PERSPECTIVES ON AUTONOMOUS UNMANNED GROUND VEHICLES: A SURVEY

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Abstract: Currently, mobile robots have been used in different scenarios and applications, even for household chores. Using these devices can increase safety and productivity, especially in industrial operations. This study aims to identify gap technologies through an updated selection and comparison of wheeled unmanned ground vehicles (UGVs). Based on a systematic review and classification of commercially available robots, the results indicated established technologies while opportunities for research, development and innovation on mobile robotics can be found in user interface, connectivity and intervention features.

Keywords: autonomous robots; mobile robotics; unmanned ground vehicles; state of the art.

PERSPECTIVAS EM VEÍCULOS AUTÔNOMOS TERRESTRES NÃO TRIPULADOS: UM *SURVEY*

Resumo: Atualmente, os robôs móveis têm sido usados em diferentes ambientes e aplicações, até mesmo para tarefas domésticas. O uso desses dispositivos pode aumentar a segurança e a produtividade, especialmente em operações industriais. Este estudo visa a identificar gaps tecnológicos por meio de uma seleção atualizada e por uma comparação de veículos terrestres não tripulados com rodas (UGVs). Com base em uma revisão sistemática e em uma classificação de robôs comercialmente disponíveis, os resultados indicaram as tecnologias já estabelecidas, enquanto as oportunidades para pesquisa, desenvolvimento e inovação em robótica móvel podem ser encontradas em recursos de interface para usuário, conectividade e intervenção.

Palavras-chave: robôs autônomos; robótica móvel; veículos terrestres não tripulados, estado da arte.

1. INTRODUCTION

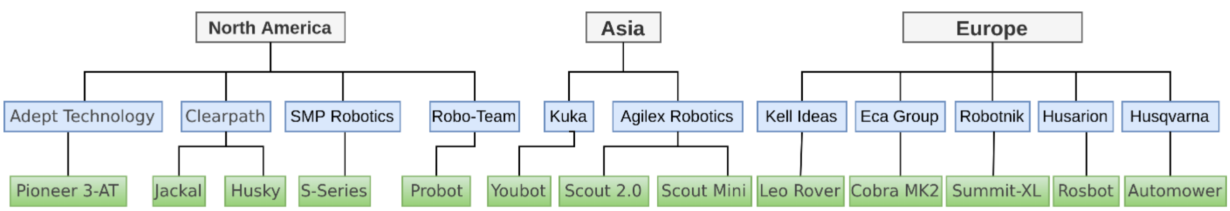
Mobile robots are electromechanical platforms equipped with a locomotion system, capable of navigating through certain environments, endowed with different levels of autonomy that may carry loads [1]. Currently, mobile robotics field is constantly evolving and there are commercially available autonomous vehicles to solve worldwide issues such as unknown locations exploration, industrial inspections or rescue missions. This paper intends to show the State of The Art (SoTA) for wheeled type Unmanned Ground Vehicles (UGVs). UGVs can be used for many applications specially the dangerous ones or considered impossible to human being to do so. These robots are useful to agriculture [2], nuclear [3] and military [4] industries. These vehicles are usually equipped with sensors and some intelligence to provide autonomous navigation or can be teleoperated by an operator in a safe distance.

This paper is organized as follows: Section 2 describes applied methodology to gather available robots' information, mostly commercial off-the-shelf and organize them according to size categories; Section 3 discusses the results on proposed criteria to classify such robots. Finally, Section 4 presents conclusion on UGVs state of the art.

2. METHODOLOGY

This study was led in three stages: search for up-to-date information about available wheeled UGVs on companies' websites, academic papers and technology news; gather and organize technical specification about identified robots; establish and classify the robots according to proposed criteria. Then this paper presents the state of the art on wheeled UGVs and offer directions on robotics research and development opportunities. Preliminary data processing of collected information was dealt through a mind map categorizing the robots by location and company (Figure 1).

Figure 1 – Mind map of current UGVs



Those wheeled robots were gathered from sources around the world and it was noticed that most relevant UGVs models are available in North America, Asia and Europe. This is possibly a consequence of robotics research centers presence in these locations and great economic power of countries on these continents. These models were grouped below according to their footprint size in three categories: Small size robots, medium size robots and large size robots.

