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Safety-Guided Design Towards Standardization 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 author believes 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.*

I. INTRODUCTION

Mowing robot is designed to automatically mow lawn in gardens at any day and time. It is small, compact, silent and easy to transport such as Friendly Robotics RL 850 shown in Fig 1. 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 [1].

Since particular safety guidelines for mowing robots do not exist, the author suggests 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 [2], the standard for safety of household and similar electrical appliances [3] providing safety requirements for domestic environment may be useful in establishing standards for these robots. Every manufacturer should follow the basic instructions summarized in the basic safety standards such as safety of machinery [4], safety distances and danger zones [5], emergency stop requirements [6], safety of household and similar electrical appliances [7], Safety Specifications for Commercial Turf Care Equipment [8], and safe features according to Safety Specifications for Turf Care Equipment – Power Lawn Mowers, Lawn and Garden Tractors [9].

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

STAMP encompasses indirect and feedback loops that could absolutely manage the levels of complexity (intellectually manageability) in these mechatronic systems, in contrast with the traditional accident modelling. Many failures are now identified as arising from technical, software and computer features resulting in systemic causal factors. STAMP considers elements of systems with a holistic approach and as a result it offers a more comprehensive view of accident modelling than it was possible before [10]. Mowing robots could be viewed as a group of single or multiple elements maintained in a design balance in terms of adaptive feedback function of actuators, sensors and automation [11]. Establishing standards for controlling hazards in anthropic environments involves the entire control system and modelling, the socio-technical that diagram which will enforce the primary constraints in design level. Ineffective operation is a consequence of lack of standards or from standards that are not adequately adopted [12].

II. APPLYING STAMP TO STANDARDS INCLUDES RECOGNITION OF SYSTEM HAZARDS AND SAFETY CONSTRAINTS

2.1 Identifying the accidents

The first step in any safety analysis is to define which types of accidents needs to be considered. Indeed, the manufacturer that develops this kind of robotic system has to take account of the accidents occurred. Accidents is considered as an unintentional or unexpected complex relation between events that results in a loss, including loss of human life, human injury, equipment damage, environmental contamination, non-accomplishment of the task etc. and involving residents, societal and organizational structures, engineering actions, and system elements." The accident model that derives from this definition does not indicate a particular causal factor [13]. In other words, in a systems-theoretic view of safety, accidents could be recognized, by categorizing the set of safety requirements that were ignored and answering why the control efforts were inaccurate in enforcing them. In addition, an accident definition in the design of a mowing robot is:

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. A child or a pet could be pinned under the robot due to overturning of the robot that is caused by operating in slopes above the permitted levels against specifications stated in the manual.
A5. A resident's hands or feet could be injured by contact with the blades of the robot during its operation due to lack of danger warning of the device.
A6. A resident that uses the robot via remote control hits a person or a pet by pulling the mower backward without looking.
A7. The released electrolyte of an intended open of the power pack may cause damages to skin or eyes.
A8. Contact of human with accessible hot surfaces of the robot may cause burns due to inadequate function of overheat protection (thermistors).
A9. The laid cord/ perimeter wire may lead to tripping hazard.
A10. Electrical component damage due to inadequate cleaning of the device using abrasive of harsh liquids.
A11. A child may fall off and be seriously injured if he rides on an operating robot.
A12. Coexistence everyday problems occur if the robot is moving at high speed.
A13. The mower could be stolen if the anti-theft system is intentionally turned off.
A14. The mower cannot localize the charging station.
A15. Inability of the device to follow the tasking path due to incorrectly placed perimeter wire/ incorrect programming/ too much slope/ overheated power supply unit/ incorrect wheel transmission/ bumper pressed during warm up/ bumper pressed for >2 sec during manual mowing/ bumper pressed while departing from the charging station.
A16. The mower cannot follow the user's commands when it is functioning on remote control such as charging, show latest faults, make factory settings, and display the functions, off/stop, start/pause and stop/emergence key.
A17. The mower cannot trim, maneuver, and cut the grass around obstacles.
A18. Navigation control on mowers that requires a cable to delimit the area to be trimmed is not functioning.
A19. If any internal malfunction such as drive problem, internal bumper failure, problem with the internal "software safety system", electrical motor failure, bug in programming, charging and calibration failure is not detected and safety rules are violated, the robot ceases its operation.
A20. User cuts its finger by contact with the blades trying to replace them.

