1
Introduction

The word *robot* has been appeared for the very first time in 1920 in a science fiction play “Rossum’s Universal Robots” written by Karel Kapek, wherein the meaning assigned as “hard work” came from Slav languages [1]. The early robots were built since the 1960s, when teleoperated robotic arms were developed under the master-slave scheme in the application of handling radioactive material. In the decade of 1970s, robots were used first in the automotive industry, however industrial robots became useful in other industries such as metal products, chemical, electronic and food.

In the 1980s, the term *robotics* was defined as the science which studies the *intelligent connection between perception and action*. Such intelligent connection was carried out by the use of programming languages, planning techniques, and control systems. The capability of exerting the action is given by the actuation system, whereas the perception ability is entrusted to a sensory system. The mechanical system is also an essential component of a robot being composed of a locomotion mechanism (e.g., wheels, legs, crawlers) and a manipulation apparatus (e.g., arms, end-effectors, hands) [2]. The 1990s brought us the need to seek human safety in hazardous environments, enhancing the human operator ability and reduced her/his fatigue, or developing robots to improve the quality of life.

In the new millennium, service robots for everyday life applications were developed and expanded to the human world (*human-centered and life-like robotics*). This new generation of robots are expected to cohabit with humans in different environments such as homes, workplaces, communities, education, healthcare, manufacturing, and assistance [3].

In recent years, there has been a considerable research effort on industrial robotics for different applications related to the manufacturing process such material handling (e.g., palletizing, packaging), manipulation (e.g., assembly of electronic boards, arc and spot welding) and measurement (e.g., object inspection, contour finding) [4]. Construction and health care are some of the industries supported by robotics: autonomous tasks such as site mapping and material handling are being carried out with robots [5]; social applications such as hospitality are improving the customer experience and efficiency by the use of service robots [6]. There are also outdoor applications of robotics such as the onshore Oil & Gas industry in different areas such as pipeline inspection, corrosion detection technology, propelling mechanisms, and the use of mobile robots for storage tank inspection [7].

1.1 Motivation

Mobile robots have became an important topic of research because of their advantages such as mobility, fast speed, and larger workspace compared to robot manipulators with fixed base. These mechanisms are being used in a variety of environments for different applications such as industry (handling of parts and tools), indoor environments (social assistance), warehouses (inspection and surveillance), hazardous environments (rescue and search), planetary exploration (sample collecting) and, more recently, in agriculture (monitoring and mapping) [8].

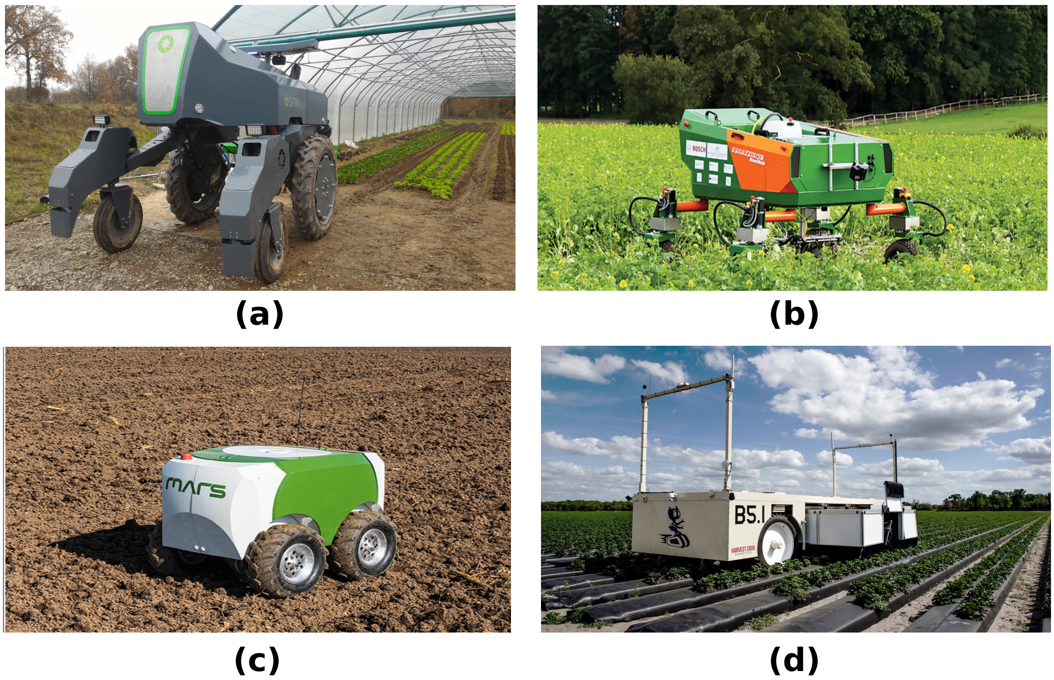


Figure 1.1: Agricultural Robots: (a) PUMAgri: robot for viticulture, arboriculture and even crop (SITIA); (b) Bonirob autonomous robots for carrot fields (Deepfield Robotics) ; (c) MARS robot system for planting (Fendt) ; (d) Berry 5, robot for strawberry fields (Harvest Crop).

Agriculture and food production are two of most relevant applications of robotics, and recently it is possible to find several robots working in open fields, greenhouses, and vineyards [9]. According to the latest estimates, one in nine people around the world cannot consume enough food and, in 2050, the population will increase in 34%. In this context, as the consumption of food and the rates of crop production have declined, it is necessary the use of automation and robotics in this field [10]. In Figure 1.1, it can be seen different types of robots employed in agricultural fields, with different size and locomotion.

Different tasks in agriculture are being carried out such as milking were a milking robot is reducing the human effort and recording automatically data such as cow ID, milk volume, product quality and milking time. In the process of plowing and harvesting, autonomous tractors are being equipped with different sensors (e.g., cameras, radar, LIDAR (Laser Imaging Detection and Ranging), laser, GPS), and used for crop picking of different plants such as lettuces, strawberries, cherries, and olives, optimizing the production. Finally, in the monitoring tasks of crop health for large open fields, a hundred of acres or hectares are required to be covered and mapped by using a number of wheeled mobile robots considering, for instance, a swarm based control approach [11].

