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AUTONOMOUS LAWN MOWERS: A COMPARATIVE APPROACH

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Abstract: *The service mobile robot market is increasingly growing. Autonomous electric lawn mowers, as part of this category of robots, pose numerous advantages for the user in what concerns the time spent conventionally mowing the lawn, the consumption of energy, and safety. Moreover, the original cost of investment and of the spare parts must be taken into account. Autonomous electric lawn mowers save the operators from repetitively doing the same job. Once the area is defined with the help of a boundary wire, the robot moves randomly, based on the navigation strategy, with trajectories that have not been previously defined, autonomously avoiding obstacles within the area, with the help of sensors. Well-known and experienced garden equipment manufacturers offer a wide variety of autonomous robots. This paper provides an insight into the field and the research trends concerning operational safety, energy efficiency, and navigation of autonomous electric lawn mowers. In this research paper, some of the most representative types of robots are compared, taking into account essential criteria for these types of robots, such as: the recommended mowed area, the robot autonomy under normal conditions of use, navigation modes and strategies, the cutting system, control, mobile applications and optional functions.*

Key words: *Mobile Robots, Lawn mowers, Autonomous navigation, Efficiency, Autonomy, Operational safety.*

1. INTRODUCTION

Robots have become part of everyday life. Whether we interact with them in the workplace, especially in companies that have adopted a hybrid production system involving interaction between humans and collaborative robots, or we see them in various industries performing repetitive and tedious tasks. They are no longer an element of novelty, but rather of normality. While some operations performed by robots cannot be performed by humans because of their high degree of precision or for safety reasons, the majority of tasks that robots perform have been transferred from humans. In fact, this paper does not aim to analyse how robots will replace humans, but how they can be integrated into various common activities. This truth, that is unfolding before our eyes, brings benefits because it gives rise to new occupations and at the same time motivates people in certain professional categories to retrain towards easier and more rewarding fields [1].

Productivity is a key word when it comes to autonomous robots, flexible systems and new technologies. The adoption rate of robots in broad applications is closely related to productivity and as it increases, the cost of manufacturing becomes competitive. These are the conclusions presented in *The Review of Economics and Statistics* [1].

Service robots are defined as autonomous machines that can adapt to complex and dynamic environments by acting in relation to the objects, devices and people around them. They are used exclusively outside industrial applications [2, 3, 4].

Currently, the market for mobile robots performing domestic tasks is dominated by floor cleaning robots, vacuum cleaning robots and lawn mowing robots. The forecast growth for 2023 for this category of robots is +31% compared to 2020 [5]. However, the adoption rate for this sector is lower than for industrial robots. This applies to the entire European Union [2].

The intention to buy autonomous lawn mowers is influenced by several factors. The degree of importance of these factors in the decision making has been ranked by a study in Sweden. The results obtained on the interviewed sample indicate that positive attitude, social pressure and availability are the main choice criteria. If the positive attitude towards product quality and reliability is the main decision factor, the availability of the robot increases the chances of purchase [6].

Mowing the lawn can become a tiring job for humans because it requires much energy [7]. Exposure to allergens, noise, pollution and other disruptive factors are some of the disadvantages of this process. These machines save time and protect the operator from accidents compared to traditional gasoline-powered rotary mowers [8, 9].

This paper aims to present a new perspective on the performance and key features of an autonomous lawn mower robot. From this point of view, an evaluation of the hardware specifications and navigation methods for some representative robot models in this field will be carried out. The comparative study is conducted to highlight the strengths of current robots. These will be

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the starting point for the development of a new product that will achieve the same performance, but with an innovative and simplified method of workspace delimitation. The method involves the use of a metal cable detected by an inductive sensor. The current problem of supplying the boundary wire with voltage from the docking station and creating a looped perimeter contour is solved.

2. GENERAL TECHNICAL CHARACTERISTICS OF AUTONOMOUS LAWN MOWERS

There are a number of significant features that we can consider when referring to a mobile robot. However, the most important ones concern the propulsion and locomotion system, the cutting system and last but not least the command and control system. We define performance as the ability of the robot to perform cutting on the surface recommended by the manufacturer both qualitatively and quantitatively. This is achieved with the help of an autonomous navigation system. Dynamic adaptation to changes in the environment must be done taking into account the data received from the sensor system.

2.1. Energy efficiency

Energy efficiency is a real issue for mobile robots. In general, robot mobility is defined as the ability to move from one place to another to fulfil requirements. The locomotion system, sensors and control system are the main energy consumers (Fig.1) [10].