A21. User could be injured trying to maintain the charging station without turning off the power.
A22. Water and other liquids are sprayed directed to the robot with a garden or a liquid spray hose causing internal electronic damage of electrical connections.
A23. User defeats important built-in safety devices.
A24. The equipment of the lawn mower starts vibrating abnormally.
A25.A pet may be hit if the mower operates its task with pets in the vicinity.
A26.A resident may be injured if the material used to built-up the robot has deficiencies.
A27.A resident may be electrocuted if the adequate electrical protection provided from the manufacturer, doesn't meet the electrical performance criteria.
A28. Robot cannot shut-off automatically exceeding its functional limits due to mechanical failure.
A29. User fails to stop the machine in case of an emergency.
A30. The collision detection system of the device is not functioning leading to trapping points.
A31.A resident may be seriously injured if the user doesn't establish a training schedule in order to inform all who live in the house about the hazards related to the device and the necessary precautions.
A32.A resident is mowing over an obstacle and the object is thrown at speeds greater than 200 mph and 50 feet or more, causing death and injuries ranging from blindness to severe bruising.
A33. User trying to make adjustments while the robot is operating causing malfunction.
A34. An untrained user may be injured trying to fix a malfunction that is stated in the manual that it should be repaired by the authorized personnel only.
A35. The mower is getting trapped due to inadequate function of specified checking procedure to determine the cause of a malfunction.
A36. The mower has got caught in something leading to lack of drive and its equipment is damaged.
A37. The mower is getting stuck in the charging station.
A38. The mower runs but the blades don't rotate.
A39. The mower is mowing outside the yard and not across the perimeter wire hitting someone.
A40. The mower cannot operate safely with one or more sensory devices inoperable.
A41. Breakdown of the robot due to oxidization of the wire caused by the damage to the protective sheathing.
A42. The robot is restarting with an abnormal harmful behavior after an emergency stop.
A43. The emergency stop doesn't block any abnormal movement of the robot.
A44.A pet or children could be pinned under the robot if the alarm of the robot doesn't warn about the restart of its operation.
A45. The wireless emergency stop or the manual stop buttons are not functional causing trapping points to nearby bystanders.
A46. The drive motors are damaged due to severe overloading of the wheel motors and overheating.
A47. The mower has burnt signs or signs of corrosion causing skin/eyes damage.
A48. The perimeter wire is cut leading to breakdown of the robot.
A49. The diagnostic software doesn't determining the cause of a malfunction on time leading to hazardous conditions.
A50. The software doesn't implement all safety rules leading to harmful incidents to residents.
A51.A built-in electronic hardware control system is not properly installed and does not prevent any property damage.
A52. The user restarts the robot, accidentally, by a single switch and starts operating abnormally, hitting someone.
A53. An abnormal high speed movement is not blocked by the stop button damaging property or robot's equipment.
A54. The user is changing the operating program leading to a harmful injury.
A55. The mower is moving near an operating rotisserie or barbecue where vapor may reach a flame or a spark causing an explosion of the device.
A56. Contact with the electrical equipment of the device leading to electrocution.
A57. Contact with overheated gasses, liquids or combustible substances that are contained inside the robot may lead to chemical burn injury.
A58. Explosion of the device caused by storing the device in an improper place against manufacturer's specifications.
A59. The robot on switching on is following arbitrary trajectories and runs into a person or another personal asset.
A60. Explosion of the device caused by stored energy due to potential overshoot action on switching on.

2.2 Assigning a level of severity

With aim to quantify the severity of the aforementioned accidents, an ordering of the levels of severity is absolutely necessary. According to STAMP methodology, severity is described as the seriousness of the hazard. Severity of accidents is typically ranked by the number and degree of injury, fatality, or damage events that occur during the accident. The general safety policy for assigning the severity of an accident is that all accidents leading to a loss of human life or human injury or damage to the robot should be eliminated or mitigated by the system design [12]. For any accidents the cannot be eliminated, despite the reasonable effort to eliminated or mitigate them, the hazard analysis as well as the design features and development procedures, including any tradeoff among goals studies need to be documented and presented to the user of the robot [10]. The author proposes the following hierarchy of accidents according to the methodology of STAMP:

