Safety-Guided Design Concerning Standardization's Requirements of Mowing Robots

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Abstract. Considering the rapidly expanding market for mowing robots to homeowners the noticeable question that arises is what are the safety-guided design requirements that could be applied to production management via safety standards? Standardization attempts to protect human during the interaction with this device. It makes an effort to confine residents by implementing more legible guidelines. There is no correct or incorrect list of hazards, only a list that customers and designers agree that is necessary to be handled. However, the requirements may differ in the design stage. All the design requirements shall be included in the physical system design of the robotic mower. In this paper, the authors believe that it is essential to put forward a comprehensive and systematic list of corrective or preventive measures in order to provide a safety checklist throughout the design stages of robot use. These safety criteria intend to minimize the chance of an accident and offer the adequate protection to users.

Keywords: safety-guided design, systemic method, mowing robot, safety requirements, standards.

1 Introduction

Recently, everyday people are dreaming about having a device that could be a kind of useful robot. Such robots for residential use, consider capable of taking over chores successfully in the domestic environment. Mowing robot is designed to automatically mow lawn in gardens at any day and time. It is small, compact, silent and easy to transport. The robot can be programmed to mow several areas. During operation, the robot mows the area delimited by the perimeter wire. Its performance depends mostly on the weather conditions (sunlight and temperature), the shape of the garden, the state of blades, the growth of grass and the humidity. It is indented for mowing large areas, preferably at daytime depends on the battery life. Whenever it comes in contact with an obstacle such as branches, small stones, wall or fence, it reverses and follows a different direction. This system uses an irregular movement pattern that is never repeated according to its sensing of growing of lawn.

Since particular safety guidelines for mowing robots do not exist, the authors suggest that their safety-guided design should be based on standards that developed in areas of agriculture and garden equipment. In addition, the methodologies for safety for agricultural equipment [1], safety signs [6], the standard for Robots and Robot Systems [4] providing safety requirements for robot systems, as well as the "Safety certification requirements for domestic robots", proposed by the authors [7] should be made applicable to robotic lawn-mowers. Every manufacturer should follow the basic instructions summarized in the basic safety standards such as Definitions of Powered Lawn and Garden Equipment [2], Safety Specifications for Commercial Turf Care Equipment [3] and safe features according to Safety Specifications for Turf Care Equipment – Power Lawn Mowers, Lawn and Garden Tractors [5].

With aim to expand and grow the acceptance of robots by the society, the authors propose a new list of safety design constraints. The authors use a systemic method that covers the safety design of the production, managing product (mowing robot) and information (standards) [10].

2 Safety-guided design

2.1 Possible accidents

The first step in any safety analysis is to define which types of accidents needs to be considered. The definition of an accident derives from the user's experience and from government efforts for systems that are certified by technical committees and corresponding regulations. Accidents are a consequence from ineffective implementation of safety requirements on the design level of the system [9]. In addition, potential accidents of a mowing robot are the following:

A1. Electromagnetic or radio frequency interference may cause person injury.
A2. Severe injury could occur if hair, fingers or clothing of resident are caught in the exposed mechanism of the robot due to indented opening of the cover.
A3. Battery may explode if user does not follow the appropriate procedure and the nearby resident could suffer from electrical shock.
A4. Stones, tools, toys and other loose objects may be thrown by the mower blades leading to harmful injuries.
A5. A resident could be pinned under the robot due to overturning of the robot that is caused by operating in slopes.
A6. A resident could be injured by contact with the blades.
A7. A resident that uses the robot via remote control hits a person or a pet by pulling the mower backward without looking.
A8. The released electrolyte of an intended open of the power pack may cause damages to skin or eyes.
A9. Contact of human with hot parts may cause burns.
A10. The cord/ perimeter wire may lead to tripping hazard.
A11. Electrical component damage due to inadequate cleaning of the device.
A12. A child may fall off and be seriously injured if he rides on an operating robot.

A13. Coexistence everyday problems occur if the robot is moving at high speed.

2.2 Adjusting a level of severity

A risk management is arranged at early design stages with a risk matrix (counting severity and probability) to agree on which types of hazards shall be mitigated during design stage or to categorize them. Statistically analyzed data estimating the probability of accidents, however, at this specific type of robots, does not exist so far. The safety policy for prioritizing the severity of an accident is that all accidents result in a loss of human life or human injury should be eliminated at the design level.