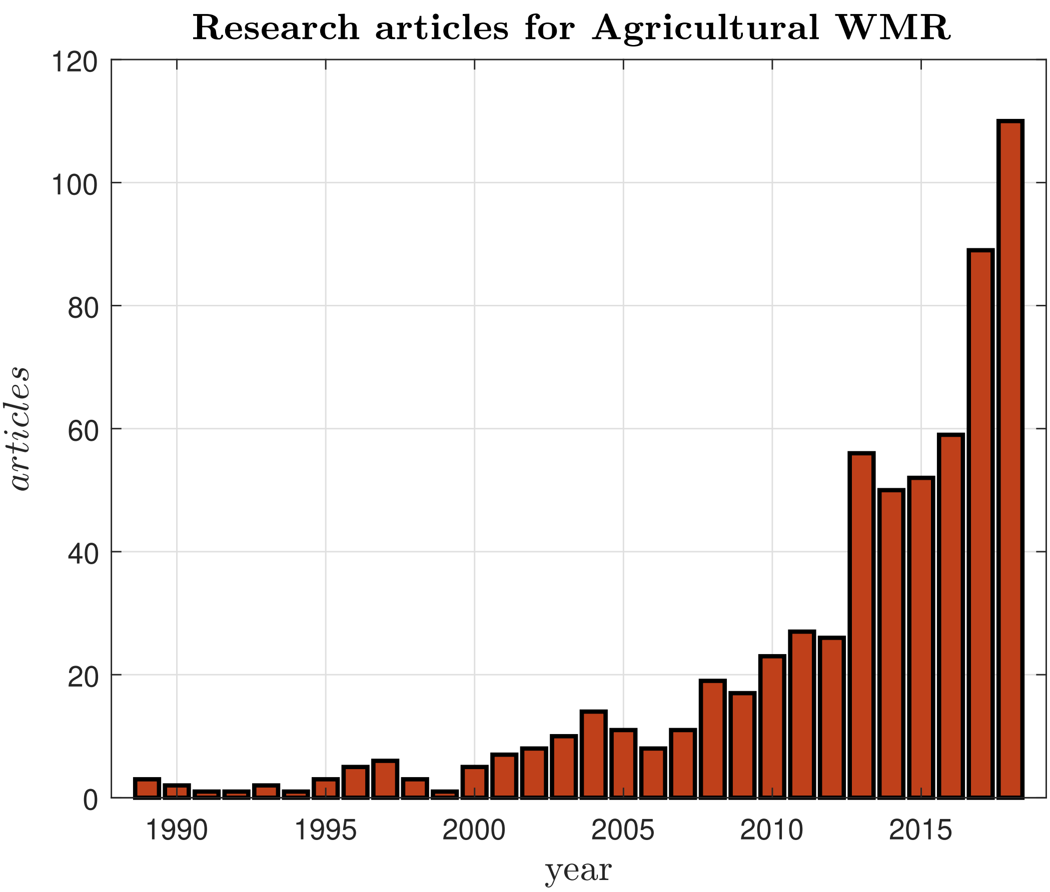


Figure 1.2: Research articles on Wheeled Mobile Robots for Agriculture.

Figure 1.2, presents the increment of quantity research papers on Wheeled Mobile Robots (WMR) for agricultural applications from 1989 to 2018. Notice that, during the last decade, the number of scientific publications increased almost three times. This figure was based on a query of the Scopus research database and was restricted to applications on agriculture such as transplanting and seeding, plant protection and weed control, harvesting, guidance and navigation, mapping and localization, fruit and vegetable grasping, as well as crops of different vegetables such as citrus, apple, tomato, cauliflower, strawberry, eggplant, melon and watermelon, rice and paddy fields. Another important implication of using mobile robots in agriculture is the reduction of fuel consumption, air pollution and manpower supply [12].

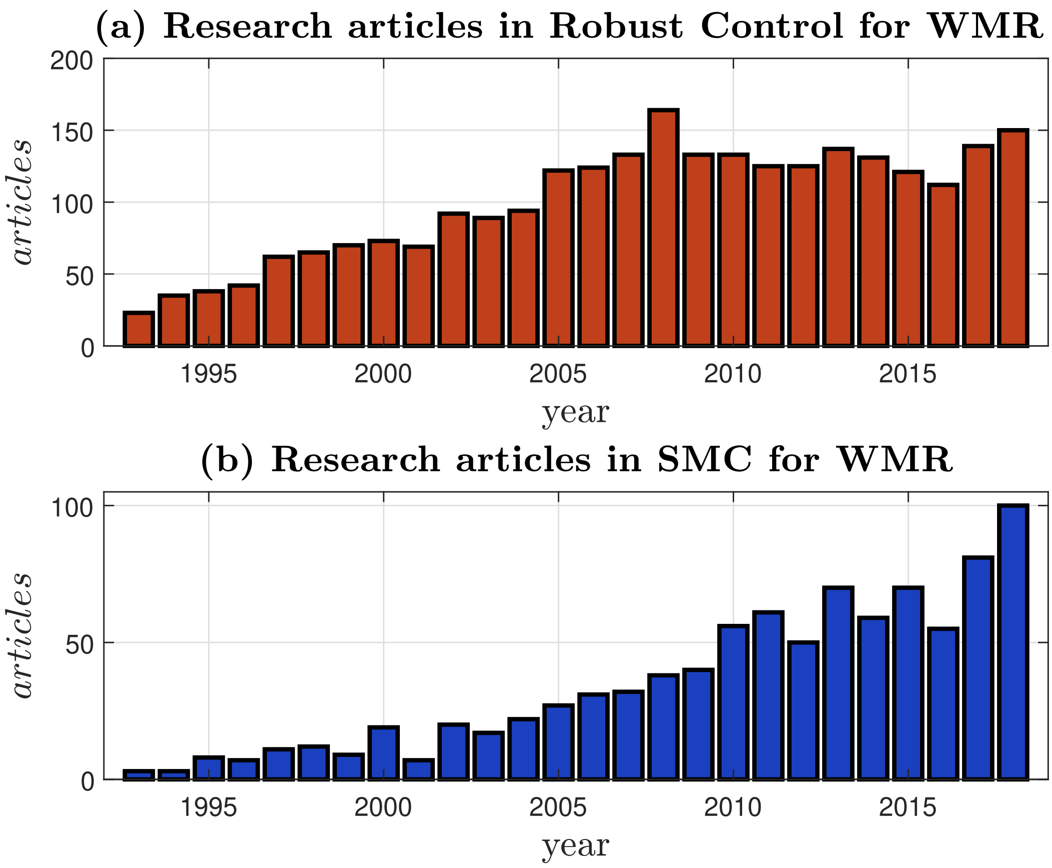


Figure 1.3: (a) Research articles on Robust Control for WMR, (b) Research articles on SMC in WMR.

An important fact to analyze is the current importance of the robust control and sliding mode control strategies applied to mobile robots. As it can be illustrated in Figure 1.3 , during the last 25 years there is an increase in the number of scientific papers for robust control and sliding mode control. This increment is because classical control techniques have problems when dealing with model uncertainties or localization problems caused by terrain slope, roughness, and surface condition - which could lead to systematic odometer errors - commonly found in agricultural fields, natural disaster environments, and rough terrains [13].

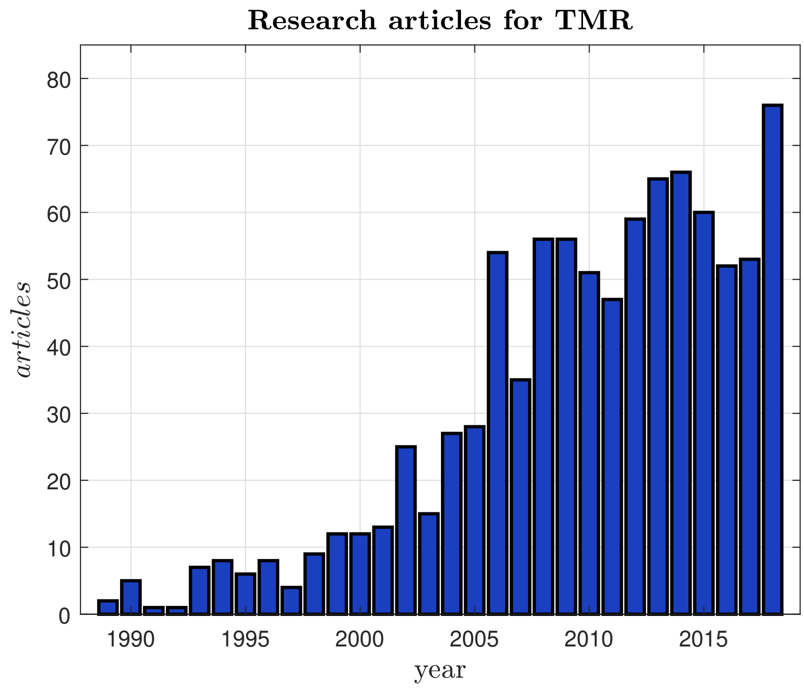


Figure 1.4: Research articles for Tracked Mobile Robots.

Recently, Tracked Mobile Robots (TMRs) are being developed and used for carrying out a number of challenging tasks such as bomb disposal, search and rescue, and surveillance. Their number is slightly increasing as shown in Figure 1.4, which depicts the histogram of the recently published articles on the topic of “Tracked Mobile Robots”. As it can be seen, there is a constant increment in the publication of scientific papers.

