A Survey of Robot Lawn Mowers

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ABSTRACT

Lawn mowing is considered by many to be one of the most boring and tiring routine household tasks. It is also one of the most promising personal robot applications. Several devices have now been invented and some manufactured products are available for lawn mowing. The purpose of this paper is to survey the state of the art in robotic lawn mowers to highlight the requirements and capabilities of current devices. A brief survey of available robot products, typical patents and some testbed prototypes are presented. Some enabling technologies which could make the devices more capable are also suggested. Some predictions indicate that the robot lawn mower will be the breakthrough device in robotics. The significance of this research lies in the presentation of an overview of a potential major market for personal robots.

Key Words: robot lawn mower, personal robots, sensing, navigation

1. INTRODUCTION

Intelligent robots are an ideal, a vision. All one has to do to see the intelligent robot model is to look in a mirror. Ideally, all intelligent robots move dexterously, smoothly, precisely, using multiple degrees of coordinated motion and do something like a human but that a human now doesn't have to do. They have sensors that permit them to adapt to environmental changes. They learn from the environment or from humans without making mistakes. They mimic expert human responses. They perform automatically, tirelessly, accurately. They can diagnose their own problems and repair themselves. They can reproduce, not biologically but by robots making robots. They are used in industry for a variety of applications. A good intelligent robot solution to an important problem can start an industry and spin off a totally new technology. For example, imagine a robot that can fill your car with gas, mow your lawn, a car that can drive you to work in heavy traffic, a machine that repairs itself when it breaks down, a physician assistant for microsurgery that reconnects 40,000 axons from a severed nerve.

Intelligent robots are also a reality. Many are used today. Many more prototypes have been built. Typical applications are: high speed spot welding robots, precise seam welding robots, spray painting robots moving around the contours of an automobile body, robots palletizing variable size parcels, robots loading and unloading machines.

The components of an intelligent robot are a manipulator, sensors and controls. *However, it is the architecture or the combination of these components, the paradigms programmed into the controller, the foresight and genius of the system designers, the practicality of the prototype builders, the professionalism and attention to quality of the manufacturing engineers and technicians, and the cost, that makes the machine intelligent and useful.*

"Although many futurists have envisioned robots that could relieve humans of ordinary tasks like cooking and cleaning, people must still do most of the domestic drudge work, at least inside the house. But outdoors, the future is here, in the form of mow-bots" according to Mindy Sink[1].

Some of the advantages of a robotics lawn mower are:

- Performs a task which may be considered boring and tiring for humans
- Removes humans from exposure to dust, pollen and allergians
- Removes human from danger of mowing blade
- Can be used in hazardous environments such as radioactive storage locations
- Is part of the substantial home care market in the U.S.

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2. PRODUCTS

Some of the available products will be described in this Section. More complete information may be obtained from the manufacturers listed in the references.

1.Friendly Robotics

Friendly Robotics[2]now offers an affordable robot lawn mower shown in Figure 1.

Figure 1. Friendly Robotics lawn mower.

Friendly Robotics was founded in 1995 and has U.S. offices is in Abiline, Texas. It developed RoboScan, a patented technology for navigating and covering an area in a systematic manner. The robotic lawn mower product, the RL500 is fully automatic. It operates on rechargeable batteries. And since it mulches as it mows, there's no need for grass bagging. The Robomow Limited Edition Silver Classic has been on the market in Israel and Europe for about 18 months and in the U.S. since late last year. The RL-500 costs $795 and became available in June 2000. More information including a simulation program and movie is at: http://www.robomow.com/docs/aboutus.htm

2. Husqvarna

Husqvarna , a Swedish manufacturer[3], this year is also introducing its Automatic Mower to the U.S. market (it's been sold in Europe for about three years). It works much the same as the Robomow with a boundary wire implanted at the border of your lawn. The Husqvarna model, however, takes care of itself. Whereas the Robomow has to be taken out and set up and watched by the owner, the Husqvarna Automatic Mower lives outside, mows when it's programmed to mow and automatically returns to its base for recharging. The Husqvarna model is also significantly lighter than the Robomow (15 pounds vs. the Robomow's 42 pounds). According to Husqvarna, this not only makes it safer, but it leaves no tracks on the lawn. This complete freedom from even the thought of mowing, however, does have its price -- $1,995 plus $200 to $300 for installation. It's available in limited quantities this year from select dealers. The company also plans next year to release a solar-powered model to the U.S. market. Husqvarna Auto Mower and Solar Mower work independently. A boundary loop wire holds the lawn mower to the lawn and a search loop ensures that it returns to the docking station for battery recharging. The solar Powered version does not need a charging station and will be in production next year. Both mowers share similar features, the only difference is the power source. Almost silent and environmentally friendly. The boundary loop wire (red) defines the Auto Mower's cutting area whilst the search loop wire (yellow) directs the mower to the charging station. The boundary loop is also laid out around trees and surfaces of the lawn which will not be cut. The lawn mower changes direction if it touches garden furniture, a tree or other solid objects, yet is able to cut under bushes and hedgerows. You can program the cutting height between 30 and 95 mm to achieve a lawn just the way you want it. Dimensions: (L) 71 cm, (W) 60 cm, (H) 26 cm

Cutting system: Blade Disc, 3 rotating knives
Cutting Heights: 30-95mm
Weight: 7,1 kg

Figure 2. Lawn mower by Husqvama.