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.
A1-6: User could be injured trying to maintain the charging station without turning off the power.
A1-7: A resident may be electrocuted due to inadequate electrical protection provided from the manufacturer.
A1-8: The collision detection system of the device is not functioning leading to trapping points.
A1-9: The user doesn't establish a training schedule about the hazards related to the device and the necessary precautions.
A1-10: A resident is mowing over an obstacle and the object is thrown causing death and injuries.
A1-11: The mower is mowing outside the yard and not across the perimeter wire hitting someone.
A1-12: The software doesn't implement all safety rules causing injury ranging from blindness to severe bruising.
A1-13: The user is changing the operating program leading to a harmful injury.
A1-14: The mower is moving near an operating rotisserie or barbecue where vapor may reach a flame or a spark causing an explosion of the device.
A1-15: Contact with the electrical equipment of the device leading to electrocution.
A1-16: Contact with overheated gasses, liquids or combustible substances that are contained inside the robot may lead to severe chemical burn injury.
A1-17: Explosion of the device caused by storing the device in an improper place.
A1-18: Explosion of the device caused by stored energy due to potential overshoot action on switching on.

Level 2:

A2-1: Hot parts cause burns.
A2-2: A battery could explode.
A2-3: The laid cord/ perimeter wire causes tripping hazard.
A2-4: Electromagnetic or radio frequency interference.
A2-5: User cuts its finger by contact with the blades.
A2-6: User defeats important built-in safety devices.
A2-7: A pet may be hit.
A2-8: The material used to built-up the robot has deficiencies.
A2-9: User fails to stop the machine in case of an emergency.
A2-10: An untrained user may be injured trying to fix a malfunction that he must have it repaired.
A2-11: The robot is restarting with an abnormal harmful behavior after an emergency stop.
A2-12: A pet or children could be pinned under the robot if the alarm of the robot doesn't warn about the restart of its operation.
A2-13: The wireless emergency stop or the manual stop buttons are not functional causing trapping points to nearby bystanders.
A2-14: Released corrosive electrolyte affects human skin and eyes.
A2-15: The mower has burnt signs or signs of corrosion causing skin/eyes damage.
A2-16: The user restarts the robot, accidentally, by a single switch and starts operating abnormally hitting a person.

Level 3:

A3-1: Problems with the coexistence in everyday living.
A3-2: Electrical or electronic component damage due to inadequate cleaning.

A3-3: An abnormal high speed movement is not blocked by the stop button damaging property or robot's equipment.
A3-4: The mower could be stolen.
A3-5: The mower cannot localize the charging station.
A3-6: Inability of the device to follow the tasking path.
A3-7: The mower cannot follow the user's commands when it is functioning on remote control.
A3-8: The mower cannot trim, maneuver, and cut the grass around obstacles.
A3-9: Navigation control is not functioning.
A3-10: Internal malfunction is not detected; the robot ceases its operation.
A3-11: Water and other liquids are sprayed directed to the robot causing damage of electrical connections.
A3-12: The mowing equipment starts vibrating abnormally.
A3-13: Robot cannot shut-off automatically exceeding its functional limits due to mechanical failure.
A3-14: The mower is getting trapped.
A3-15: The mower has got caught on something.
A3-16: The mower is getting stuck in the charging station.
A3-17: The mower runs but the blades don't rotate.
A3-18: The mower cannot operate safely with one or more sensory devices inoperable.
A3-19: The robot ceases its operation due to oxidization of the wire.
A3-20: The drive motors are damaged due to severe overloading of the wheel motors and overheating.
A3-21: The robot ceases its operation due to cut of the perimeter wire.
A3-22: The diagnostic software doesn't determining the cause of a malfunction on time leading to hazardous conditions.
A3-23: A built-in electronic hardware control system is not properly installed.

The severity scale classifies the accidents in these categories [10]:
Level 1: Serious human injury or loss of human life
Level 2: Includes all accidents that could lead to human injury that requires hospitalization/ medical attention leading to long-term permanent physical effects. Additionally, it includes incidents that could lead to damage of human assets and property damage to home asset or to robot leading to economic loss more than a certain amount of money (assigned by stakeholders).
Level 3: Includes all accidents that could lead to single minor human injury that does not require hospitalization or medical attention but only minimal intervention. Moreover, it includes damages to objects or to robot leading to economic loss less than a certain amount of money (assigned by stakeholders).