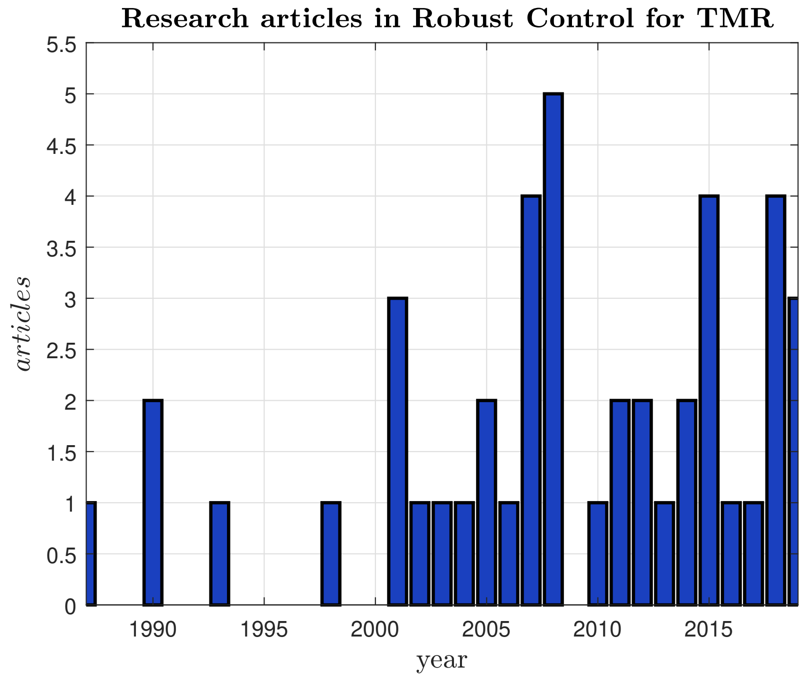


Figure 1.5: Research articles in Robust Control for Tracked Mobile Robots.

However, considering the topic of “Robust Control”, we can observe in Figure 1.5 that there is low occurrence during the last 20 years, which is being incremented in the early years. TMRs have as a main feature the adaptability to rough terrains, because of the large contact surface of their tracks on the ground.

TMRs are being used in different applications such as planetary exploration, surveillance, search and rescue missions in disasters, bomb and explosive disposal [14]. As was previously mentioned, TMRs are preferred over WMRs due to their improved traction and a large contact area on the terrain.

These advantages are useful in agricultural fields [15], since could facilitate the robot mobility over different ground conditions such as loose sand, mud, and cluttered terrain. In these challenging scenarios are required a significant amount of traction for a successful execution of the navigation task, which can be achieved thanks to the use of tracks and crawlers [16].

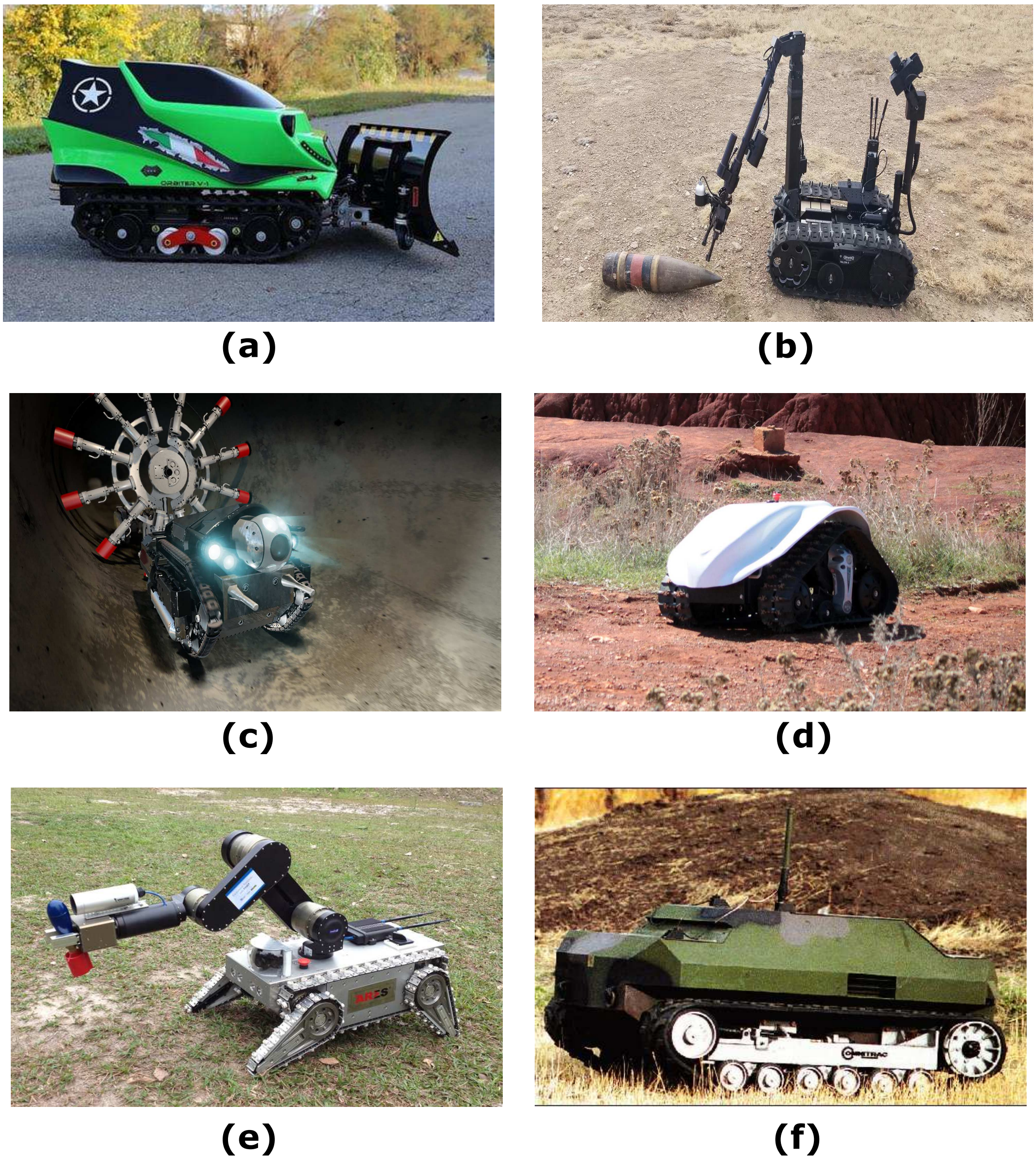


Figure 1.6: Tracked Mobile Robots: (a) ATR-Orbiter Robot: Snow Plow Robot (Orbiter) ; (b) Talon robot for military applications (QinetiQ) ;(c) PureRobotics robot for pipeline inspection (Pure Technologies) ;(d) XBOT robot for agriculture applications (DRONYX); (e) DIANE robot for bomb deactivation (COPPE-UFRJ); (f) Gladiator military robot (United States Marine Corps)

In Figure 1.6 it is possible to see different examples of TMRs applications such as plowing in snow environments, military operations, pipeline inspection, precision agriculture, bomb deactivation, where all the aforementioned advantages are used to improve the mobility in different types of terrain.

However, it is well-known that the large contact area of the tracks brings an inherent slippage caused by different velocities between them, increasing the complexity of the kinematic modeling because classical configurations such as differential drive, car-like Ackermann steering or skid steering models, do not consider the slippage and the non-holonomic constraints violation [17].