3. SN Eno

A robot that operates on an on-board, solar charged battery has been designed by the French manufacturer SN Eno. The Robo-Mower[4] the capability of steering itself across a person's lawn . This robot called the Atawa A34, uses built-in infrared sensors to avoid obstacles. This system uses wires buried beneath the surface of the ground to control it. It operates at a top speed of 21 ft/min. Robo-mower is a 12.5-pound solar-powered robotic lawn mower that cruise the yard continuously and silently, using an on-board computer and sensor to guide the device while it cuts the grass. Poulan Weed-Eater and its parent company A.B. Electrolux of Sweden, plan full production next year. (St. Petersburg Times 3/12/94 A17)

4. Technical Solutions

Another example is called the Lawn Ranger described by Rafaels[5] and developed by Technical Solutions of Frederick, Md. The design uses an onboard computer to control the mower and interact with sensors that guide the robot. The robot has two modes – operation :remote mode in which an individual guides the mower around the outer perimeter of a person's yard and around any obstacles in its path. The system is switched to automatic mode in which the robot's infrared sensors make a comparison between cut and uncut grass. The mower continues this process until it completes the job. The inventor was seeking to manufacture the prototype at a cost of $900 with the intension of creating larger models for the future.

5. Weed Eater

Another example of an autonomous lawn cutting system is called the "Weed Eater" developed by the Weed Eater Corporation[6]. The system is a solar powered emission free mower that harnesses enough power to operate itself. The robot is equipped with 34 iridescent solar cells imbedded on top of the system's platform and has the capability of handling properties up to 13,500 sq-ft. The system operates on the same principle as the Lawn Ranger except it uses a cable beneath the surface of a person's lawn. The mower uses this wire along with its sensors to allow the robot to maneuver around while keeping the system on track. The mower will continue to operate as long as the mower has energy, from the sun. The robot is equipped with a flexible bumper that when activated backs the mower up and continues the robot on a different path. The system has an on-board memory system which remembers all of the previous cutting paths and identifies what grass has not been cut. the unit weighs about (12.5lbs) and its safety precautions are much more precise than most mowers. It has the advantage of cutting grass in the form of a mulch so that the use of a grass catcher or raking is not required.

4. PATENTS

A preliminary patent search was conducted and brief summaries are given in this section. Please refer to the original patents for exact wording and ideas.

The most recent patent found was by Nelson[8]. This automated, self propelled *lawn mower* uses a rotating directional loop antenna to determine its position within the cutting area by measuring the angle between transmitters placed in a known configuration beyond the cutting area, and by calculating the solution of simultaneous circle equations defined by that configuration. Orientation is determined by comparing present and previous positions. Stored path information is compared with the calculated position to determine steering signals which direct the mower to move directly toward the next point in the desired path. When the mower reaches that point the next coordinates are retrieved from memory and the process is repeated similarly for all successive points in the path.

Next is a remote controlled guidance system invented by Zondle[9]. A remote control method of guidance for a work vehicle including a handheld control unit, an antenna/transponder placed on the periphery of the worksite, a controlling unit on the work vehicle itself. The control unit compares timing signals to subsequently control of the speed of independently powered wheels. There is a manual and automatic mode of control for the vehicle. The vehicle is positioned at a starting point by the user, and upon activation of the automatic mode, a timing pulse, either ultrasonic or electromagnetic is issued from the control unit on the vehicle. When the pulse is sensed by the transponder on the antenna, a responding pulse is transmitted. This is, in turn, received by the vehicle and thus a base time is set for the interval between the transmission of the pulse and the return signal from the transponder, the interval being indicative of the distance between them. The vehicle moves forward while continuing at intervals to send the pulse and if the secondary timing interval is larger than the base interval, the inner wheel is slowed to bring the vehicle closer. If the interval is shorter, the inner wheel is speeded up to move the vehicle away from the transponder. Thus, the vehicle describes a smooth arc about the transponder until the user sends another signal to the device, indicating that the device is to move a preset distance further away from the transponder, reset the base interval, and continue.