2.3 Identifying the High-Level System Hazards

For practical reasons, a restricted set of high level system hazards need to be identified considering safety as an emergent property and not a component property, as a freedom of accidents or losses and combining potentially hazardous conditions with accidents identified at first step. According to systems theory, accidents could be characterized by failure to comply with these four circumstances: (1) hazards and the respecting safety requirements are violated or are not required to the controller-subsystem; (2) the controller-subsystem is not adequately enforce or follow the safety requirements required or it does not make the proper operational control activities; (3) the process model used by the users (mental models) and automation turns out to be incontrollable with each other; and (4) the controller-subsystem is incapable to maintain a state of equilibrium of the whole system. Hazard identification is considered as a top-down procedure that should take into account the harmonization of the system, eliminating or controlling a hazard that is considered possible to allow an unacceptable loss to take place [13]. The definition of High Level System Hazards for the selected robotic systems should not include causes (e.g., human error) [10]. According to ISO 12100 [14] there is the following list of hazards:

H1. Mechanical hazards (cutting, severing, velocity, high pressure, severing, entanglement, shearing, acceleration/ deceleration, crushing, impact, potential elements or elastic elements) [A4, A5, A12, A20, A28, A32, A39, A51, A53]
H2. Environmental hazards (temperature, wind, snow, lightning, vapor, explosive or flammable atmospheres) [A3, A60, A55, A58]
H3. Slipping, tripping and falling hazards. Trapping points can be caused by irregular movement of the robot [A3, A6, A9, A11, A25, A30, A35, A36, A37, A42, A43, A44, A45, A52, A59]
H4. Thermal hazards (burns, scalds) [A57, A8, A47, A46]
H5. Hazard generated by materials and substances (ingestion, inhalation of fluids, gases, mists, fumes, fibers,

dusts or aerosols harmful toxic, corrosive, teratogenic, carcinogenic, mutagenic, irritant or sensitizing effect, biological hazards) [A7, A26].

H6. Electrical hazard (contacts of persons with live parts, breakdown, leakage current, electrostatic phenomena, and thermal radiation) [A10, A14, A15, A16, A17, A18, A19, A22, A27, A38, A40, A41, A48, A49, A50, A56].

H7. Hazard generated by radiation (electromagnetic fields, infra-red, light, visible light and ultra-violet, light, laser radiation, X and c rays, a and b rays, electron or ion beams, neutrons, ionizing or non-ionizing radiation) [A1].

H8. Hazards generated by neglecting ergonomic principles in machine (physiological and psycho-physiological effects, human errors) [A2, A13, A21, A23, A29, A31, A33, A34, A54].

H9. Hazard generated by vibration [A24]

2.4 Translating hazards into safety design constraints and requirements

After the list of high-level system hazards is identified, the next step of STAMP is to specify the safety requirements and design constraints necessary to prevent those hazards from occurring. These constraints will be used to guide the system design. The design constraints can be refined further executing STPA where design decisions are made [12]. The ultimate objective is to design a robotic system or else to estimate and develop an active system that enforces the constraints as much as achievable and to continually advance the design over time combining feedback with new applied engineering practices [10]. Table 1 represents all design constraints for mowing robots according to the identified hazards.

Table 1. Design constraints for some of the mowing robot's hazards identified above