Surveillance and monitoring in agricultural fields are being explored in order to avoid inherent problems such as fire, air pollution, detect unusual patterns on the field and lack of information to patrol the area of interest in open fields [18]. A surveillance task has different reasons to be applied namely: (i) provides a more sophisticated approach of data management and analysis; (ii) the necessity of study how disparate aims and modalities of surveillance (e.g., CCTV cameras and occupancy sensors) converge into integrated architectures and systems; (iii) the inclusion of human or non-human factors (e.g., animals, objects) as well as climate parameters on the data analysis; (iv) the exploration consists on the inclusion of a new tridimensional "space of surveillance", justifying the necessity of using different types of robots (e.g., aerial and ground) [19].

Human Robot Interaction (HRI) is growing up, as the robots are increasing their capabilities of processing and decision-making the human has to interact with them in a safe and efficient manner. This new reseach area is divided in four areas of application [20]:

1. Human supervisory control of robots in performance of routine tasks: these machines are also called telerobots and are capable to perform a limited series of actions based on a computer program and are capable of sensing the environment and communicate it to the operator;

2. Remote control of vehicles for non routine tasks in hazardous or inaccessible environments: this area covers different applications such as space, surveillance, search and rescue, police work, medical applications. The interface, in this case, is called *teleoperator*;

3. Automated vehicles in which the human is a passenger: includes an autonomous car that has different embedded algorithms to radar-augmented cruise, vehicle-to-vehicle communication, and collision avoidance;

4. Human Social Interaction: outlines robot devices to provide entertainment, teaching, assistance for children and elderly people, and handicapped persons.

Mobile phones and tablets contain powerful processors on board to perform a complex task. These devices can communicate with the robots over the network and process the sensor data from the robot [21]. These types of interfaces are ubiquitous, have gained widespread use, offers simple operational interfaces, provides mobility and their high-performance displays give feedback in order to provide a high level of telepresence [22].

1.2
Review of the State-of-the-Art

1.2.1
Agricultural Mobile Robots

Precision agriculture is able to increase the food production, reducing the water consumption and minimizing input costs. One of the factors for achieving these benefits is the inclusion of a mobile robot to carry out hazardous and repetitive tasks in agricultural fields, and other tasks that require the manpower supply. In the literature review four main applications were found:

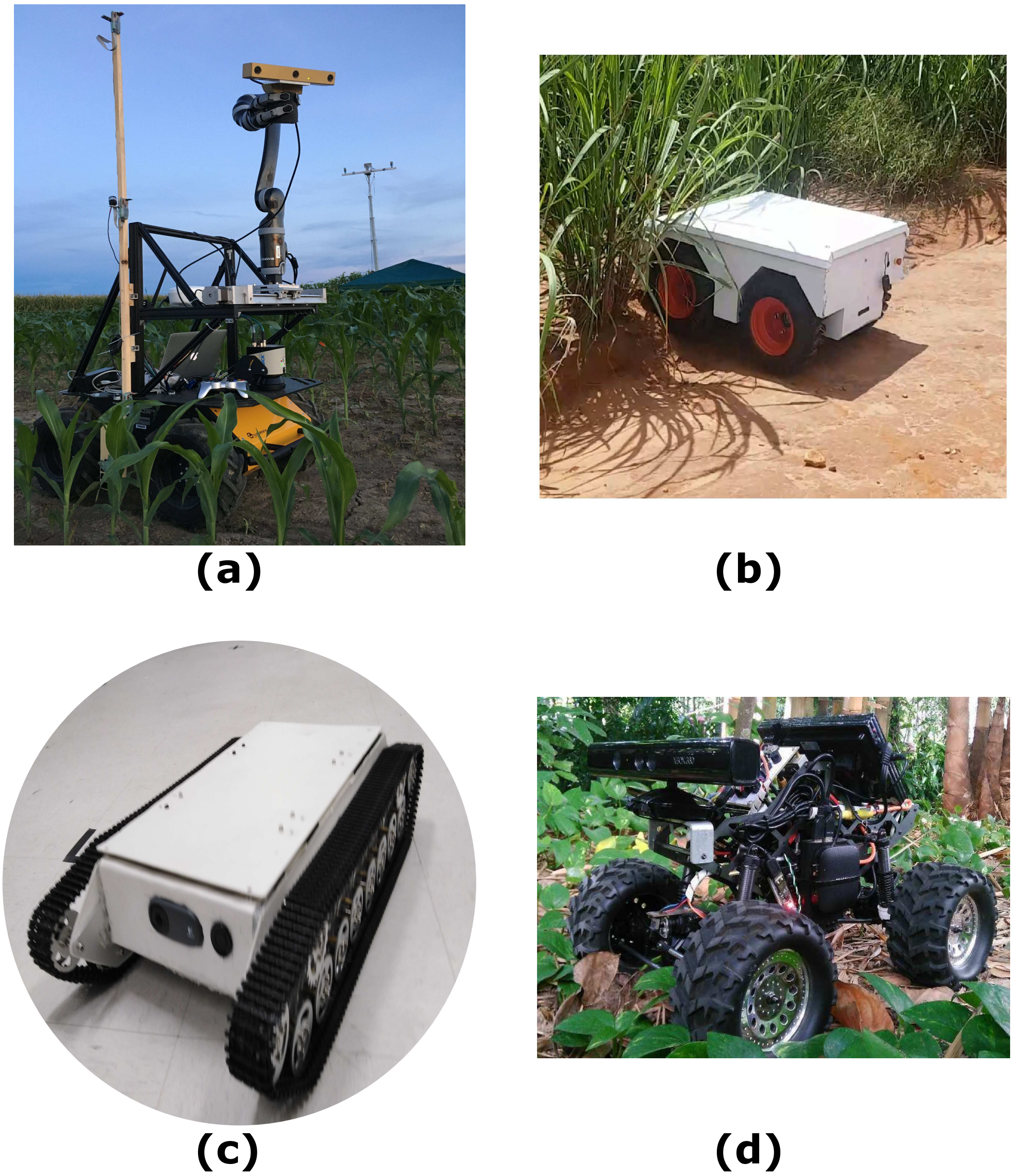
1. **Mapping:** the first step to carry out any robotic application is to obtain the full (or partial) knowledge of the environment. The key idea is to build a map of the agricultural field. Such a mapping task will help the farmer to know about the status of the crops and make decisions early. Orchards are one of the environments to be explored by using maps in order to enable the autonomous navigation with radars [23]. The mapping task would also be used to find the tree of the apple and the ripe fruit location [24]. Other interesting application could be in sugar beet fields obtaining the whole state of the field [25, 26].

2. **Spraying and weed control:** in agricultural fields is very common the presence of weeds, pests and invasive species which undermine the crop production. This problem can be solved with the use of pesticides and herbicides or resorting to a mechanical apparatus for weed removal and control. In this case, it is necessary to perform the automation of the removal process in order to locate the precise position of the weed on the field, avoiding the excessive use of herbicides. [27, 28].

3. **Harvest, collecting and sowing:** among the main activities commonly found in the field we can mention the sowing. In this process, the robot has to navigate autonomously in the field and performs the operation of sowing seeds [29]. Other interesting activity is the harvesting process that could be driven by using a mobile robot manipulator, endowed with a specialized tool (e.g., a vacuum picker), that identifies the best apple and picks it [30]. A challenging activity is the collecting of soft fruits, where the stem orientation has to be estimated and the fruit has to be collected by using a cut-and-hold mechanism without touching it. In this

context, a similar mechanism can be used to collect eggs in a poultry house [31].

4. **Monitoring:** the monitoring activity is one of the most used in agricultural fields and also is one of the case study of this work. In this activity, the mobile robot will need different types of sensors in order to describe the environment as accurately as possible. A mobile robot that autonomously collects data such as temperature, moisture and luminosity in a greenhouse has been developed in [32]. Camera and GPS can be used to generate a map of the crop field covering the major area as possible to improve the autonomous robot navigation [33]. Monitoring tasks can help in the detection of the rows in maize fields and also to detect weeds [34]. Plant phenotyping is another activity that is performed during the monitoring task which could increment the knowledge of the farmer about the plant health [35].