Next is a continuous autonomous mowing system invented by Colens[10]. The invention relates to an automatic, self-contained machine for continuously mowing grass. The machine is powered by means of photovoltaic cells and can be wheeled or tracked. A device comprising a microcomputer programmed by an algorithm allows to search for spots where the grass must be cut and to detect the boundaries of the surface to be mown. The obstacles are detected and passed around by analysis of relative movements of an upper panel comprising the photovoltaic cells and a lower frame.

Next is a position adjustment structure using an eccentric shaft invented by Masaru [11]. A device for adjusting the height of a vehicle, by rotating the angle of a base shaft eccentrically supporting a support shaft. Wheels are fitted to a support shaft eccentrically connected to a base shaft rotatably supported by bearings disposed on push-pull type electric mowing machine. One of the ends of a connecting member is fixed to the core of the base shaft and an adjustment device is fitted to the other end of the connecting member. Alternatively, a base shaft is supported concentrically and rotatably at the core of a composite shaft type mowing machine in such a manner as to protrude from both end portions of a rotary shaft. The base shaft is rotatably supported by an apparatus main body at both end portions of the base shaft and eccentrically with respect to the base shaft, and wheels are fitted to both end portions of the support shaft. An adjustment pulley is fixed to the base shaft either inside or outside the bearings. The position of the height is adjusted by controlling this adjustment member.

An autonomous lawn mower was also invented by Noonan, et al. [12]. This invention is an automatic, self propelled lawn mower that references its position within a cutting area using electronically stored path and terrain information as a primary navigation system, senses a non magnetic, non-current carrying metallic guide path as a secondary navigation system, senses underground metallic references for use as position reference points as a further navigation system, incorporates an ultrasonic obstacle detection system to stop the vehicle if unexpected obstacles are encountered. The vehicle further includes a cow-catcher front bumper arrangement to divert small objects away from the cutting blades, contains bumper switches to shut off the vehicle upon contact with large objects, contains an inclinometer sensor to halt the vehicle during unexpected tilting, incorporates a radio communications link to notify an off-board monitoring system of problems, contains an on-board power generation system using an internal combustion engine, generator, and a battery arrangement. The lawn mower also provides

a navigation controller and servo motor positioning system that plans path motion, using sensory data and stored map data and to turn the drive wheels to propell the vehicle in the desired manner.

The next patent relates to a floor cleaning machine was invented by Pong, et al.[13]. A means and method for control of an autonomous vehicle while working on a surface, specifically for operation of an automatic floor cleaning machine using power derived from line power through a wall plug and cord. The vehicle uses information derived from contact between bumpers and objects in the environment to sense the geometry of its environment and utilizes a recursively applied algorithm to systematically and efficiently cover the floor area.

The next invention by Shyu and Chang [14] is for an automatic vehicular system. This vehicle comprises a guiding signal device and an automatic working vehicle which has a power source, driving devices, detecting devices and control devices. By means of a guide wire device for limiting the operational area, the vehicle can start at a preset time, travel from a position in a garage to a specific operation site, complete the required range of operation along a parallel reciprocating course of travel, and return to the garage. The vehicle also comprises devices to control the garage door, detect the fuel level, return itself to the garage when raining, adapt to load variations, change speed automatically, warn moving obstacles, detour obstacles, and prevent its theft.

Another automated lawn mower or floor polisher was invented by Martin[15]. An automated self propelled lawn mower utilizes a pair of drive motors for independently driving left and right hand drive wheels. Each drive motor is coupled to the respective drive wheel by a double output gear reduction unit. One side of the output shaft from each gear reduction unit is provided with a rotary photo encoder for providing speed and position information relating to each drive wheel. This information from each rotary photo encoder is fed to a computer control via a computer interface. Each independent wheel drive motor is computer controlled through an interface and motor drive relays. An infrared obstacle detector is mounted on each corner of the mower frame for detecting obstructions. Grass touch detection switches on the rear of the mower frame provide an indication of the relative position of the cut or uncut grass which is fed through the computer via the interface circuit for providing computer directional control to the independent wheel drive motors which steer the mower along the proper track. A separate blade drive motor is turned on or off by a photo switch which detects uncut grass. The speed of the blade drive motor is controlled by a manual switch. A floor polishing pad may be substituted for the lawn mower blade to enable use of the device as an automated floor polisher.

A method of guiding a robotic lawnmowerwas invented by Rafaels [16]. A method for guiding a robotic vehicle includes the steps of establishing a tracking position along a row of vehicle sensors at which the border is to intersect the row, positioning the vehicle on the border so that the border intersects the row at an intersecting position, generating a positive signal when a sensor senses any obstruction by vegetation of a path of radiation from a respective emitter to a respective detector, generating a negative signal when a sensor does not sense any obstruction, repeating said generating steps as said vehicle advances, sending a plurality of groups of said generated signals to a processor, averaging said signals, identifying the intersecting position by identifying an adjacent pair of oppositely signalling sensors on the basis of said averaging of said signals, determining whether the tracking position is at or to the right or left of the intersecting position, and steering the vehicle straight when the tracking position is at the same location as the intersecting position, to the left when the tracking position is to the right of the intersecting position, and to the right when the tracking position is to the left of the intersecting position.