Level 1:
A1-1: Rotating blades catches part of resident's body.
A1-2: Coming in contact with any exposed mechanism part of the robot.
A1-3: A child rides on an operating robot.
A1-4: A resident is pulling the mower backward without paying attention.
A1-5: A resident could be pinned under the robot due to overturning.
Level 2:
A2-1: Hot parts cause burns.
A2-2: A battery could explode.
A2-3: The cord/ perimeter wire causes tripping hazard.
A2-4: Electromagnetic or radio frequency interference.
Level 3:
A3-1: Problems with the coexistence in everyday living.
A3-2: Loose objects may be propelled.
A3-3: Electrical or electronic component damage.
A3-4: Released corrosive electrolyte affects human skin and eyes.

2.3 High level system hazards

A restricted set of high level system hazards need to be identified combining potentially hazardous conditions with accidents identified at section 2.1. The high-level systems hazards arise from the accidents are the following:

H1. Mechanical hazards (cutting, severing, inadequate velocity) [A4, A6, A13].
H2. Environmental hazards (explosion) [A3].
H3. Tripping and falling hazards [A7, A10, A12].
H4. Thermal hazards (burns) [A9].
H5. Hazards generated by substances [A8].
H6. Electrical hazard [A11].
H7. Hazard generated by radiation [A1].
H8. Hazards generated by neglecting ergonomic principles in machine [A2, A5].

2.4 Define design constraints

The next step is to define the safety constraints that are considered critical to protect from incidents (Table 1). The greatest challenge is to design such robot that enforces the requirements as much as achievable. Furthermore, we accompanied these protective measures by one real lawnmower in order to prove that implementation of these guidelines are crucial and ought to be applied. The chosen product is Friendly robotics RL850 (Fig. 1).

Fig. 1. A commercially available robotic mower (Source: http://www.robomow.com).

Table 1. Safety-Guided Design constraints concerning mowing robot's hazards.

HAZARD	SAFETY DESIGN CONSTRAINTS	FRIENDLY ROBOTICS RL 850
Electromagnetic or radio frequency interference	• The device shall not be subject to interferences such as high ambient noise, radio transmissions, unshielded computers, infrared remote controllers and magnetic fields. • If the robot is operating in close proximity to another one (by the same or a different manufacturer), then you should make adjustments so that the frequencies of the two robotic devices do not interfere with each other. • Make sure that mower is placed away from light, microwaves, magnetic fields, heat or sound.	• The device shall not be subject to interference cause by nearby metal objects, underground wires, and another wire in a nearby grass, neighbor's lawnmower or another electric device using similar frequency. • The interference shall not lead to calibration failure, ignoring of wire and mowing outside the designated area, changing of direction with no progress.
Exposed mechanism	• The mechanism of the robot shall be protected. The respective covers shall be kept in good condition.	• The mowing covering hood shall not collect grass residuals after mowing damp or wet lawn. It shall be inspected and maintained regularly for foreign material using a damp cloth or another similar tool. • The mechanism of Robomow is protected with plastic cover to prevent from bumping or changing it.
Explosion of the battery	• Safety features such as battery pack or sealed batteries shall continue to be active in order to protect residents under all emergency circumstances. • User shall be informed by the manufacturer that in case of mowing robot performing on batteries, there exist electrical hazards such as fire, electrical shock or chemical burn hazard in case that battery is mistreated and explosion hazard, if the battery is incorrectly placed [7].	• The 24V sealed lead acid battery, that is used to drive the three 150W motors on the RL850 and all electronic components ought to be charged at the recommended charging station. Improper charging may causes shock or overheating hazard. • *The charging station ought to be designed according to the following:* • It shall be placed on compact, flat and stable surface with good drainage, on level ground, preferably in a wide span area of the house. • Make sure that water or other liquids is not directed inside the charging station. • The entrance of the charging station shall be positioned so that the robot can enter away from leaves, sticks or twigs. • The charging-station shall be well fastened to the ground. • Deal with any insect with a proper insecticide.
Loose objects	• The operational area shall be well defined	• Safety features, in case of Robomow [8], such