(a) **(b)** **(c)** **(d)**

Figure 1.7: Examples of agricultural Robots: (a) Vinobot, agricultural mobile robot [35] ; (b) TIBA Tankette for Intelligent BioEnergy Agriculture [26] ; (c) Red-Cat Robot for agricultural task [36]; (d) Kamayoq Surveillance Robot in Agricultural fields.

A wheeled mobile robot, equipped with actuators and a sensor package (e.g., camera, GPS, IMU and LIDAR) as well as a robotic arm, has been developed for plant phenotyping in vineyards can be observed Figure 1.7 (a). There are also mobile robots endowed with robot manipulators which manage the spraying, weeding, harvesting, soil sampling and sowing tasks. Generally, actuators are coupled directly to wheels axles or indirectly by means of a transmission system, being in charge of the mechanical locomotion of the robot. Transmissions systems are used generally in skid-steering robot as can be observed in Figure 1.7 (b) where is presented a robot for sugarcane mapping, or TMR showed in Figure 1.7(c) that represents a surveillance robot developed in this work called *Kamayoq* in which the transmission system carry out the locomotion on their tracks, finally a transmission system is used in the car-like Ackerman agricultural robot named RedCat as is showed in Figure 1.7 (d).

Table 1.1: Main sensors used for Mobile Robots in Agriculture.

Author	Application	Type Field	Sensor						
			Camera	**RGBD**	**IMU**	**Radar**	**Ultrasound**	**Laser**	**GPS**
Dogru [23]	Mapping	Orchard Field			X	X		X	
Habibie [24]		Simulated Field						X	
Chebrolu [25]		Sugar beet field	X	X					X
Patel [28]	Spraying	Small Field					X		
Ozgul [27]	Weed control	Small Field					X		
Vroegindeweij [31]	Harvesting	Poultry	X					X	
Salah [30]	Collecting	Simulated Field	X						X
Santhi[29]	Sowing	Small Field	X				X		X
Durmus [32]	Monitoring	Greenhouse		X	X		X		X
Bengochea [33]		Maize crop Field	X						X
Zhang [34]		Maize crop Field	X	X					X
Ali [35]		Grape Field	X						X

Additionally, mobile robots applied to agriculture have different types of sensors as it can be seen in Table 1.1. These sensors can be classified according to the applications: *proprioceptive* which provides the internal state of the mobile robot such as temperature, battery, moisture and *exteroceptive* in charge of the external information of the surrounding environment. Visual sensors such as cameras, lasers, GPS and RGB-D sensor, provide images and depth information that helps in the process of mapping and monitoring. Other sensors such as IMU, radar, ultrasound are widely used in the localization process which is extremely necessary for autonomous navigation purpose. A relevant aspect about the actuators is the internal information of them. For this goal the actuators have Encoders and tachometers can also be useful providing the angular position of the motor shaft and its angular velocity, enabling us to compute the position and velocity of the mobile robot.

1.2.2
Robot Surveillance Problem

Security is one of the most important concerns in companies, warehouses, airports and open fields. Currently, these take different security systems such as cameras, people, alarms and occupancy sensors [37]. Terrestrial or aerial, mobile robots have became a new solution for surveillance tasks [38, 39], because they are capable to reach different areas in the buildings that static sensors are not able to do. The main advantage of ground robots compared to flying robots is their high level of autonomy since the former can carry a larger battery management system as well as a higher number of sensors.

Figure 1.8: Surveillance Robot example [40].

An example of these robots, named Espionage [40], is depicted in Figure 1.8, which shows a ground mobile robot for security and surveillance tasks, with its sensors and actuators . This robot has different software interfaces to remotely control its posture, store data and manage the communication protocols .

Recently, Robot Operating System (ROS) has emerged as a software framework for communication and control of robotic systems [41] and it is being used for surveillance robots.

Generally, security and surveillance tasks consist of mapping large areas, taking care of high-cost equipment, detecting abandoned objects, finding and identifying possible intruders. These tasks can be carried out using surveillance camera systems, however, it is well known that cameras with fixed base are not capable of covering large areas and do not have an automatic interpretation of the scenes.

For this reason, there is a need to use surveillance and security robots equipped with integrated sensors and intelligent algorithms so that these mechanisms are able to make decisions and provide friendly user interfaces [41].

Security robots can only be used to protect a certain perimeter (e.g., airports, shopping centers, warehouses), while surveillance robots can be used to map and search a certain area. For example, water pollution monitoring can be performed by using an underwater mobile robot endowed with a camera, an accelerometer and a pressure sensor [42].

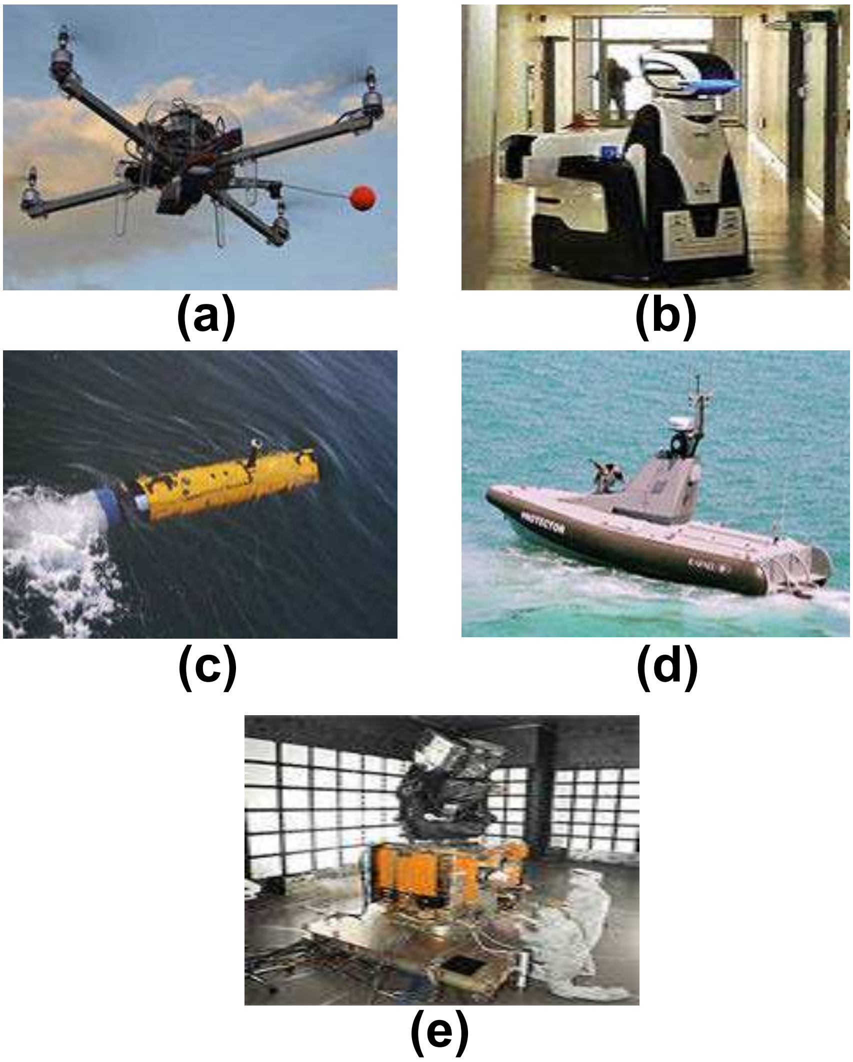


Figure 1.9: Different applications of surveillance robots: **(a)** Air-Tacocopter; **(b)** Ground robot Robo-Guar; **(c)**Underwater-Bluefin; **(d)** Surface water-Rafael Protector; **(e)** Space-Ball Aerospace SBSS Satellite (SBSS: space based space surveillance) [43]

The security and surveillance robots have application in different fields such as those mentioned in [43] and can be observed in Figure 1.9.