3. PROTOTYPES

Before a product can be manufactured, a prototype must be developed. Examples of robot lawn mowing prototypes are giv en below.

The Lawn Nibbler is being developed at the University of Florida[17]. Scott Jantz, University of Florida engineering student. "*The idea is that the robot would recharge itself at night and come out during the day, probably when you were at work and cut the grass, and then go back in… And you'd never see it. You'd just have grass that was well taken care of all the time*."

The Lawn Nibbler is shown in Figure 3.

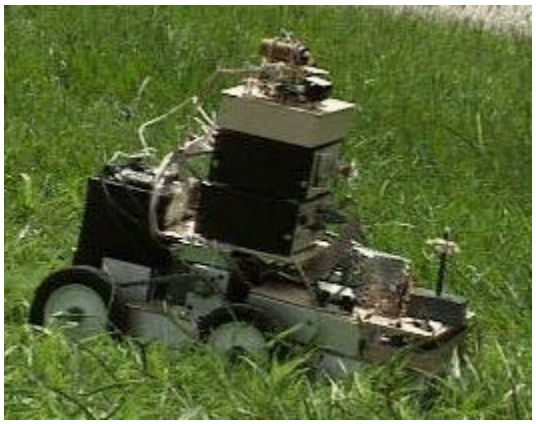

Figure 3. Lawn Nibbler developed at University of Florida.

The lawn mower has been studied by Dr. Hall[18-20] and his students both at the University of Tennessee and the University of Cincinnati. The 1986 team is shown in Figure 4. It is a great educational testbed for new ideas.

Figure 4. University of Cincinnati robot lawn mower in 1986.

5. PROMISING IDEAS

Mobile robotics is a broad field and many mobile systems have been developed as forms of automated guided vehicles (AGV's) for use in structured environments such as factories and self guided vehicles (SGV's) for use in more unstructured environments. Navigation, obstacle avoidance and motion control are the key functional elements needed for safe, reliable and accurate operation

of the mobile unit. In a remote control (RC) vehicle, the human operator must provide the high level navigation and path planning and obstacle avoidance operations. Since the human can directly view both the mobile robot and environment, the RC operation can be safe and reliable.

In general, a robot lawn mower can operate in three distinct modes: remote control, teach control and automatic operation. For remote control operation, the human commands must be executed in the mobile lawn mower. Also, sensory information such as motor speed, blade status, tactile information and an image of the local environment can be transmitted to the operator to provide a "telepresence" in which the operator senses enough information about the environment to perform the proper action. The general telepresence concept is still being researched and more information is needed in some situations. In teach mode, the storage capacity of the microcomputer is used to store command and encoder information so that repetitive operations can be performed. In some operations, the use of a given home position for calibration may provide enough accuracy for simple repetitive operations. In the general case, an absolute global positioning system such as the target update method for navigation is required to provide accurate teach programming or automatic operation. With this capability, full region filling algorithms may be implemented for lawn mowing.

6. CONCLUSIONS

Safety is the most important consideration in the use of a remote controlled lawn mower. In the hazardous environment, it is prudent to keep the operator at a remote distance from the hazard. However, even in a less hazardous environment there is good reason to consider remote controlled lawn mowing operations. Approximately 50,000 people are injured by lawn mowers in the U.S. Injuries are caused by humans encountering the machine cutting blade or by objects being flung by the mower. Hazards from deliberate misuse are also of concern. The goal of current research is to reduce the number of people injured to zero. This will require greater knowledge and telepresence control of the machine. Until this is fully developed, a safety training course must be held for operators of the remote control lawn mower. This course should cover the basic operation with special attention to the emergency stop switches on the teach pendant and remote machine. The "deadman" switch may be set to stop all power or stop only the blade and wheel motion. A corresponding emergency stop switch on the machine should have the same function of halting all operations. These switches should have the highest control priority. Other switches such as the loss of communications signal to the machine could be given the same priority and function. For the remote operation in the area around the waste pits, it is assumed that no humans will be present in the immediate vicinity of the machine. If the machine is to be operated in an environment containing humans, other sensors such as proximity switches and safety bumpers are needed.

A brief survey of robot lawn mower products, patents, prototypes and promising technologies has been presented. The lawn mower provides an excellent educational testbed device and may become the first breakthrough in personal robots.

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