Optimising energy consumption can be done in different ways. One of these is to divide the robot's working phases into three stages: standby, startup and running. This can simplify the mathematical calculation of system consumption. The presented variant does not take into account the robot path [10].

Another option is route planning and predicting energy consumption in difficult working conditions such as rough terrain or obstacles. The robot must be able to operate for long periods of time, so decisions made by the robot must also take into account the remaining energy so that it can go back to the charging station [11].

There are several sources of energy. Mobile robots, including autonomous lawn mowers, can use the following energy sources: Engine powered AMR (Autonomous mobile robot), Fuel cell powered AMR, Solar charging AMR, Solar Powered AMR, Wireless charging AMR and other energy sources [12].

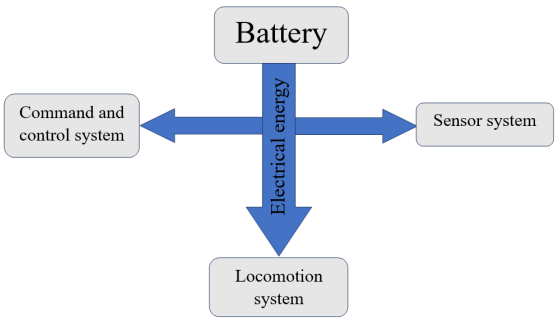

Fig. 1. Power distribution in mobile robots.

Some manufacturers opt for a hybrid system where the propulsion system is electric and, because of the high energy consumption, the cutting system is driven by an internal combustion engine. Such models are manufactured by Avatech. However, well-known manufacturers also take into account the negative environmental effects of internal combustion engines. Therefore, in order to eliminate air pollution and reduce noise pollution, fully electric robots are more ecologically friendly [13]. Successfully meeting this requirement is translated into practice by the actual area of land the robot can mow. This, expressed in square meters in the technical specifications section, is a differentiating criterion between robot models from the same manufacturer or between different brands.

2.2. Safety

Widespread adoption of autonomous robotic lawn mowers is also necessary in terms of the number of accidents reported among users of conventional mowers. A study in the United States of America shows for the period 2005-2015 approximately 934,000 such reported incidents. Thus the annual average is 84,000 accidents [14]. Therefore, more attention should be paid to this chapter. Robot sensors, cameras and artificial intelligence are additional safeguards to recognise and avoid interactions with possible human or animal obstacles in the robot workspace. Automatic stop systems when lifting the robot or stopping the cutting system are considered prevention methods. Also the presence of an emergency button to stop the power supply of the whole robot is a necessity. We can discuss new trends in this field, which emphasise concepts such as: human-robot interfaces, safe human-robot [15].

2.3. Navigation and control

The robot's command and control depends on several electronic components - each with a well-defined role - that are connected to each other.

In order to carry out their task, lawn mowers must have a proper locomotion system. Most manufacturers opt for a differential locomotion system. It best meets the requirements for flexibility and adaptation to different working environments. The spaces in which robots are used are often irregularly shaped. Differences in level and uneven terrain should not influence the robot's performance. Cutting to the appropriate height and moving across the entire space are two important aspects to consider. Therefore, in order to achieve these goals, it is important that at all times the robot acquires enough information about the environment [16].

Obstacles, the limits of the working space and the current position are just some of the data the control system receives from the sensors. Some robots use GPS sensors exclusively for localisation while others use LIDAR sensors for mapping the territory. The absolute position on Earth and the relative position to surrounding objects will be known, so the location problem is almost completely solved [17].

For a precise delimitation of the trimming space, several constructive solutions are used. The most popular one among autonomous lawn mowers is the wire delimitation, placed below ground level and powered

from the charging station. Visual odometry, more commonly used for cleaning robots, has also become a method used in the field of lawn mowers. It uses one or more cameras for Simultaneous Localisation and Mapping (SLAM) [18].

Some fixed obstacles, whose position does not change during robot operation, can easily be marked using the boundary wire method described above. Unforeseen obstacles such as pets, people and objects, whose position can change while the autonomous robot operates, can be detected by it using an RGB-D camera. This is presented as an optimal variant considering both price and accuracy [18]. Ultrasonic sensors are also widespread among mobile robots. Their operating principle is simple and the purchase price is not high. The data provided by ultrasonic sensors is accurate and can be used to generate trajectories.