1. **Aerial:** most long-distance aerial applications use fixed-wing vehicles (similar to airplanes) that fly at an established altitude and monitor large surface areas. Aerial vehicles vary in all sizes from full-size platforms that are the size of passenger aircraft to small quadruple rotors, vertical take-off, and landing vehicles.

2. **Ground:** ground vehicles are custom designed or based on the adaptation of an existing commercial or military vehicle. These are built in all sizes from car size to desktop size and shoe box size.

3. **Surface water:** surface water vehicles are custom designed or based on the re-adjustment of an existing boat such as a Rigid Hull Inflatable Boat (RHIB). These mechanisms vary in sizes, from small watercraft to an 11-meter RHIB. The surface water robots used for surveillance and security are only in initial development phases.

4. **Underwater:** unmanned underwater vehicles (UUVs) vary in size from portable lightweight platforms to large diameter vehicles over 10 meters in length. Larger vehicles have an advantage in terms of resistance and payload of the sensor weight capacity.

5. **Space:** a spacecraft requires the development of robotic systems. There is a combination of on-board automation and commands from Earth during critical events. Space surveillance robots range in size from micro-satellites (50-100 kg) to traditional surveillance spacecraft (approximately 15,000 kg), and typical payload sensors include high definition cameras and SAR (Synthetic Aperture Radar).

1.2.3 Human Robot Interfaces

Surveillance robots require the development of graphical interfaces in which the human operator can control the robots remotely. In this context, there exists different types of human robot interfaces such as: haptic devices [44], voice interaction [45], telephones using *Dual Tone Multifrequency* (DTMF) [46]. Furthermore, web interfaces can be used [47, 48] in a desktop computer and also in mobile devices [49, 40, 50].

Interfaces in mobile devices have different advantages such as wide use and low cost, also providing additional sensors for control purposes (e.g., cameras, accelerometer, magnetometers, GPS). These interfaces use wireless communication protocols to ensure a safe and efficient interaction with the robot [51, 52].

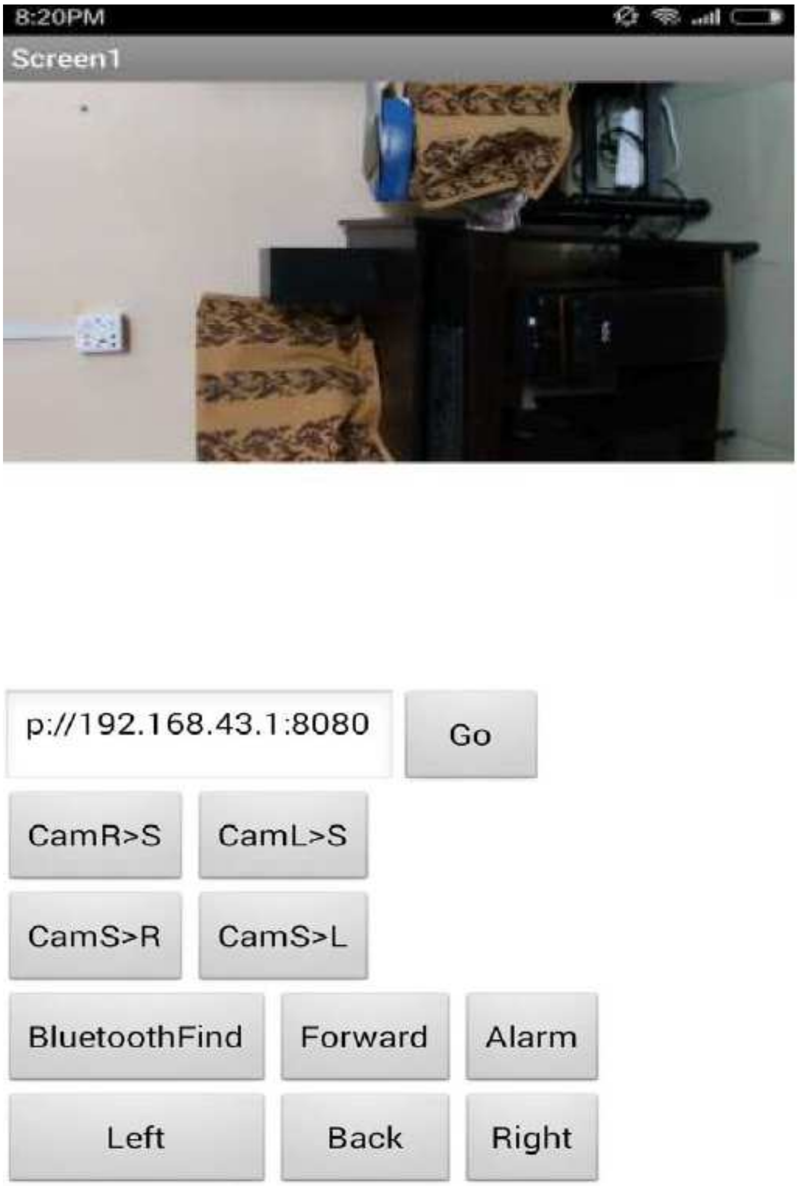


Figure 1.10: Web Interface on IP camera [44].

1.2.3.1
Web Interfaces

Surveillance robots have different types of web interfaces. Some authors use web browsers and additionally use the cloud computing technology [37]. Conversely, in order to use a web browser as a human-robot interface a mobile device can be used as the "brain" of the robot. Moreover, the mobile device can use 3G or 4G data transmission to publish the data into the web and perform the robot teleoperation [44] using an IP Camera, as it can be seen in Figure 1.10.

Another approach to develop web interfaces is to use an embedded computer in the robot as a web server, where a client can be easily connected

[40]. Finally, there are web interfaces that use the IoT technology to operate the robot which is equipped with PIR sensor, smoke sensor and camera, giving the robot the ability to detect people [48]. A web interface can also be used to obtain a map of the robot environment, using sonar sensors, gyroscopes, encoders and compass to carry out surveillance tasks [51].

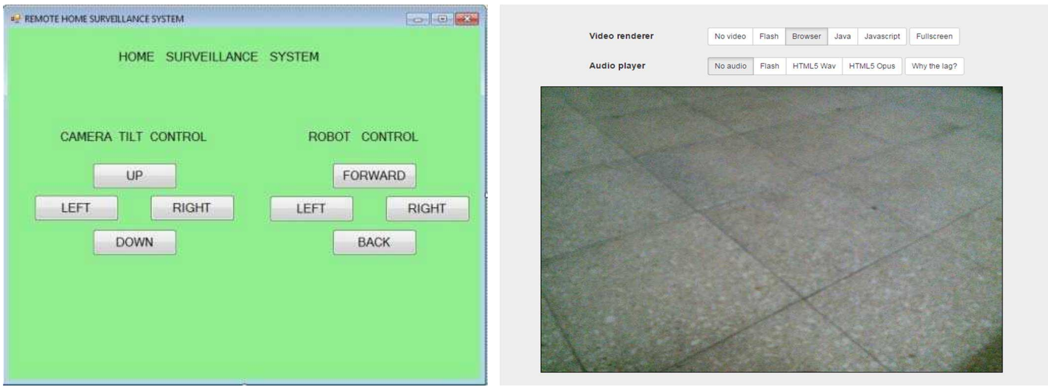


Figure 1.11: Desktop Interface Example: On the left we can see the teleoperation interface, and on the right we can see the camera's view[47].