Hazard	Safety design constraints
Robot is moving at high speed	A restart procedure shall be functioning after an emergency stop. In case of an incorrect restart, program and data may be saved on disk inappropriately which might affect the ability of the robot to perform specific safety critical paths, as well as user's ability to control it (as in industrial robots). Frequent stops and restarts require additional battery energy. User should try to control continuously the robot when operating it via remote control.
The mower could be stolen due to intended deactivation of anti-theft alarm	User should discuss the relevant safety features of the robot. The anti-theft alarm should be enabled through the programming mode. The anti-theft alarm shall be activated by a password in order to deactivate the alarm that will have to be entered in order to turn on the robot. A continual and downward sound signal emits the deactivation of the alarm. If the robot is picked up by its handle, the alarm should activate. A triple beep emits the signal of activation of the alarm. Lifting alarm may be used as a protection of the unfamiliar persons. User will have to enter a four-digit password as safety code. Contact the authorized service personnel for help in case of lost password.
The mower cannot localize the charging station.	Charging station shall not be affected by vibration and positioned on a relatively level ground away from concrete, incline or hard or slopping ground and especially, on the edge of the yard, at the largest yard where subareas are easily accessible [1]. The charging station shall be positioned with a large yard in front of it (at least 3 metres). It should be placed, in a shady place and in the centre of the mowing area. The yard around the station shall be flat to achieve best charging of the robot in the charging station. Both drive wheels should be levelled with the charging station.
The mower cannot follow the user's commands when it is functioning on remote control.	The software implementing the safety rules on the robot, shall be totally isolated from the rest of the software operating the robot, and so as it cannot be subject to malfunctions caused by any other operating reason. Safety rules include the settings of local and remote emergency stop button, safety guard, and perimeter switch. The settings of remote control should be arranged through programming mode. The batteries of the remote control should be replaced.
The mower cannot trim, maneuver, and cut the grass around obstacles.	User shall check and, if necessary, correctly fasten the wheels. User shall check the signal reception. The mowing robot shall be as compact as possible with minimum size and weight, in order to maneuver and trim around obstacles in the

	garden and transport easily.
Navigation control on mowers that requires a cable to delimit the area to be trimmed is not functioning.	The robot shall be capable of operating totally autonomously. Otherwise confined control shall be executed via remote control. Robotic mowers might be maneuvered using the controls installed on the robot covering hood or with a remote control unit. A mowing robot should react according to the signals from sensors, respond appropriately and does not require to be constantly attended from the user. A remotely operated vehicle (ROV) is a type of robot that is manually controlled. Mowing robots might be used from physically and visually impaired persons and this affects the control design. Navigation control on mowers requires a cable to delimit the area to be trimmed. Manual Controller shall be used for transporting it from area to area [1]. It allows user to automatically blocks the blades, and while transporting, to cut small areas.
If any internal malfunction is not detected and safety rules are violated, the robot ceases its operation.	The software malfunction might not result in any of the following: • Unintentional robot movement. Mower is equipped with an emergency stop switch on the manual controller. Pressing this switch ceases any hazardous movement, the rotation of blades and the wheels within seconds. • Expected and unpredictable stops and starts of robot. • Improper initial robot start-up procedures. • Blocking of motors. • Precision efficiency, deterioration. • Faults of tools. • Fault in data transmission. • Deactivation of safety devices.
User could be injured trying to maintain the charging station without turning off the power.	Any maintenance performed on the charging station, should be carried out with the power turned off. The charging station shall be installed according to the following guidelines: User shall not use power supply of the charging station with an extension cord to avoid tripping hazard. User shall not put metal objects on the contacts of the charging station and on the charging pins of the mower. After disconnecting the power plug from the robot, user should set the correct date and time. Failure to do so may result in improper settings and unexpected startup of the mower, which may cause severe accidents. User shall use only the manufacturer's charger to charge the device.
Water and other liquids are sprayed directed to the robot/ charging station with a garden or a liquid spray hose causing internal electronic damage of electrical connections.	User or residents shall not spray water towards the robot, the charging station or the panel of the station. User shall never use the charger or charge the device in grasses with dampness or when wet contact is expected. Nonwaterproof robots shall be prevented from spraying with high-pressurized liquids. User must not, under all circumstances, remove, bend, and cut, fit, weld electrical or electronic parts inside the chassis of the robot.
User defeats important built-in safety devices.	User shall not remove the protective guards that need to be used with the mower. The protective devices were installed to enhance the protection of the user against harm. Check safety guards regularly and repair or replace, if necessary. The manufacturer should inform the buyer of mower that he/she should keep all guards, shields, switches, safety devices such as front and rear bumpers, thermistors (overheat protection), manual controller buttons and lift sensors in place and properly connected. Inspect to verify that these protective devices are appropriately installed and operating correctly. A visual checkout procedure shall be developed and implemented. A visual inspection is required to ensure that proper guard, plates or other safety protective devices are in place. Shields and guards are installed for residents' protection and will prevent severe bodily injuries, if used properly. If the function of the protective measures is unreliable, user should have them maintained or replaced before switching on the robot. User shall never tamper with safety devices. Inspect their proper function frequently.
The equipment of the lawn mower	In case of abnormal vibrations, user should stop the robot, remove the

