP	Rigid	Regular	Soft	Low	(YOUNG; KAYACAN; PESCHEL, 2019)
Lady Bird	Rigid	Regular	Firm	Low	(UNDERWOOD *et al.*, 2015)
RIPPA	Rigid	Regular	Firm	Low	(SALAH SUKKARIEH, 2016)
ecoRobotix	Rigid	Regular	Firm	Low	(ECOROBOTIX, 2017)
ARA	Rigid	Regular	Firm	Low	(ECOROBOTIX, 2019)
Xaver	Rigid	Regular	Firm	Low	(FENDT, 2020)
MARS	Rigid	Regular	Firm	Low	(BLENDER *et al.*, 2016)
Asterix	Rigid	Regular	Firm	Low	(UTSTUMO *et al.*, 2018)
AgTracker	Rigid	Regular	Firm	Low	(XUE; ZHANG, L.; GRIFT, 2012)
Octopus	Rigid	Regular	Firm	Low	(REN *et al.*, 2020)
Vegebot	Rigid	Regular	Firm	Low	(BIRRELL *et al.*, 2020)
Levin Robot	Rigid	Regular	Firm	Low	(LEVIN; DEGANI, 2016)
TED	Rigid	Regular	Firm	Low	(NAÏO TECHNOLOGIES, 2017b)
OZ	Rigid	Regular	Firm	Low	(NAÏO TECHNOLOGIES, 2019)
Grape-Project	Rigid	Regular	Firm	Low	(ROURE *et al.*, 2018)
Shrimp	Rigid	Regular	Firm	Low	(GUTIÉRREZ; WENDEL; UNDERWOOD, J., 2019)
Phenomobile	Rigid	Regular	Firm	Low	(DEERY *et al.*, 2014)
Bakken Robot	Rigid	regular	Firm	Low	(BAKKEN; MOORE; FROM, 2019)
UGV Platform	Rigid	Regular	Firm	Low	(BARRERO; TILAGUY; NOVA, 2018)
mBase-MR7 robot	Rigid	Regular	Firm	Low	(BENGOCHEA-GUEVARA *et al.*, 2016)
RobHortic	Rigid	Regular	Firm	Low	(CUBERO *et al.*, 2020)
Vitirover	Rigid	Regular	Firm	Low	(DIAGO *et al.*, 2015; KERESZTES *et al.*, 2014)
MARIO	Rigid	Regular	Firm	Low	(SHARIFI *et al.*, 2018)
Cotton Harvesting Robot	Rigid	Regular	Firm	Low	(FUE, K. *et al.*, 2020)
MARIA	Rigid	Regular	Firm	Low	(IQBAL *et al.*, 2020)
AgROS	Rigid	Regular	Firm	Low	(TSOLAKIS; BECHTSIS; BOCHTIS, 2019)
Hiremath Robot	Rigid	Regular	Firm	Low	(HIREMATH *et al.*, 2014)
ByeLab	Rigid	Regular	Soft	Low	(VIDONI; GALLO *et al.*, 2017)
Xf-Rovim	Rigid	Regular	Firm	Low	(REY *et al.*, 2019)
Barbosa Robot	Rigid	Regular	Firm	Low	(BARBOSA *et al.*, 2019)

Source: Authors' own elaboration

Table 2 - Passive Suspension Robots

Name	Suspension Type	Terrain characteristics			Cited work
		Regularity	Cohesion	Slope	
AgBot II	Passive	Regular	Tilled	Low	(BAWDEN; BALL. *et al*., 2014; BAWDEN; KULK. *et al*., 2017)
Autonomous Weeding robot	Passive	Regular	Tilled	low	(BAKKER; ASSELT. *et al*., 2010)
Thorvald II	Passive	Regular	Tilled	Half	(GRIMSTAD; FROM, 2017)
Agribot	Passive	Regular	Tilled	Low	(TABILE. *et al*., 2013)
TerraSentia	Passive	Regular	Tilled	Low	(KAYACAN; ZHANG, Z.; CHOWDHARY, 2018; ZHANG, Z. *et al*., 2020)
IAW	Passive	Regular	Tilled	low	(BAKKER; VAN ASSELT. *et al*., 2010)
AVO	Passive	Regular	Tilled	Low	(ECOROBOTIX, 2020)
Kiwi Harvester	Passive	Regular	Firm	Low	(JONES. *et al*., 2019)
Ball Robot	Passive	Regular	Firm	Low	(BALL, 2015)
Strawberry harvesting robot	Passive	Regular	Tilled	Half	(XIONG. *et al*., 2020)
DINO	Passive	Regular	Tilled	Low	(NAÏO TECHNOLOGIES, 2017)
Vinbot	Passive	Irregular	Tilled	High	(LOPES. *et al*., 2016)
VineRobot	Passive	Regular	Tilled	Low	(ROVIRA-MÁS; MILLOT; SÁIZ-RUBIO, 2015)
Autonomous Tractor	Passive	Regular	Tilled	Low	(KAYACAN, Erkan; KAYACAN. *et al*., 2015)
Multi-sensor Robotic Plataform	Passive	Regular	Firm	Low	(MILELLA; REINA; NIELSEN, 2019)
CERES	Passive	Regular	Tilled	Half	(SOLAQUE; GUILLERMO SANCHEZ; ADRIANA RIVEROS, 2019)
Bergerman Robot	Passive	Regular	Firm	Low	(BERGERMAN. *et al*., 2015)
Swagbot	Passive	Irregular	Soft	High	(WALLACE. *et al*., 2019)

