

Development of Robotic Lawnmower Miimo

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ABSTRACT

Development of the robotic lawnmower Miimo was pursued in response to people's need to make their lawn look nice without spending time and effort on it. The product was developed on the three concepts of giving people a sense of security about letting it do the work, making it simple for people to use, and allowing people to spend their time in comfort.

In order to enable the lawnmower to continue its work automatically without imposing a burden of labor on the customer, the unit was given the capability to recognize its work area, to automatically recharge its battery, and to avoid obstacles it might encounter. In order to maintain an attractive-looking lawn, the product assures finish quality by adopting movement patterns that cause the mower to work through the entire area thoroughly, a mowing method with a mulching system that distributes mown grass over seedbed soil, and movement patterns that avoid leaving ruts. Because the product works automatically, a conceptual approach of functional safety was built into the system so that there will be nothing to worry about even if someone other than the user approaches the machine.

1. Introduction

Honda brought the HR21 walk-behind lawnmower to the market in 1978. The HR21 established the qualities of ease of use and reliability, giving Honda lawnmowers a foothold in the European and American markets.

With the worldwide aging of populations and heightening of environmental awareness in recent years, Honda has worked actively as a leading global corporation to seek greater environmental compatibility in such things as simpler garden maintenance and reduction of garden waste. Unlike the maintenance of garden trees and flowers, people see mowing lawns as hard work and have sought lawnmowers that require less time and trouble in order to ensure their leisure time.

This paper introduces the robotic lawnmowers Miimo 300 and Miimo 500 (Miimo), which were developed in response to people's desire to have attractive-looking lawns without spending time and labor on them. Figure 1 shows the external appearance of the Miimo, and Table 1 shows the basic specifications.

Sales in the robotic lawnmower market have been trending upward consistently and rapidly, going from about 10000 units annually in the European market in 2006 to 90000 units annually in 2012. The major lawnmower manufacturers in Europe have also been actively participating in the market. Figure 2 shows the changes in the annual number of robotic lawnmower units sold in Europe.

Table 1 Basic specifications

Name		Miimo300	Miimo500
Model		HRM300	HRM500
Overall length	mm	645	
Overall width	mm	550	
Overall height	mm	275	
Wheelbase	mm	300	
Mass	kg	11.5	11.8
Wheel diameter	Front wheel	mm	100
	Rear wheel	mm	200
Running speed (Forward)	m·s ⁻¹	0 - 0.55	
Trimming width	mm	220	
Trimming height	mm	20 - 60	
Blade rotating speed	min ⁻¹	2200	
Blade type (number of blades)		Swing-back type (3 blades)	
Motor performance	For driving	W	10.8 x 2
	For mowing	W	25.3
Battery	Type	Li-ion	
	Capacity	22.2V x 1.8Ah	22.2V x 3.6Ah
Transformer output current		A/VA 2.3 / 60	



Fig. 1 Robotic lawnmower Miimo

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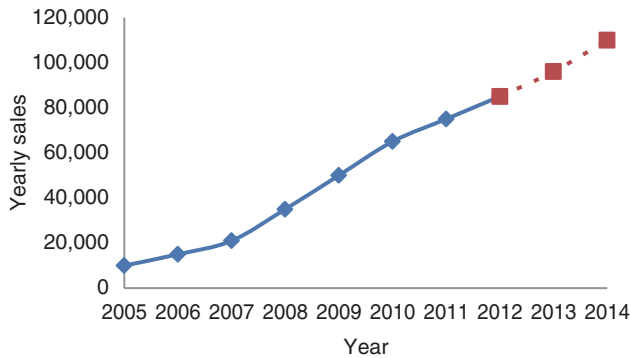


Fig. 2 Prediction of European robotic lawnmower market growth

2. Development Goal

Development of the Miimo followed the three product concepts of giving people a sense of security about letting it do the work, making it simple for people to use, and allowing people to spend their time in comfort. These were pursued with the following objectives:

- (1) Definite capability to continue work without imposing a burden of time and effort
- (2) Works with a high quality of finish to maintain an attractive-looking lawn
- (3) Reliability as a gardening partner

3. Miimo Configuration

The Miimo is made up of a transformer that converts commercial electric power to supply as safety extra-low voltage (SELV) or lower, a docking station for recharging, and the mower that runs and mows automatically. The docking station is also able to output a signal to a wire that marks the working area boundary. Figure 3 shows the configuration.