All this information, generated by the sensor system, is transmitted to the control system. This is where the most important decisions are made. How the autonomous robot reacts to external factors depends on navigation algorithms, artificial intelligence, real-time data analysis and interpretation. The effectiveness of navigation methods differs from case to case. Tuning methods fall into two categories. The first is where the travel trajectory is a known and regular one. The movement is along straight lines in the forward-backward direction. This is done until the wire delimiting the working area is detected or an obstacle is encountered. For the latter situation, navigation strategies include either a 180° turn or a detour. The second navigation strategy aims to move the robot without a predetermined pattern. This method is effective when the navigation strategy also uses GPS tracking. In this way, areas already covered by the robot can be recognised and the robot is guided to uncovered areas. This option can bring benefits in terms of how freshly cut grass is spread on the field. Research shows that autonomous robots using the mulching system have an advantage for the grass blade. The debris shredded by the robot blades turns into fertiliser. Mowing thickly and in an irregular shape will reduce weed growth.

3. COMPARATIVE STUDY BETWEEN THE MODELS OF THE MAIN SUPPLIERS OF AUTONOMOUS LAWN MOWERS

3.1. Robot 1

Robot 1 lawn mower is a leader in the field of automatic lawn mowing and is available in several design variants. The difference between these models lies in the working area (600 [m^2], 1000 [m^2], 5000 [m^2]), but also in the technical features and functions available. The most important features of the premium model will be presented below, as it is equipped with all the technologies developed by the manufacturer.

Maintaining a healthy lawn does not take much work for Robot 1 lawn mower. This automation concept performs the task for the user without constant supervision. A random pattern of movement allows the product to find any corner of the defined area. It can easily handle wet and rainy weather conditions as well as difficult terrain, including slopes, potholes and even temporary obstacles such as cones and fruit. The robot is so quiet, it can even operate at night without disturbing anyone. Through the trimmer app, the user can have full access and control over operating hours.

- It is not necessary to cut in straight lines: Unlike traditional lawn mowers, the robot mows in irregular patterns, a fact that benefits the grass. It is not wrong to mow the grass in straight lines, but it is not necessary in order to achieve a perfect result. The light weight means it does not leave streaks on the lawn. The machine can find its way through narrow passages and can even detect areas of lawn where the grass has grown taller. The result is a completely even lawn.
- No restrictions because of the weather or time of day: The results are just as satisfying, even when mowing in wet conditions or at night. It is equipped with GPS, making it possible to schedule working times and define mowing areas.
- It is not necessary to collect grass clippings: This is possible because the robot mows the grass little by little and frequently. The cutting disc finely chops the grass into barely visible shreds. This is definitely the most "friendly" way to cut grass. While ordinary mowing usually cuts a few centimeters of lawn - which is then collected and removed - the Robot 1 cuts are only a few millimeters long. The blades of grass will fall to the ground, form a protective layer and fertilise the lawn.
- Anti-theft protection: The lawn mower is protected in several ways against theft attempts. A PIN code is required for any intervention. An alarm will go off if the mower is stopped or lifted. The machine is useless in case of theft, as the charging station is uniquely built, so if theft is reported, the robot is locked and located by GPS.
- Delimiting the workspace: This product operates on a surface defined by a boundary wire. If the batteries run down, the machine is able to return to the charging station in several ways: by following the wire that delimits the mowing area, by radio waves or by creating a travel path based on GPS coordinates. The wire enclosing the workspace is installed at ground level or under a shallow layer of earth. If two wires are installed next to each other, they cancel each other, leaving no barrier to the autonomous robot.
- Robot 1 is capable of mowing lawn on uneven terrain, as well as up to 45% slopes.

Some of the characteristics of this robot are listed comparatively to other robots in Table 1.

3.2. Robot 2

Robot 2, developed by another company, sets new performance standards with parallel cutting technology. The intelligent navigation system measures the surface and calculates the right route to mow the lawn in parallel rows. It is equipped with sensors, through which it avoids obstacles and moves to the loader autonomously. As with competitor models, the grass from the mowing process is not collected but used as fertiliser, since it is very fine.

The robot can be used in all weather conditions, can operate on slopes with a gradient of 27% and is equipped with safety systems such as an alarm system and PIN

code. It has a "user-friendly" interface, and after installation only a few simple operations are needed to get it ready for work. It has no harmful emissions, thus protecting the environment. This robot is available on the market in several models. Its main features are shown in Table 1.

3.3. Robot 3

The autonomous lawn mower has an outstanding performance in terms of working area and effective operating time. If the humidity exceeds a certain maximum value, the robot stops mowing and moves autonomously to the loading station, also called docking station. A special feature is the possibility of quick loading, should the robot consider it necessary to continue mowing. Otherwise, loading is done in economy mode. The console, the control component, is detachable from the body of the robot, making it possible to carry out the program from a comfortable position.