	and operational contingencies detected shall be eliminated by the designer. Such operational contingencies include: inability to determine location in the house; obstacles within its path; not accessible charging station; inability to follow the tasking path. • Guards and shields are designed to protect user.	as lift sensor, sensor equipped bumpers, perimeter switch, automatic departure warning alert shall continue to be active in order to protect residents under all emergency circumstances.
Overturning of the robot	• Designer should simulate some test manoeuvres on first use to identify the commands and main functions. • User command execution precisely without putting the resident's life in danger. • The robot shall have easily accessible safety commands and functions, so that the user shall be able to stop the robot in case of overturning. • Emergency stop shall execute the proper stop function in case of overturning. In particular, wiring, communication devices, sensors, electrical and utility connections should meet the performance criteria.	• Robomow is already equipped with an emergency stop switch on the manual controller in order to block its mowing path. • The emergency stop switch shall be applied with a push button switch in series among the battery and the robot. When pushed, the switch shuts-off power to the robot, pausing the turning of motors and blades until the button is released. When power is returned to the robot, the controller will execute the command of the robot.
Contact with the sharp rotating blades	• Manual should advice the user to present dramatic description on the hazardous behaviors of mistreating the robot and warn correctly concerning the appropriate safety features. • The replacement of not well-maintained or worn out blades shall not require routine or extraordinary maintenance more than once a year. • User's manual indicates that every maintenance, service, replacement or inspection of worn or damaged parts should be carried out by service experts.	• Blades shall be sharp and offer a safe and effective cut. • Not well-maintained blades will shred the lawn, which can provide an entry point for disease organisms and weaken the grass plant. • It is recommended to replace all three Robomow blades once a year [8].
Pulling the mower backwards without looking	• Online tutorials and help menus shall contain the appropriate instructions, so that users shall have direct access to information on how to operate the robot. • A built-in electronic hardware control system and/or safety operational software shall be selected to force the robot to shut itself down in an emergency. • Mowing robot shall be equipped with an emergency stop switch on the manual controller that ceases the rotation of blades and wheels within seconds.	• The remote emergency stop shall be applied to Robomow with a radio frequency receiver and relay positioned in series among the battery and the robot. When the receiver receives a signal from the remote RF transmitter, the relay ceases the power to the robot blocking any hazardous movement. When power is returned to the robot, the controller will execute the command of the robot.
Released electrolyte	• The power pack shall not be able to be opened or spoiled. • The robot ought to be designed so that no additional clothing against hazardous materials and solvents requires to be worn by the user during the charging of the device.	• *Always disconnect Power Pack from Robomow in the following cases:* before clearing blockage/ checking/ cleaning/ working on Robomow or replacing the blades. • Always disconnect Power Pack from Robomow after throw a loose object or in case that Robomow begins trembling irregularly.
Contact with hot parts	• *In case that robot containing parts that are likely to overheat, these parts should be constructed so as:* • The temperature of accessible surface does not cause injury to the user. • If gasses and liquids are contained inside the robot, the designer should ensure that any increase of temperature will not cause burn injury.	• Hot parts of Robomow shall not cause burns, the engine and exhaust system shall be kept as cool as possible.
The power cord/ perimeter wire causes tripping hazard	• The use of adequate insulation, cable cross-sections, panel covers shall prevent an electrical shock.	• Robomow cables must be embedded inside the body of the robot. • Robomow shall use cable cross-sections and

		panel covers.
A child rides on an operating robot	• Warning signs shall be established to protect residents who may consider that they can ceaselessly be reckless with the operating robot. • Specific responsibilities concerning safety shall be assigned to an adult user. • The robot shall be equipped with a specific audio or visual signal, easily recognizable by everyone, to let people know whether it is on or off. Use a frequency that is not within the range of noise frequencies, in case of an audio signal.	• Safety features of Robomow such as child guard/safety guard, lift sensor, sensor equipped bumpers, warning alert shall continue to be active in order to protect unauthorized persons under all emergency circumstances. • When adjust settings the automatic departure time schedule, do not let Robomow to operate unattended if there are pets, children or people in the vicinity. • Child guard provides a safety feature to offer protect children or unfamiliar bystanders with the safe function of the device to control it easily.
Electrical of electronic component damage due to inadequate cleaning of the robotic device	• The designer should take into account the fact that objects will be dropped and liquids will be spilled upon the robot, eventually. • Adequate electrical protection shall be provided such as regulators, filters, proper ground circuit.	• The robot electrical equipment should follow the appropriate instructions of the relevant requirements. • An appropriate danger sign for electrical shock shall be generated if needed.
Robot is moving at high speed	• Post-manufacture check of the full scale system, about its maximum, minimum, optimal speed and settings, start / end points, path, process. • Speed mode should meet the performance criteria.	• Switch “deadman” shall be applied to Robomow in order to cease the power supply or blocks only the blade or only the rotation of the wheels in case that speed exceeds the manufacturer’s specification tolerance. • The emergency stop switch, ought to perform the same function as the switch “deadman” blocking all abnormal high speed movements.