The mower powertrain is made up of three motors that drive the blade and the two rear driving wheels, the battery that serves as power supply, and the electronic control unit (ECU). The mower is also equipped with a display unit, which shows the mower's status and allows input of settings, and sensors that enable independent operation. Figure 4 shows the mower components.

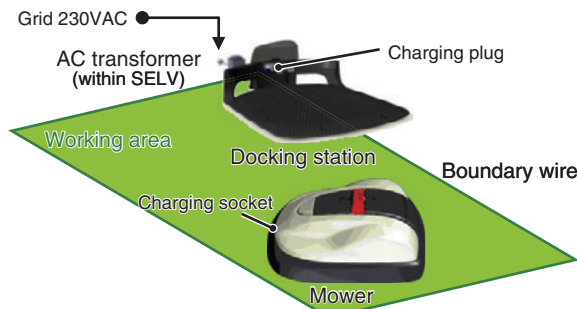


Fig. 3 Miimo configuration

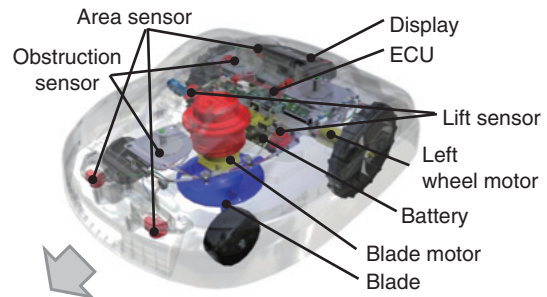


Fig. 4 Mower components

4. Technology for Automatic Operation

4.1. Functions for Continuous Performance of Work

In order to perform work automatically, the robotic lawnmower needs functions for recognition of the work area, assurance of power supply, and ability to continue working even in the presence of obstacles.

4.1.1. Detection of work area

In order for the robotic lawnmower to work automatically, it needs to recognize the area where it is to perform its mowing work. As it is essential that the mower not move outside that area, the area where the Miimo is supposed to work is outlined with an electric wire.

The mower has permission to work only inside that wire, and it is configured so that when it reaches the wire while working, it turns back without crossing over the wire. When the wire is broken or when the mower is placed outside the wire, the mower will stop.

A method of detecting magnetic field changes was adopted in order to recognize whether it is within the area. Specifically, this is done by sending a current pulse from the docking station in a clockwise direction through the wire that marks the area boundary. When this is done, the downward magnetic field intensifies while the current is increasing, and diminishes while the current is decreasing on the inside of the wire. On the outside of the wire, the magnetic fields change inversely with the inside.

This minute change in the magnetic field is amplified and filtered to enable the mower to recognize the inside and outside of the work area. Figure 5 shows the receiver circuit and Fig. 6 shows the waveform after amplification.

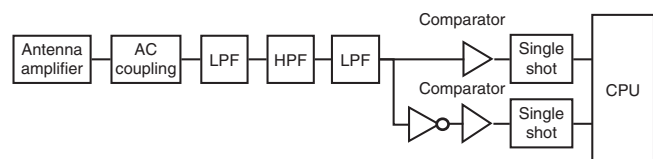


Fig. 5 Area signal receiving circuit

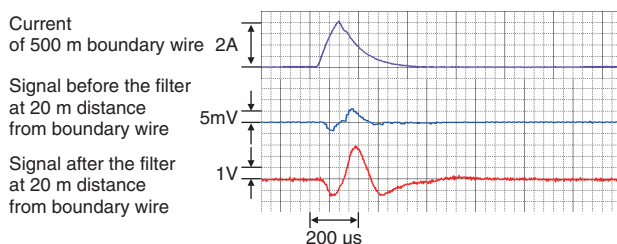


Fig. 6 Current of boundary wire and received signal

4.1.2. Li-ion battery

The Miimo uses a battery as its power supply while it is mowing. The mower carries on work according to a set-up by the user, but when the battery charge becomes low while the mower is working, the mower is set to return to the docking station automatically to recharge itself.

