Autonomous Systems Lab

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User-Integrated Semi-Autonomous Lawn Mowing Systems: Example Basic, Functional, Non-Functional, and Safety and Security Requirements

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Abstract

This technical report gives a set of fundamental requirements for the design and development of user-integrated semi-autonomous lawn mowing systems. The requirements provided here are general and can be adapted for use with several systems, depending on the needs of the user. They can also be used as a guide for the development of requirements for other systems. The basic architecture of this type of system is given along with the set of requirements. This document is intended to serve as a template and guide for the development of requirements for the design and development for specific semi-autonomous systems.

Keywords: Requirements; systems engineering; engineering design

Software and Code: No code or software was used in the completion of this technical report

1 Introduction

This report presents an example set of design and development requirements for a semi-autonomous, user-integrated lawn mowing system. The system will involve three basic components, namely the mowing system hardware, the mowing system software, and the human user. This kind of system is meant for residential use, as demonstrated in the concept-of-operations shown in Figure 1. On the most basic level, the mower must be able to cut the grass within a well-defined area, communicate and accept commands and control from a user through some mobile device, be able to localize and navigate itself (relative to fixed and mowing obstacles, such as trees and animals, respectively), and be able to be stored and secured within a dock or other secure area when not in use.

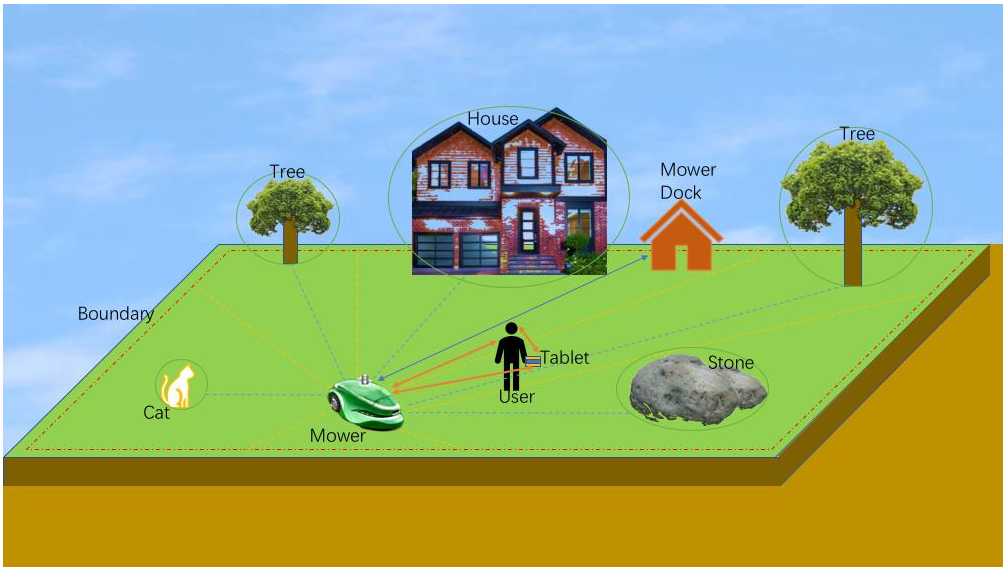

Figure 1: Concept of operations (CONOPS) for home-based semi-autonomous lawn mowing system

The system will be able to mow automatically or manually, depending on the needs and settings of the user. The set of requirements presented here are not meant to describe a specific system, but to serve as a starting point and template for the development of useful and clear requirements once the use conditions are known. The requirements of a real system should be divided into "basic" requirements, functional requirements, non-functional requirements, software and user update requirements, and safety and security requirements.

2 Basic System Requirements

A set of basic, high level requirements for the previously described system was developed by the authors to consider all major aspects of the system. Further refinement and specification of the requirements will be necessary for a specific system configuration, but this set of requirements will provide a reasonable starting place and template for completing this task.