2.5 Assign responsibility to the user for implementing safety requirements

The responsibility for enforcing each behavioural requirement ought to be assigned to the users of the product as in any production management system. The high-level system requirements for eliminating the hazard was recognized and then enhanced into more distinctive requirements.

However, there is no possibility to develop an ultimate list of requirements that controls every robotic product apart from a restricted list of requirements quite essential with aim to be helpful in a safety analysis. Each production manager has to decide what its specific safety features are possible to certify a particular product. Design takes account of the whole spectrum of the product eliminating human errors by redesigning the equipment.

HIGH LEVEL SYSTEM HAZARD (1): Electromagnetic interference.
Protective measures taken by the user

- Do not use solvents or benzene for cleaning purpose.
- Do not wash the internal parts of the robot and do not use jets of pressurised water.
- To clean from deposits and residuals from the blade, use an indented brush.
- Use a dry cloth to clean the battery charger and the contact plates.
- Non waterproof robots shall be prevented from washing with liquids and shall be prevented from being turned over in water completely.

HIGH LEVEL SYSTEM HAZARD (2): Exposed mechanism.

- To prevent human health, residents shall not open the mower's covering hood with aim to avoid damaging internal electrical components.

HIGH LEVEL SYSTEM HAZARD (3): Explosion of the battery.

- Charge the battery in a dry, well-ventilated area where the temperature is moderate.
- Follow the correct procedure for charging.
- Keep all sparks, open flames, and smoking materials away from the battery.
- Keep the battery away from explosive and/or flammable environments.
- Station for battery charging shall not be placed in sites subject to vibration and away from concrete, incline or hard surfaces.

HIGH LEVEL SYSTEM HAZARD (4): Loose objects.

- User shall be informed that mowing over objects may cause malfunction to the blade and lead to an injury due to thrown objects from the mower's chute.

HIGH LEVEL SYSTEM HAZARD (5): Overturning of the robot.

- Check the slope of the ground and make sure the maximum values allowed.
- User is not supposed to operate the machine on slops or hills. Mow the slope as recommended by the manual.

HIGH LEVEL SYSTEM HAZARD (6): Contact with the sharp rotating blades.

- Wear heavy work gloves when working with and around the blades.
- User shall be informed from the manual about maintenance information.

HIGH LEVEL SYSTEM HAZARD (7): Pulling the mower backward.

- Look down and behind before and while operating backwards.
- Never try to mow in reverse using the manual controller.

HIGH LEVEL SYSTEM HAZARD (8): A child rides on an operating robot.

- The operating area should be clear of people (in particular children, the elderly or disabled people) and domestic animals. Operate the robot at suitable times of the day.
- Do not let a child to ride on a mower or walk along side. Children ought to stay inside the house and supervised so they don't suddenly come into the garden while robot is operating.
- Shut off the product in case of a child coming in the lawn.

HIGH LEVEL SYSTEM HAZARD (9): The perimeter wire causes tripping hazard.

- Ensure the robot does not run into obstacles, corners or harmful objects.
- Wear gloves when installing the perimeter wire and driving the wire pegs.
- The power cord shall be fixed firmly to the ground.

HIGH LEVEL SYSTEM HAZARD (10): Robot is moving at high speed.

- Never turn on the device in a garage even if the outdoors and openings are opened.

3 Conclusion

Safety in a domestic environment is much more complicated, due to the presence of much more untrained people as well as due to many unpredicted situations that might arise. This gave the main thrust to this paper, which attempt to approach the problem of robots safety, from a systemic point of view. This method could be applied as a preventive means at the stages of planning, organizing, directing and controlling the safety design of production in order to reduce the defective procedures that could lead to an incident. Moreover, it could be applied to other types of robot such as biped, toy-robots, personal care, service and automated guided vehicle robots. A robot is considered safe when fulfill the safety standards, which draws from research on the national, and when all requirements that had been pointed out by the authors, are fully satisfied. This Systems-Theoretic framework supports robot's business firm to achieve objectives, increasing firms reputation and facing the competition in the market, while supporting in decision-making related to rapid changes according to specification of the robotic system.

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