Li-ion batteries were adopted for their weight and service life. Figure 7 shows the change in capacity of single-cell Li-ion and NiMH batteries in charge-discharge cycle testing.

In order to simplify the circuit, voltage balance control between cells is not implemented. Deterioration of cell voltage balance is mitigated by limiting charging so that the battery does not receive a full charge. This also has the effect of mitigating degradation. As a further measure to mitigate degradation, charging is stopped when the battery reaches 60% capacity so as not to stay on standby in a high-capacity state. The battery is then charged to 100% capacity before starting work.

The battery pack also has a built-in battery management system (BMS) that monitors overcurrent in the battery pack as well as overvoltage and low voltage for each cell. The battery is further equipped with a precharge function for when the battery is discharged to a low-voltage state.

Figure 8 shows the change in battery pack capacity from charge-discharge cycle testing. It was confirmed that the battery pack retained 70% or better capacity after 1500 cycles, which is equivalent to two years of use, without cell balance control.

4.1.3. Avoidance of obstacles

When the mower collides with an obstacle, it stops moving forward and then bypasses the obstacle before continuing its automatic work. If the mower has been lifted

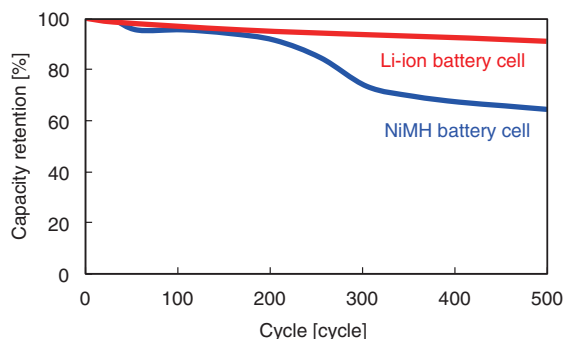


Fig. 7 Cell battery cycle performance

off the ground, it then stops not only its drive wheels but also its mower blade. Once it is returned to ground level, either through a bypassing maneuver, it then continues with its automatic work.

4.2. Functions for Maintaining Attractive-Looking Lawns

In order to maintain attractive-looking lawns, the lawnmower needs to work thoroughly throughout the entire area. In order to produce an attractive-looking finish, a mowing system suited to continuous operation is needed, and footprints also have to be taken into consideration.

4.2.1. Straight-forward movement control

The Miimo movement while working is straight forward. When it reaches the area boundary, it turns and again moves straight forward until it reaches the boundary. The Miimo needs to repeat this operation to move over the entire work area and cover it thoroughly. In order for the Miimo to work on wet sloping lawns that are slippery, it needs to move straight forward on this kind of surface, as well. Otherwise it will not be able to climb to the top of a slope nor work efficiently over the entire area.

In order for the Miimo to move straight forward under these circumstances, straight-forward movement control is implemented. The straight-forward movement control detects angular velocity and measures it cumulatively so that even if the Miimo slips, it will sense the deviation in direction, apply fuzzy logic control to the magnitude of the turn, and regain straight-forward movement.

4.2.2. Mower movement patterns

In order to maintain a large lawn in an attractive condition, it is important to mow the entire area thoroughly. If it were to mow each area in order like a walk-behind lawnmower operated by a human being, there would be no wasted motion. Depending on the shape of the work area, however, a regular movement pattern could result in the mower moving repeatedly across some parts of the determined path. It was therefore decided to adopt both a reciprocating working pattern suited to mowing a single section of lawn area and a random pattern for thoroughly

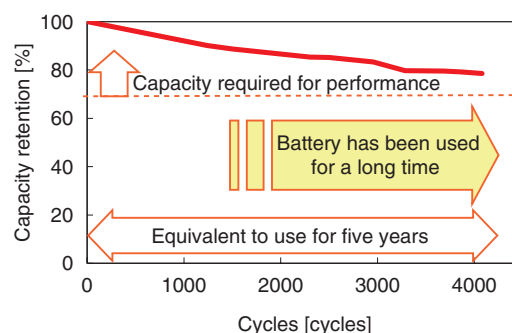


Fig. 8 Battery pack cycle performance

mowing a larger area with a more complex shape.