2.1. Small Size Robots

This category selects up to 0.25 m² footprint size robots (Figure 2). Most of these models have been developed for research and education applications, such as *ROSbot*, an open-source mobile platform developed by Husarion. This mobile platform is focused on Robotic Operating System (ROS) education and can be used as a base for a variety of robotic applications like inspection and custom services [5]. Small robots can also be used in military applications as they can reach places that are difficult for human access, for example *Cobra MK2 E*. This UGV developed for defense and security applications by the ECA Group weighs only 5 kg. It has GPS module, camera, temperature sensor, artificial intelligence and an intuitive graphical user interface [6]. *Leo Rover* is a mobile robot developed by Kell Ideas in 2019 for company and education applications. It can also be outdoorsy applied due to waterproof casing that offers resistance to extreme environments. By being open-source and having its architecture based on ROS, it becomes accessible for developers [7]. Although it is no longer available, many researches are still being carried out with *youBot.* This platform developed in 2010 by KUKA for research and education applications has extended movement capability due to its omnidirectional wheel system and can have one or two manipulators integrated with [8]. *Jackal* is a fast mobile robot developed by Clearpath Robotics in 2014 for field research and education applications. Due to its robust aluminum chassis and weatherproof housing, it is ideal for outdoor operation. It has localization and vision sensors fully integrated with ROS. In addition, an extensive list of advanced sensors can be added to it because of its mounting plates [9].

Figure 2. Small robots: a) ROSbot; b) Cobra MK2 E; c) Leo Rover; d) youBot; e) Jackal

a **b** **c** **d** **e**

2.2. Medium Size Robots

The robots classified in this category are from 0.25 m² to 0.60 m² footprint size. It has been noticed a greater variety of applications for these models shown in Figure 3 than in previous category. The *Pioneer 3-AT*, for example, is a research mobile robot developed by Adept Technology in 2011. Due to its reinforced tires and lacquered aluminum body, it is ideal for all-terrain exploration missions. This robot run under ROS and can be improved by Pioneer's software development kit (SDK). In addition, there are several supported and tested accessories that could be integrated with it [10]. Focused on research and education applications, *Scout Mini* is a lightweight and flexible robot developed by AgileX Robotics that can ride both indoor and outdoor environments. It can support peripherals like cameras, IMU and LiDAR [11]. Mobile robots can also help with household chores: *Automower 535 AWD* is a robotic lawn mower developed by Husqvarna that can work outdoor, up to 30 degrees' inclinations. It has GPS, ultrasonic and height sensors [12]. *Summit-XL* is a versatile and resistant robot developed by Robotnik for surveillance and military purposes, it has high modularity and mobility and can operate indoor and outdoor due to its two kinematic configuration which incorporate rubber or mecanum wheels. This robot has ROS based architecture and it is equipped with laser scanner, GPS, and camera. It can carry heavy loads and navigate in rough environments due to its strong mechanical structure [13].

Figure 3. Medium robots: a) Pioneer 3-AT; b) Scout Mini; c) Automower 535; d) Summit-XL.

a b c d

2.3. Large Size Robots

Robots with more than 0,6m² footprint size have been grouped in this category. As shown in Figure 4 they are generally more robust and resistant, being commonly used in security and military applications. *Scout 2.0* is a multiuse UGV developed by AgileX Robotics for research and education, indoor and outdoor security patrolling applications. It has a modular design, flexible connectivity and a powerful motor system, capable of high payload. In addition, components such as stereo camera, laser, radar, GPS, IMU and robotic manipulator can be installed on it [14]. *Husky* was the first field robotic platform to provide native support for Robotic Operating System (ROS) providing open-source code examples in ROS community. This mobile robot developed by Clearpath Robotics is suitable for robotics research in real and simulated environments. It supports additional modules such as camera, GPS, LiDAR, IMU and even manipulators [15].

Figure 4. Large robots: a) Scout 2.0; b) Husky; c) S-Series; d) Probot.

a b c d

S-Series robots were developed by SMP robotics for outdoor security and inspection applications. Due to a rigid aluminum coating used for protection, robot can be used in moist and rough environments. Most notable feature of these models is auto charging docking station which allows robots to charge their batteries without any human intervention [16]. Professional Robot (*Probot*) is a military robust and versatile robot developed by Roboteam for indoor and outdoor operations. It can perform semi-autonomous missions and carry heavy payloads while maintaining high speeds. It can also be teleoperated, follow the leader or use GPS waypoint navigation [17].

2.4. Classification Criteria

As a way to provide a comparison among presented models, 10 robotics development parameters, shorten as criteria, were defined and ranged into 3 score levels where L1 stands for 1 point, L2 stands for 3 points and L3 stands for 5 points.