vibrating abnormally.	power plug and visually check for any damage of the blade or mowing chassis and search directly for the cause. The cause might be unstable blade disc or worn out blades. Vibration is usually a sign of malfunction. Protective measures against any abnormal movement using manual controller include the use of Personal Protective Equipment like goggles or other polycarbonate protective eyewear to protect eyes when installing the perimeter wire around stakes/pegs, helmet to protect head from the overhead branches and the falling foreign material, face shield to protect face from grass residuals accidentally hit by the blades, ear muff, ear plugs or other hearing protection to protect ears against noise, gloves to protect hands and when inspecting or servicing the blades, safety boots with the non feet from the thrown debris. It is recommended that user shall wear dust mask if he suffers from the allergic rhinitis, for example, pollinosis, etc. The dust mask decreases the amount of pollens when user breathes. User shall remove the power plug from mower, in case that it begins trembling irregularly [1]. User shall check the blades and screws and replace them if they are damaged. The malfunction that leads to continuous vibration has to be repaired by service experts.
A pet may be hit if the mower operates its task with pets in the vicinity.	When adjust settings the automatic departure time schedule, user should not let mower to operate unattended if there are pets, children or people in the vicinity [1]. Before turning on the mower, user should make sure that small children, pets or obstructions are far away of the yard where the robot is operating. Some dogs have a frantic-like compulsion to hit robots. If a dog hits a mower or put its paws, nose, or mouth-parts under the edge of the chassis, the possibility of injury increases.
A resident may be injured if the material used to built-up the robot has deficiencies.	Any material on mower or the supplementary equipment shall be checked for corners that sticking out the chassis because there might alert for potential hazard. Any material used to build up the mower shall not contain carcinogenic, allergenic or toxic substances above the allowable limits. Deck, chassis, and wheels, mounting brackets, batteries and motors shall be tested for toxic substances.
The electrical protection provided from the manufacturer, doesn't meet the electrical performance criteria.	Mower's emergency stop switch, manual drive speed control, cutting blade speed, ground speed, wheel motor speed, mowing speed, connection of the power cable, connection of the mains power, electrical connections, wall socket connections, connection between the wires, connection between power supply unit and the charging station, perimeter/boundary/guide/station/ fastening wire buried or laid on the ground, wire connector, charger plug, program buttons should meet the performance criteria. Adequate electrical protection shall be provided against electrical surge such as regulators, filters, proper ground circuit.
Robot cannot shut-off automatically exceeding its functional limits due to mechanical failure.	The mower shall be equipped with two shutdown methods. The first is a main emergency stop button that may stop the current that operated the drive wheels and the blade motor. This is controlled via a relay that is automatically in the power chain. Additionally, there is the preference of controlling the mower remotely via software.
The collision detection system of the device is not functioning leading to trapping points.	Protective measures at points of collision shall be added. A subsystem that accomplishes the whole range management of collision detection through a virtual force field. This system allocates a force vector to obstacles across the mowing field. This force is controlled by the system using the signals obtained from sensory devices. Once a threshold has been reached, the system will request that the appropriate avoidance routine be performed. Obstacles such as trees, flower beds, fountains or bushes higher than 15 cm shall not have to be delimited by the perimeter wire. Mower will bang and bounce when it collides with this type of obstacle creating an island around them. The perimeter wire shall not be laid around an object that robot can be allowed to collide with, like a fence or a dense hedge. User shall pay extra attention when mowing near blind corners, shrubs, and trees, or other obstacles that may block its tasking path due to a collision. These items also present great danger to the operator, bystanders, and the mower when mowing begins.
User fails to stop the machine in case of	The robot shall have easily accessible safety commands and functions,