Making wider-angled turns allows the mower to follow the area boundary more easily. Acute-angled turns characteristically allow the mower to travel to the center of the area more easily. In deciding the random turning pattern, the range of acute-angled and wide-angled turns was taken as a parameter. In addition, values for movements that would efficiently cover variously shaped work areas were simulated. The model was made up of movement patterns, mower body model, and area model. The model outputs the movement area and uneven patches. A parameter optimization tool was applied to these output results to derive optimal values. Figure 9 shows a conceptual diagram of the simulation. Figure 10 shows confirmed area models.

Three patterns supporting a variety of different lawn shapes were configured.

- (1) The random pattern is effective over large areas and was optimized by simulation.
- (2) The directional pattern works in a reciprocating manner that concentrates operation in a designated zone.
- (3) The mixed pattern is capable of well-balanced work that combines the random and directional movement.

Figure 11 shows a conceptual diagram of the movement patterns.

Figure 12 shows the motion capture results for the Miimo movement filling in the mowing area. Every mode yielded results as obtained in simulation. Areas that have been mowed only once are shown in yellow, and areas mowed two times or more are in red.

4.2.3. Mulching work

The mown grass is reduced to minuscule fragments and scattered over the seedbed soil at the grass roots. This mulching process allows the mown grass to decompose quickly, making practical use of it as fertilizer.

The mowing component has a fan structure by which

the mown grass is distributed equally. This enhances its mulching value. Figure 13 shows the structure of the mowing component.

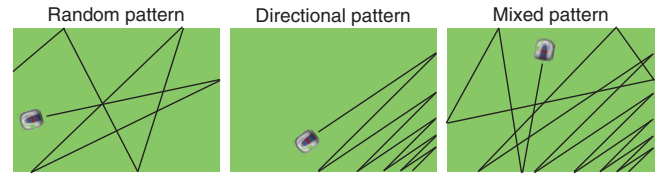


Fig. 11 Movement pattern

Mowing time [min]	5	10	15	20	25	30
Random pattern						
Mowing area [%]	51	73	84	91	95	97
Directional pattern						
Mowing area [%]	47	74	87	94	97	98
Mixed pattern						
Mowing area [%]	49	72	84	91	95	98