1.2.3.2 Desktop Interfaces

Other type of interface that can be used is called desktop interface. In this approach, we can take advantage of the multiple additional peripherals (e.g., mouse, keyboard, speakers) to interact with the robot and communicate it using internet or DTMF [47]. This type of interface can be seen in Figure 1.11, where we can observe that in the left-hand side there is a command interface in which the robot can be moved in four directions (left, right, up, down) as the control camera tilt. On the other hand, the right-hand side presents only a separate window to visualize the information obtained from the camera.

1.2.3.3 Mobile Interfaces

One of the most used ways to teleoperate a robot consists of using a mobile device. Recently, two mobile devices have been used to control a surveillance robot: one is used to remotely control a robot, and other can be used to transmit the sensor data and receive the data through the 3G [39] or 4G communication systems [53]. Moreover, the smartphone can be used to transmit information to a robot which is controlled by an Arduino microcontroller [41].

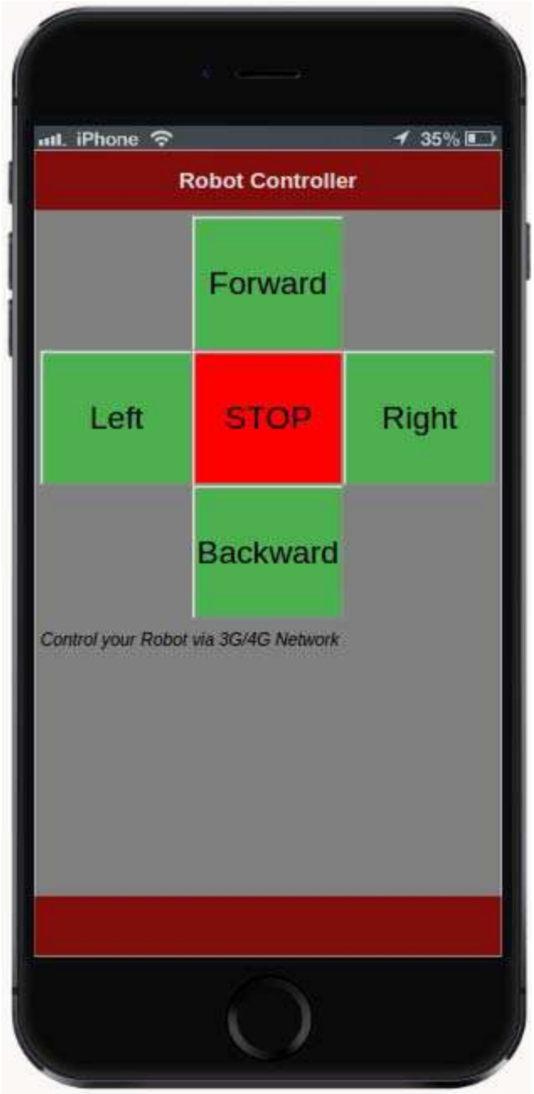


Figure 1.12: Mobile Interface Example: It is showed different buttoms of teleoperation [53].

A minicomputer *Raspberry Pi* can be used as the controller for the robot which can be teleoperated by using a smart application developed in *MIT AppInventor* [45]. A climbing robot, named Lizbot, was developed for crack monitoring on walls and the smartphone is used only to visualize the camera images [49]. These interfaces usually have buttons for robot teleoperation as it can be seen in Figure 1.12. Such buttons can drive the robot to the left, right, up and down. On the other hand, there are interfaces that represent the real robot with a virtual robot in order to be teleoperated using the master-slave criteria [54].

Also, there are approaches called multimodal interfaces, that combine different types of interfaces such as voice commands, mobile device commands, and web browsers [40, 46]. Other authors have studied the security and reliability of the data in a teleoperated system such as a similar algorithm for the pheromones transmission to the ants in order to communicate group of robots [40], or avoid computer attacks in the transmitted data [50], or recover sensory data that were corrupted by external agents [52].

1.2.4 Modeling Tracked Mobile Robots

In spite of the advantages of using the TMRs, the modeling process is a complex task because of the inherent slippage in the locomotion apparatus. In this context, there are three different approaches to deal with the modeling problem namely (i) the differential-drive, (ii) the skid-steering and (iii) using variations of the skid-steering model.

Table 1.2: Modeling and Control on TMR

Author	**Application**	**Kinematic Modeling**			**Control**
		Unicycle	**Skid Steering**	**Other**	
Sidi [55]	Theoretical		X		PID
Li [56]	Cleaning	X			Cartesian
Zeng [57]	Theoretical		X		Dynamic
Ji [58]	Navigation	X			Sliding Mode
Nardi [17]	Navigation	X			State Feed back
Sebastian [16]	Rough Terrains	X			PID
Liu [59]	Theoretical		X		Dynamic
Endo [60]	Theoretical		X		Proportional
Nagatani [61]	Climb Stairs		X		-
Martinez [62]	Theoretical		X		-
Zhou [63]	Theoretical			X	Backstepping
Moosavian [64]	Rescue			X	Feed forward
Kalantari [65]	Climb Stairs			X	Feed forward
Ji [66]	Theoretical		X		Backstepping

In the first approach, authors have neglected the presence of the lateral slippage, using the pure differential-drive model [16]. In addition, the independent velocity of each track is considered as a part of the kinematic model [58]. Authors also consider the length of the track in the kinematic model [56] and the time-varying friction coefficients on each track [17]. In the second approach, authors have considered the slip coefficient for each track [55]. Instantaneous Center of Rotation (ICR) is also considered as part of the model and some authors use only one ICR to formulate the kinematic model [60, 61]. Additionally, other approaches consider multiple ICRs: one ICR for each track and a global

ICR for the mobile robot, also considering slipping on each track [62, 57]. Finally, the third approach faces the modeling problem including time-varying coefficients on the skid-steering model in order to properly include the slippage on the terrain [63, 65]. All of these approaches can be seen in Table 1.2, as well as some applications that are suitable for the kinematic model of TMRs.

In this work, the third approach is used, the variation of the skid-steering mechanism is considered using a time-varying slippage factor. This slippage factor (d) depends of the angular velocity and a factor that describes the terrain of the application of the TMR.

1.2.5
Controlling the Tracked Mobile Robot

The control design for both the kinematic and dynamic models of TMRs is a complex task because of the presence of the wheel slip, when the robot is moving at a high speed or on a slippery terrain. Next, we will discuss some control approaches commonly founded in the robotics literature. The control strategies for TMRs has been designed considering different techniques, for instance, using the dynamic model of the robot as well as the parameters of the terrain to obtain a suitable control law [57]. On the other hand, using the PID controller, different tasks can be achieved such as stabilization of a skid steering mechanism and autonomous navigation of TMRs in rough terrains [16, 55].

Different authors have proposed state feedforward and kinematic based controllers [64] as well as a state feedback [17] control approach in the context of trajectory planning and a combination of them [65]. Moreover, the Lyapunov stability theory and Barbalat's lemma can be used to design a Cartesian based control strategy of a TMR for trajectory tracking [56]. Other control approaches include robust nonlinear control techniques including backstepping controllers to reach a fixed point in the workspace [63] or trajectory tracking [58]. To the best of the author knowledge, robust controllers based on sliding mode control (SMC) and super twisting algorithm (STA) can be found only for differential driver and car-like Ackerman steering models [67, 68, 69].

In this work, two classical control techniques generally applied to the unicycle model are suited to the TMR. Additionally the sliding mode technique is applied as well as [58], but modeling the system as a chained form system.