an emergency.	so that the user shall be able to stop the robot in an emergency or turn off the power/software. Mowing robot shall be equipped with an emergency stop switch on the manual controller that ceases the rotation of blades and wheels within seconds [1]. It must be directly available by the user around the area of the mower. If anyone approaches the mower, user shall turn it off. User is not supposed to operate the mower near children.
User doesn't establish a training schedule in order to inform all who live in the house about the hazards related to the device and the necessary precautions.	User should inform unaware residents about any inflammation, electrical, overheating, cutting or tripping hazards that might be caused by improper handling of the device, by the rotation of sharp blades, or by thrown objects resulting in deep cuts, loss of fingers, hands, toes, feet, broken/dislocated bones, burns, eye injuries and soft tissue damage. User is responsible for accidents or hazards occurring to other people or their property. User that is trained should be sure that he understands how the mower operates and then present to everyone who lives in the house how it should be used. Any user responsible for the safety of the robot shall be trained appropriately, prior to operating the robot, and shall be aware of the dangers and precautions to be taken. User shall not wear the clothes with the tapes, laces and/or ribbons, loose clothes, necktie, necklace during manual controlled operation. They can be caught leading to injury. He shall bind his hair if it is long, and do not let hair below his shoulder. He shall put on close-fitting clothes with long sleeves, long pants and sturdy, nonslip substantial sturdy shoes and button up or zip up the clothes firmly. User is not supposed to leave the sleeves and bottom of the shirt/jacket loose.
User trying to make adjustments while the robot is operating causing malfunction.	Settings in order to maintain backup power for robots bearing RAM shall be tested, so that all data shall not be erased if there is a power failure causing a malfunction. Settings that could be stored in RAM might include: manual user options, user preferences (sound, wire position, language, learn edge, blades replaced, anti-theft), charging options (weekly program, entry points, auto depart), safety tests, information (total time, run time), temperature, software version, charging voltage, charging temperature, entry points (set, default), child guard, lock settings, alarm function (disable, enable), rain sensor (restart, disabled, pause), auto setup (enable, disable), sound, date and distance format, time (set real time clock), signal type, lock keyboard, scan width, zones setup, first time calibration and ground clearance, follow loop, garden shape (open, normal, complex). User should Arrange mowing height before operate the robot. User is not supposed to change wheel height settings while the motor is still operating. High grass is preventing the front wheel from fully riding on the ground. User shall cut the lawn regularly enough to prevent over growth. Cutting wet grass is not recommended. User should attempt to change the cutting height in case of extremely over grown or wet lawn. User shall not operate the robot while under the influence of alcohol, drugs, medication or substances that can affect the ability of reacting and concentrating. User should set the mower on the highest cutting level when executing on rough ground.
An untrained user may be injured trying to fix a malfunction that is stated in the manual that it should be repaired by the authorized personnel only.	A caution note shall be included in the user manual that only service experts, having the necessary technical skill, should work on repairing a robot's malfunction. An emergency button shall be provided for unaware users when malfunction occurs, since unqualified users may get injured. Regular maintenance is essential for optimizing the relevant efficiency.
The mower is getting trapped due to inadequate function of specified checking procedure to determine the cause of a malfunction.	A check out shall be selected to determine the cause of a malfunction. Malfunctions may result in not working anti-theft alarm, noisy robot, incorrect position of the robot in the charging station, incorrect position of the perimeter wire, incorrect programming mode, blocked sensors, electric motor failure, charging or wheel problem, mowing overload, no wire signal, bumper sensor not activated when striking an obstacle, not flashing operating lamp, mowing robot get stuck frequently, blades do not mow, robot does not detect the charging station and front or rear bumper constantly pressed.
The mower has got caught in something leading to lack of drive and its equipment is damaged.	User should unplug the mower and detect the cause of the lack of drive. If the cause is wet grass, user shall wait until the grass has dried before operating the device. The mowing covering hood shall not collect grass