Fig. 12 Grass cutting in each pattern

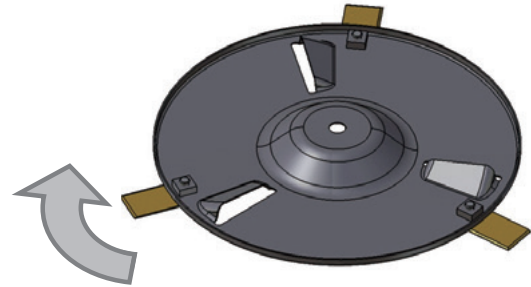


Fig. 13 Mowing part structure

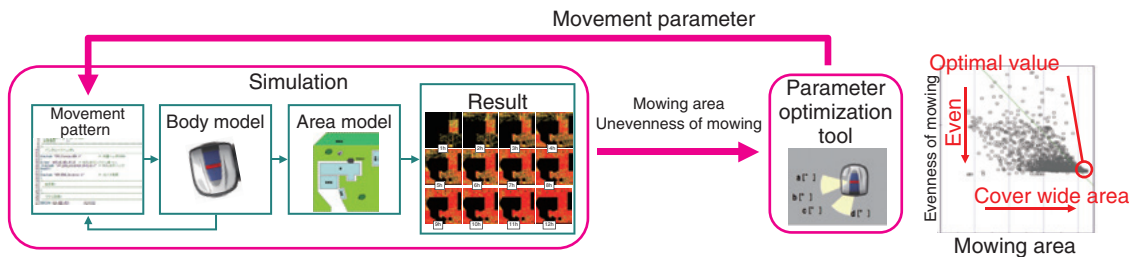


Fig. 9 Movement pattern simulation

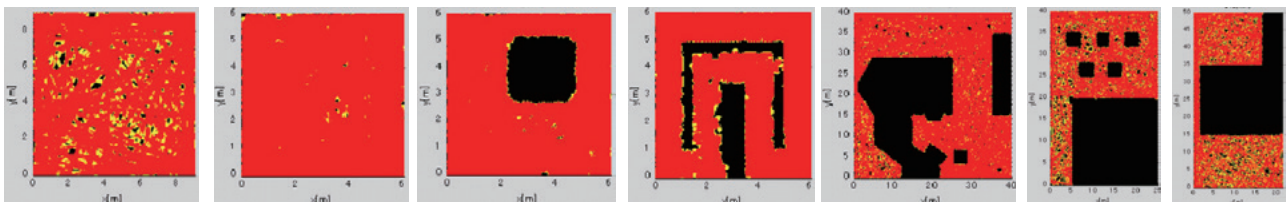


Fig. 10 Area model

Figure 14 shows the results from flow field analysis of the effect of the fan using computer-aided engineering (CAE), and Fig. 15 shows the dispersibility. It has been confirmed that dispersibility is assured.

4.2.4. Return movement

The flow of mowing operation by the Miimo is as follows:

- (1) When the configured work starting time arrives, the mower moves away from the docking station and moves to the designated area.
- (2) The mower begins working in the designated area.
- (3) When the battery charge becomes low, the mower stops working and returns to the docking station.
- (4) At the docking station, the mower charges to 100%.
- (5) When the charging ends, the mower again moves to the designated area.
- (6) The mower begins working again in the designated area.
- (7) When the configured work ending time arrives, the mower returns to the docking station.

This includes movement from the docking station to the designated area and movement to return to the docking station. The important point about movement to the docking station is that return is definitely needed in order for the automated work to continue. The Miimo is therefore programmed to start the return movement while it still has adequate power to return.

These movements are made along the boundary wire around the work area. The Miimo does not mow grass during this movement, so a shorter distance makes for greater efficiency. Another concern is that repeated movement over the same places will cause ruts to develop. In order to reduce the distances traveled, therefore, the Miimo is configured to return by the reverse of the route it took when moving to the designated area. Figure 16 shows a conceptual diagram of return. The reasoning here is that the Miimo is configured to start work after traveling 40 m in an anticlockwise (ACW) direction. In this case, therefore, it is likely that when it is time to return, the Miimo will be in the area where it started working, so that returning to the docking station by a clockwise (CW) movement can reduce

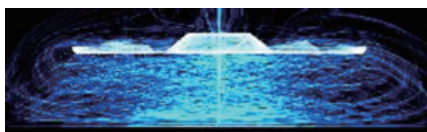


Fig. 14 Grass diffusion simulation



Fig. 15 Dispersibility by fan

Table 2 Stop functions

Functions	Description
Manual stop switch detection	Blade motor and wheel motor are stopped by pushing a stop switch
Lift detection	Lift sensor detects when user lifts up mower, and then it stops blade motor and wheel motor.
Tilt detection	When tilt sensor observes limit angle of inclination, blade motor and wheel motor are stopped.
Rollover detection	Rollover sensor monitors mower. Rollover sensor detects the rollover of mower, and then it stops blade motor and wheel motor.
Detection of area interior	Area sensor detects pulse from boundary wire and constantly monitors the status of inside/outside the area. Area sensor stops blade motor and wheel motor when pulse is not detected due to disconnection or short circuit of boundary wire.
Obstruction detection	Wheel motor stops at time of collision. After mower collides with person or obstruction, obstruction sensor maneuvers the mower to avoid them.

the movement distance in many cases.