Another important function is that the direction of rotation is reversed every time the cutting knife stops, which ensures even wear of the cutting edge. It is equipped with an intelligent anti-theft system and wheels with a traction profile that can make it usable in areas with dense vegetation and on uneven terrain with slopes of up to 45%. The wheels also have a self-cleaning function.

Other functions include continuous adaptation of the propulsion according to the level of inclination of the ground measured by the gyroscopic sensor. Lithium-ion batteries power both the propulsion system and the cutting system. The height of the latter can be adjusted in 15 steps. Grass clippings remain on the ground surface and will act as a fresh mulch after decomposition. The cutting method chosen by the manufacturer is random. The algorithms of the control system will ensure a navigation that ensures complete coverage of the working area. Operator planning and moisture sensors will optimise the mowing process so that the turf is always fresh at the same quality level.

The main features of the Robot 3 lawn mower are shown in Table 1.

3.4. Robot 4

The Robot 4 producer is a well-known manufacturer of grass cutting equipment with a history of more than 180 years. In order to adapt to market demand but also to remain competitive with other companies in the industry, the company has developed an autonomous lawn mower. It sets new standards in quality and know-how acquired over time. Even if the robots do not get tired and bored in performing the same tasks for which they were designed, the more qualitative they are, the higher their performance and reliability will be.

Robot 4 lawn mower is designed to make the user's job easier and its control is intuitive. It does not require too much time to set up. The movement mode and the trimming mode are random. The robot can detect obstacles and areas with more intense grass growth. The robot has a red button, mounted in plain sight on the housing, which instantly stops locomotion and the cutting system when pressed. It is also important to note that the anti-theft protection is done with a PIN code.

The command and control system manages the energy supplied by the battery in real time. This allows the robot to calculate its trajectory and the amount of energy it needs to return to the docking station. As it is an electrically driven mobile robot, noise pollution is reduced. The robot can therefore operate at night without causing discomfort.

The large screen is easy to operate and program. Both, the assembly and the screen have high water protection to increase product life and reliability. Rough terrain is not a problem for the robot. It can operate on surfaces that have a 36% slope.

A strong point for this robot is the cutting system. The one-piece knife is made of a special material that will last throughout the season.

Some of the main technical features are compared to those of other lawn mower robots in the table below.

Table 1

Comparative features of Robot 1, Robot 2 and Robot 3

Technical specification	Robot 1	Robot 2	Robot 3	Robot 4
Height of cut [mm]	20–60	30–50	20–60	19–102
Battery charge time [min]	60	60	-	80
Battery run time [min]	270	75	75	-
Recommended lawn area [m^2]	5000	700	4000	2200
Navigation	Random	Parallel rows	Random	Random and spiral
Battery voltage [V]	-	18	29	25
Width of cut [mm]	240	190	280	-
Cutting system	3 pivoting blades	3 pivoting blades	-	1 blade
Maximum gradient [%]	45	27	45	36
Blade motor speed [rpm]	-	-	3.150	2600
Mowing duration [h]	-	-	40	90
Weight [kg]	13,9	7,6	14	15
Sound power level [dB]	59	59	62	62,2
Tool dimensions (L x W x H) [mm]	720 x 560 x 310	445 x 364 x 202	730 x 540 x 270	775 x 535 x 360
Price [€]	3900	1100	2000	2100

4. CONCLUSIONS

In conclusion, at the moment, the essential characteristics of this category of robots are similar, but we can see in recent years from studies and research that there is desire for improvement. Therefore, new energy systems, including hybrid systems, are being researched to increase the performance of lawn mowers.

At the same time, space definition using classical methods involving cable boundary will be replaced by complex mapping systems thanks to the integration of new lidar sensors and cameras. With the upgrading of the sensor system, the navigation algorithms will also be more complex, so positioning and obstacle avoidance will be more accurate. The navigation strategy and trajectory generation has been focusing recently on increasing energy efficiency. At the same time new cutting methods take into account studies concerning the health of the grass blade and the eradication of pests.

Last but not least, safety in use for both humans and animals implies both the use of additional systems and components, and the definition of new concepts such as safe human-robot. The ultimate goal is to design autonomous lawn-mowing robots that meet the high standards for which they have been created and at the same time coexist and work alongside humans.

Taking into account the main characteristics of the existing lawnmowers on the market, the specifications for the design of a robot that meets the latest requirements and trends in terms of navigation system, energy efficiency and safety in operation, but is still competitive in terms of price, have been outlined.

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