- Payload Ratio (PR): Ratio of the payload of the robot to its weight. L1: PR < 0.5; L2: 0.5 < PR < 1.0; L3: PR > 1.0.
- Speed (S): Moving speed in m/s. L1: S < 1.0; L2: 1.0 < S < 3.0; L3: S > 3.0.
- Runtime (R): How long full charged battery lasts in hours. L1: R < 1.0; L2: 1.0 < R < 3.0; L3: R > 3.0.
- User Interface (UI): How user may interact with the robot: L1: Command line (No GUI); L2: Installed program (GUI); L3: Web app (GUI).
- Autonomy Readiness (A): Ability of robot navigate and execute tasks without human intervention. L1: Remotely operated; L2: Autonomy-ready; L3: Full autonomous.
- Terrain Type (T): Ability of the robot to operate in different environments. L1: Flat terrain; L2: Rough terrain; L3: Soft sand.
- Perception Readiness (P): Available sensors on the robot. L1: IMU and range finder; L2: LiDAR or camera; L3: RGBD or Stereo camera.
- Connectivity (C): Robot communication standards. L1: USB and RS232; L2: Ethernet or Wi-Fi; L3: 4G/5G network.
- Ingress Protection (IP): Degree of protection against solid particles and liquid ingress. L1: IP < 23; L2: 23 < IP < 64; L3: IP > 64.
- Terms of use (TU): Accessibility of robot technology. L1: Proprietary technology; L2: Free and Open Source Software (FOSS); L3: Free and Open Source Hardware (FOSH).

3. RESULTS AND DISCUSSION

The classification of selected robots based on proposed criteria is shown in the Table 1. Rate column displays an arithmetic mean as a global robot classification. Criterion score shows each parameter performance as an arithmetic mean too.

Table 1. UGVs Comparison

	PR	S	R	UI	A	T	P	C	IP	TU	*Rate*
ROSbot	5	3	5	1	5	1	5	3	5	3	3.6
Cobra MK2 E	3	3	3	3	5	5	5	3	5	1	3.6
Leo Rover	3	1	5	5	3	3	3	3	5	5	3.6
youBot	3	1	3	1	3	1	3	3	1	3	2.2
Jackal	5	3	5	1	3	3	5	3	5	3	3.6
Pioneer 3-AT	3	3	5	3	3	1	5	3	1	3	3.0
Scout Mini	1	5	1	1	3	5	5	1	1	3	2.6
Automower 535	1	1	3	5	5	1	1	1	3	1	2.2
Summit - XL	1	5	5	1	5	5	5	3	3	3	3.6
Scout 2.0	3	3	3	1	3	3	5	1	1	3	2.6
Husky	5	3	5	1	3	3	5	1	3	3	3.2
S-Series	1	3	5	5	5	1	5	5	5	1	3.6
Probot	5	5	5	3	5	5	5	3	5	1	4.2
Criterion score	3,0	3,0	4,1	2,4	3,9	2,8	4,4	2,5	3,3	2,5	-

These results point out to possible development directions and indicate mobile robotics' current state of the art according to the robotics development parameters. It was not expected to have full scoring criterion, since this technology field has only just begun to be explored. However, it can be stated that a plenty of high quality sensors are already available on most robots to enhance their autonomy capabilities. While perception feature is almost consolidated, manipulator-integrated robots for mobile intervention are still uncommon and present a great opportunity for future developments. On Table 1 it can be noticed lower performance scores on user interface, connectivity, terrain type and terms of use criteria. Most of robots only offer command line access, while a few offer web based applications which indicates strong relation with poor score of connectivity criterion. Since robots become less restricted (by physical or local wireless networks) and more connected, multiplatform applications become demanding as well. Otherwise, if 4G/5G networks are not pursued, development of more complex multi-robot systems could face a barrier. The results for the terrain type criterion is expected as suppliers usually limit robot applications and this feature improvement could increase overall product costs. The result of the terms of use criterion is not restricted to the field of robotics, as recently open software increasingly acquires market share, whereas open hardware does it at a slower pace [18].

4. CONCLUSION

This paper has presented some of the most relevant UGV models currently available on the market and compared according to ten classification criteria. The results indicated that perception and runtime features are established technologies whereas user interface and connectivity integration features are not so mature. Therefore, they offer great opportunities for research & development on mobile robotics. Complimentary analysis revealed that an intervention feature such as integration of robotic manipulators is a challenging one, since it is not available on most of current solutions and it is a favorable topic for future work and market investments.

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