Source: Authors' own elaboration

Such robots have good performance in medium cohesion and operate on higher slopes owing to the better contact of the wheels with the ground, but they do not properly handle abrupt transitions in the terrain profile.

Table 3 presents the remaining analysed robots and classifies their suspension systems as active or hybrid.

The only instance of a robot with exclusively active suspension for agricultural applications was the one proposed by (FERNANDES; GARCIA, 2018), which allows the vehicle to travel on uneven terrain while keeping the chassis stable. However, this work does not include a practical experiment capable of evaluating the simulated control system in a real environment. Few agricultural robots with hybrid suspension systems have been found in the literature. Some of them have a purely passive suspension system and platform position control, such as the Wang Robot (WANG *et al*., 2019) and Agri.q (QUAGLIA *et al*., 2020). However, both present a passive suspension system together with an active platform positioning system.

Table 3 - Active and Hybrid Suspension Robots

Name	Suspension Type	Terrain characteristics			Cited work
		Regularity	Cohesion	Slope	
Fernandes Robot	Active	Irregular	Tilled	High	(FERNANDES; GARCIA, 2018)
Wang Robot	Hybrid	Irregular	Soft	High	(WANG. *et al*., 2019)
Agri.q	Hybrid	Irregular	Soft	High	(QUAGLIA. *et al*., 2020)

Source: Authors' own elaboration

Although there have been few reports of robots with active or hybrid suspension in the agricultural context, one can observe the use of these types of robots for locomotion in other contexts, where they traverse challenging terrains, such as (BOUTON; BENAMAR; GRAND, 2017), and (GRAND *et al.*, 2004). Such robots can be considered for agricultural applications.

SUSPENSION SYSTEM CONTROL

The use of a more complex suspension, such as partially passive, active, or hybrid, has a drawback concerning the complexity of its control system. In such cases, the control system required to respond rapidly, analyse the stability criterion, and act on the active element during its movement.

In addition, to determine the stability criterion, a set of sensors is required that is capable of determining the position of the center of gravity of the robot and its supporting polygon, such as an inertial measurement unit (IMU) and ground contact sensors. In some cases, it is necessary to measure the contact force of each wheel with the ground.

Based on the measured data and the robot model, it is possible to calculate the appropriate stability index for the application. When the robot travels at lower speeds and does not suffer from the action of external agents, the simple correction of the Euler angles is sufficient to keep it stable. However, in the absence of these conditions, it is necessary to use a more robust stability concept, such as those based on moment (ORIN, 1976; VUKOBRATOVIC; STEPANENKO, 1972) or energy (GHASEMPOOR; SEPEHRI, 1998; GARCIA; SANTOS, 2005).

The mechanical complexity, the use of sensors and actuators, and the need to establish a stability criterion can explain the low adherence of robots of this type in the literature. However, this limits the applicability of such robots to more regular terrain with high cohesion and low declivity. These challenges must be addressed in the project or selection of robots destined for field agricultural operations in order to make them successful in the operation for which they are designed.

CONCLUSION

1. This study analysed and classified agricultural robots from the stability point of view. In general, it was observed that the literature has devoted insufficient attention to the subject up to now, focusing on other activities necessary for the viability of robots in the field, such as navigation, weed control, and crop treatments. However, these approaches restrict the applicability of agricultural robots to more regular, cohesive terrain with lower slopes. This work contributed to the literature by analysing a fundamental dimension that is still under-explored in the agricultural context;
2. In general, most works do not consider a stability criterion, with the exception of those reported by (FERNANDES; GARCIA, 2018), which uses the S_{ZMP}, and Wang Robot (WANG *et al.*, 2019) and Agri.q (QUAGLIA *et al.*, 2020), which control the stability of a platform on the chassis with passive suspension;
3. To implement agricultural robotics in areas with challenging terrain, it is necessary to use more complex suspension systems and a control system that accounts for the platform stability criteria. In particular, hybrid suspension systems are more suitable because they present the advantages of both passive and active systems; however, they have a more complex control system;
4. Finally, the criteria for the classification of agricultural robots outlined in this study can be used as a starting point for the selection or design of an agricultural robot to suit the conditions in any terrain.

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