	residuals after mowing damp or very wet grass. It shall be checked and maintained regularly for foreign material using a damp cloth or another similar item. User shall not cut grass on slippery conditions where the traction is reduced and it may block the discharge or dry/scorched lawn. User shall inspect the drive wheel and remove grass residuals or other object.
The mower is getting stuck in the charging station.	An obstacle may block the mower from returning of the charging station. The object ought to be removed. User should drive manually the mower to the charging station and inspect that strips and contacts are properly connected in case that it needs manual recharging and this behavior is normal. In case of incorrect positioning of the perimeter wire or power cord of the charging station. Check the connection of the charging station. Collapsing of ground next to the charging station. Position the charging station on a flat and stable surface. User shall check that the charging station is positioned on a flat surface. Turn the robot off and on while in the charging station and try again. If the batteries are about to be exhausted, they shall be replaced with original components. If the batteries do not fully charge then user shall clean and remove any oxidization from the contact of the batteries.
The mower cannot operate safely with one or more sensory devices inoperable	The user is not supposed to operate the robot if any parts are damaged or inoperable. The reliability of sensory devices such as ultrasonic, infrared, bumper, lifting, rain, rollover, perimeter wire, body, mowed lawn recognition, inclinometer, shall be tested under dynamic conditions and safety features like safety guard, child guard, theft guard system, emergency stop switch, automatic mode recognition, electronically controlled charging system, over current monitor protection shall be provided to avoid a malfunction. The robot electrical equipment shall follow the appropriate instructions of the relevant requirements [15]. The electrical equipment includes batteries, drive motors, computer and programing control systems, sensory devices (sensors and encoders), robot hardware, electronically controlled charging system. The robot should be able to operate safely with these sensors inoperative: lifting or rollover and rain sensor. Shutting off the rain sensor, the mower can operate on wet or damp grass conditions and during the rain. If possible avoid operating the equipment on wet grass. If grass is wet, it may clog the discharge. User is likely to slip. A slip on wet grass or soil could cause foot to slip under the mower, into the blade. Always user shall be sure of his footing; keep a firm hold on the handle and walk; he shall never run. The robot have to shut down automatically and stop rotating the blades within seconds in case of bumper with touch sensitive sensors activation during manual operation, of anti-theft sensor activation due to lifting from the ground, of pressing local or remote emergency stop switch, of the sensor not receiving the signal of the perimeter wire, of deactivation of global positioning system, digital compass or sonar sensor. Lack of acquaintance with the relevant equipment of the device. Make sure you are familiar with the mower and its safe use. User should be aware that child guard provides a safety feature to offer protect children or unfamiliar bystanders with the safe function of the device to control it easily [1], rain sensor detects rain and commands the robot to return to the charging station and perimeter wire delimits the area mowed using small pegs for fastening it. In case that the mower is lifted from its position on the area during operation, the blades will stop turning automatically according the signal of lift sensor. Safety features shall continue to be active, so that the robot will halt when necessary to protect people. Otherwise a person might be crushed between the robot and another object, person or the wall. Test thoroughly the safety performance and force level of proximity sensors such as bumper, touch sensitive, sonar or child/safety guards and shields. Test thoroughly all the sensors for malfunctions. Faulty sensors could damage the product or hurt people. Mower's sensors such as lift, rain, and bumper, touch-sensitive, sonar, emergency stop, sensor for perimeter wire, shall be shall be checked thoroughly by the manufacturer for possible malfunctions and their functionality. It was noticed that if the sensors and other vital

	components of the electrical systems are too close to the ground or not properly mounted, the rough surfaces caused interference and vibrations that led to failures in the sensors as well other sensitive equipment. Read, recognize, follow, check and practice all commands between the robot and the manual. The responsible individual of the mower should be thoroughly familiar with the controls and the appropriate use before turning on and with the function of all controls, guards and gauges. The manufacturer should take the necessary measures to inform the user that regular tests on all safety protections need to be performed. Detailed instructions on how to perform these tests shall be provided.
Breakdown of the robot due to oxidization of the wire caused by the damage to the protective sheathing	User shall contact the service personnel for testing the impedance of the perimeter wire. User should have the damaged wire repaired using an original waterproof coupler. The software of the robot should bear a self-checking program that manages suspicious movements. Unless such a program exists, the user shall not be able to reach a control to stop a disoriented robot in proper time (as in industrial robots). Suspicious movements are mowing out of the mowing area due to a disconnection of the wire, work less that being programmed, doesn't cross over the wire, doesn't complete the edge, doesn't following the plot, doesn't working at the time scheduled, doesn't position correctly in the charging station, doesn't mow properly around the flowerbeds.

V. CONCLUSION

Since specific safety standards for mowing robots are not available, this paper draws from research on the fundamental user / designer requirements in the domain of robotics safety. Besides, the author proposed the implementation of STAMP on standards that links system requirements with accidents, so as to ensure safety on such an emerging technology and to spread the presence of such robots in every-day life. A system is considered safe when firstly meets the basic standards of safety, which are defined from the national directives and regulations, and secondly all the safety requirements that had been pointed out by the author, are fulfilled. These design constraints and requirements could serve as a robust base on building standards in order to increase commercialization and acceptance of these robots by the end-users.

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