1.3
Contribution

In this work, the author intends to contribute to the State-of-the-Art on modeling and control design of Tracked Mobile Robots (TMRs) operating in agricultural fields in the presence of parametric uncertainties and external disturbances. The main expected contributions are the following:

- Analysis of the current State-of-the-Art in research topics such as modeling, control, and teleoperation of TMRs. Additionally the surveillance robots and agricultural applications of mobile robots;
- Evaluate different kinematic modeling approaches of TMRs such as unicycle, skid-steering and its variations;
- Application of different control techniques on the kinematic model of TMRs for regulation tasks, formulating a new theorem for each type of controller;
- Numerical simulations in MATLAB and 3D computing simulation in Gazebo of TMRs for surveillance tasks of agricultural fields;
- Development of a Mobile User Interface (MUI) to teleoperate and control a surveillance mobile robot in agricultural fields.

1.4
Goals and Objectives

This work seeks to provide a successful modeling and control design methodology for a TMR as well as developing a MUI to allow the safe, natural and efficient interaction between an operator and the robot. Next, we will describe the short and long term objectives.

1.4.1
Short Term

- Implement a suitable kinematic and dynamic model of a TMR, taking into consideration the inherent slippage of the tracks on the terrain;
- Implement different control techniques for TMRs, from classical approaches such as Cartesian space control to advanced approaches such as Sliding Mode control, for two different tasks: regulation and tracking;
- Verify and validate the control strategies with numerical simulations and the virtual representation of the TMR in 3D robot simulators;
- Implement a MUI based on the Android OS to perform surveillance tasks in agricultural fields.

1.4.2 Long Term

- Propose a framework to model and control a TMR which is capable to be applied to different tracked mobile robots in different environments;
- Combine the developed control strategies to planning algorithms and obstacle avoidance techniques for achieving autonomous robot navigation;
- Extend the use of the designed MUI to other TMRs supported by Robot Operating System (ROS) to carry out experimental tests in agricultural fields.

1.5 Methodology

In this work, we seek to address the problem of modeling, control and teleoperation of a TMR by using a MUI based on Android OS. Such a interface will be used to help the user in the surveillance of agricultural crops.

In order to deal with the problem of modeling, we take the advantage of the skid-steering mechanism with a modification in the slip factor calculation. The chained form is also formulated using the generalized form obtained from Lie Algebra, adapting the kinematic model to the requirements of TMRs.

The motion control problem can be tackled using two different approaches: regulation and tracking. Regulation problem is solved using three different methods such as Cartesian space control, polar coordinates control and sliding mode control. The stability analysis of the first and third control strategies is carried out by using the Lyapunov theory, where as the second control strategy relies on the linearization approach and the Routh-Hurwitz criteria to establish the stability conditions. Three theorems are introduced to validate the proposed control strategies used to solve the stabilization problem of a TMR.

A Mobile User Interface is developed to teleoperate the TMR during the execution of the regulation tasks. The communication protocol between the mobile robot and the server is designed using the Robot Operating System (ROS) framework. The server is responsible for sending and receiving commands to and from the Android device (Tablet). This interface is built using the socket library of Java and the communication system is implemented by using a Wi-Fi network deployed in infrastructure mode. The commands sent by the user will run the control algorithms into the mobile robot ensuring the successful execution of the surveillance task.

1.6
Problem Formulation

Here, we consider the robust stabilization problem of a Tracked Mobile Robot (TMR) in the presence of parametric uncertainties and external disturbances. It is well known that wheeled mobile robots are not suitable for carrying out surveillance tasks in outdoor environments, such as agricultural fields, due to the presence of irregular terrains and wheel slippage. To deal with this problem, TMRs arise as an alternative because of the large contact area between the terrain and the tracks. The kinematic model of a TMR is in general based on a slightly modification of the kinematics of a skid steering mobile robot and takes into account a time-varying slippage factor as a function of the robot angular velocity. In this context, the kinematic control approach provides a satisfactory performance with respect to the norm of posture error when the regulation task is carried out with low velocity and slow acceleration. Since the classic kinematic control strategies are not able to deal with parameters variations and perturbations, we consider a robust control strategy based on the sliding mode control approach.

In this work, we consider the surveillance problem of agricultural crops according to a demand for security suggested by the Embrapa Agrobiology unit, located in Seropédica (RJ), namely:

– Invaders who steal plants, fruits and experiments (e.g., mango, guava));
– Wild animals that eat the sugarcane plantations (e.g., capybaras).

To deal with this security problem, electrical fences are commonly used but these devices are not able to properly protect crops located in remote and open fields. In this context, a TMR can be used to carry out surveillance tasks in the neighborhood of the experimental fields. The key idea is to define a square monitoring area surrounding a crop of interest and move the TMR in the direction of the checkpoints. Since the robot achieves a given checkpoint it has to stay there for a short period of time, while capturing images and data from the environment. The robot has to use sirens, lights and send the images of the potential intruders (people or animals) to a monitoring center, reporting the GPS coordinates as well as the detection date and time.

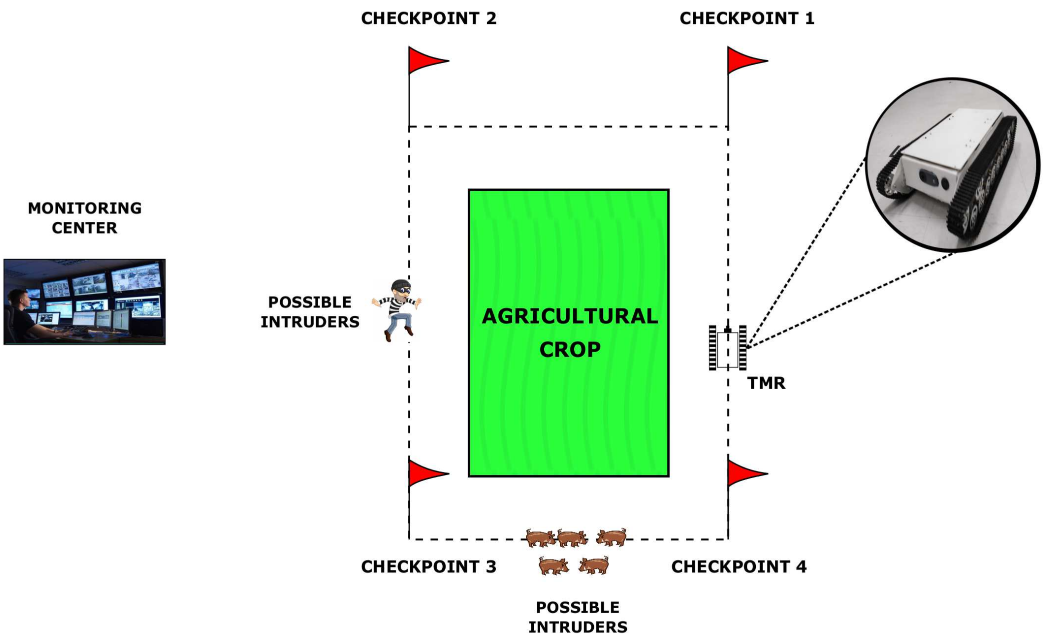


Figure 1.13: Problem formulation for a surveillance task in agricultural fields.

Figure 1.13 shows the entire problem formulation, the plantation and the checkpoint that the robot will check. Additionally can be see the possible intruders around the plantation as the monitoring center.

1.7 Text Organization

This work is organized as follows:

- Chapter 2: presents classical kinematic models for the TMR and the control approaches for regulation tasks;
- Chapter 3: presents an advanced control technique with robustness properties, such as sliding mode control wherein this technique is developed in order to deal with modeling uncertainties and external disturbances;
- Chapter 4: outlines the design and implementation of the MUI, explaining the communication approach between the interface and the robot, and the different ROS packages used inside this user interface.
- Chapter 5: presents the concluding remarks obtained in this work as well as discussion and future works.