In order to keep from always traveling over the same places, the Miimo also has the ability to shift its route slightly each time it moves. When the Miimo is not configured to move to a designated area, it will return to the docking station by alternating CW and ACW directions.

4.3. Functions for worry-free use

The robotic lawnmower carries out its work automatically even if no controlling person is present to supervise. When no person is present to supervise the robotic lawnmower's work, however, the possibility exists that someone other than the owner will unexpectedly approach the mower. This possibility had to be taken into consideration when developing the robotic lawnmower.

4.3.1. Functional safety

The stop functions shown in Table 2 are implemented in the Miimo by redundant design. The Miimo has been made capable of stopping even if there is a malfunction in the components for the stop function, and it is also made capable of detecting such a malfunction. The switches and sensor inputs are configured as dual systems, so that the Miimo will stop even with detection from only one side, and the system can compare one side with the other to detect malfunctions. The motor stoppers are also dual systems, so that the motors can be stopped even if only one of the stoppers operates, and feedback on the operating status of the stoppers enables detection of malfunctions.

In order to enable people to use the Miimo with a sense

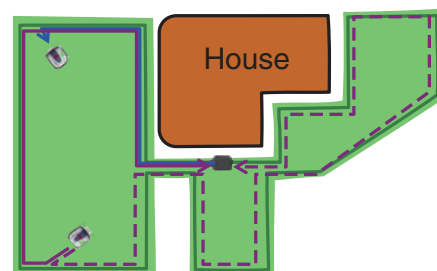


Fig. 16 Concept of return

of security, the working part that rotates and cuts grass has been positioned so that it is difficult to access and thus be touched. It is also capable of detecting collisions in every direction, and is able to detect being lifted up at any point around the periphery. This is achieved by mounting the cover onto the frame that holds the working components so that the cover can freely move laterally, longitudinally, and vertically in relation to the frame. Figure 17 shows the collision detection mechanism. Figure 18 shows the lift detection mechanism.

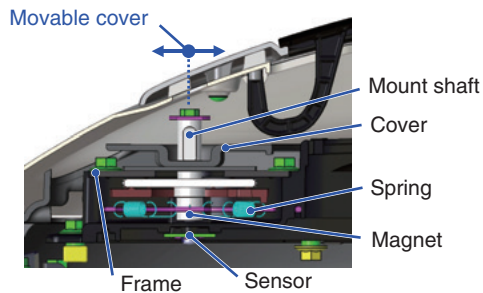


Fig. 17 Structure of collision detector

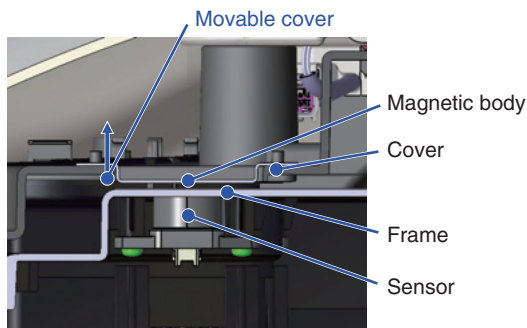


Fig. 18 Structure of lift detector

5. Conclusion

The development of this robotic lawnmower yielded the following results.

- (1) Area detection enables the mower to continue working within the set working area without leaving that area. It is capable of working for extended periods without greatly reducing battery life. Further, if there is an obstacle in the working area, the mower can avoid it and continue working. The certainty of these results has been assured.
- (2) The mower's straight-forward movement control and movement patterns enable it to work throughout the entirety of the working area. It is able to assure the finish quality of its work by mulching, and move without making excessive wheel tracks. These capabilities enable the mower to maintain an attractive-looking lawn.
- (3) The mower incorporates the conceptual approach of

functional safety and is able to detect collisions from all directions as well as to detect when it is lifted up anywhere around its periphery. This has produced a working machine that can be used with a sense of safety and security.

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