1. **Fundamental requirements**
   (a) The mowing system must be semi-autonomous, where real-time decisions (such as obstacle avoidance and emergency shut down) should be made by the machine under normal use, but there will be at least partial input and control from the user.
   (b) The mowing system should be run (including all functions, navigation, etc) from an on-board computer system and not by a remotely-connected computer system
   (c) The system will have three components at the top level: Human user, mowing system hardware, and mowing system software
   (d) The mowing system must be able to localize within the yard while working using some method (beacons, camera-readable landmarks, or other method), especially when GPS coverage is unavailable
   (e) The mower used in the system must be able to complete the basic and fundamental tasks of a lawn mower
      i. Mower shall be able to consistently cut standard grass to a specified length
      ii. Mower shall be adjustable in terms of ground speed, cutting height, and blade speed
      iii. Mower should be able to use two modes, either specified by the user or selected automatically based on the yard conditions
   (f) The mowed space must be mappable
      i. Yard size and geometry must be mappable by some means (UAV, ground robot, beacons, user-input of map, etc.) to generate an occupancy grid or other machine-readable map
      ii. Yard boundary must be clearly definable
      iii. Path planning for the mower shall be based on the yard map,the occupancy grid, the location of expected obstacles, and the yard boundary
      iv. Yard map may be stored for future use or a new map may be generated each mowing cycle, depending on the needs of the user and how dynamic the environment is
      v. Path plan should be able to be modified if an obstacle or unexpected conditions are encountered by the system
   (g) The system must be configurable for the job at hand
2. **Mower system functional requirements**
   (a) The mowing system must have two basic modes, one automatic and one user-initiated
      i. The user must be able to select the automatic mode for regularly scheduled jobs, where mowing is initiated by the mowing system itself
      ii. The user must be able to select manual mode, where the user can direct the mower system to start or stop a job from the user interface
   (b) The mower system must be able to interface with a human user, preferably through a mobile device or laptop computer

(c) The mower system must be able to be controlled remotely by a human user (via joystick or controls from the user interface or other means)

(d) The mower system must be able to be remotely shut down safely in an emergency

i. The mowing system must have at least one remote kill switch, preferably one in the user interface, one in the mower storage area, and one mechanical kill switch easily accessible to the user at all times when the system is running

ii. There must be a way to kill the mower directly (switch or key on the hardware itself or way to cut power or fuel manually) in case all other kill switches fail

(e) The mowing system must be able to evaluate the condition of the yard

i. All conditions of the yard shall be communicated to the user through the user interface in real time as the mowing job is being completed

ii. The mower shall be able to evaluate the average length of the grass to be cut, both before and during operation

iii. The mower shall be able to measure the moisture content of the grass

iv. The mower must be able to evaluate the level of light and visibility in the yard

v. The mower must be able to determine if the weather is too poor to successfully complete the assigned job

vi. In automatic mode, the mower shall not initiate the mowing tasks if the conditions are too poor; the cutoff values for yard conditions may be determined and set by the user or may be automatically determined based on a historical data using the system

vii. The mowing system may use simple machine learning to learn over time and use cycles what the appropriate conditions are for completing the assigned jobs

(f) The mower system must be able to track the yard to locate (and avoid) obstacles or to be able to accept a map from the user, depending on the conditions and needs of the user

i. Mower must be able to effectively localize itself within the yard and relative to any other mowers within the system using GPS or some other means (such as cameras and LIDAR)

ii. Mower shall be able to identify the location of fixed obstacles (such as buildings and trees) and avoid them while following an optimal path plan as closely as possible. This requirement holds for both known and unknown obstacles (i.e., those encountered during operation that were not on the original map).

iii. Mower shall be able to identify and safely avoid moving obstacles (animals, children, etc.) not on the original yard mapping which are encounters during operation

iv. Mower must be able to check later to ensure that a temporary or moving obstacle has been removed before mowing the previously skipped area

(g) Mower must be containable and manageable in a secure storage area

i. Mower must be stored in a secure location with a dock-based charging system (for electric mowers)

A. Mower shall be able to identify the location of the dock at any time

B. Mower must be able to monitor and report its own power status in real-time

C. Mower must be able to return itself to the dock once the mowing job is completed

D. Mower must be able to return itself to the dock to charge if its power becomes too low before its job is completed. The cut-off power level is determined by the user, but it must include enough buffer for the mower to be able to return to the dock.

E. Mower must be able to return itself to the dock if it determines that the yard conditions (humidity, wetness of grass, etc.) makes it difficult or impossible to continue the job. The under interface should allow modes where this could be done automatically or after asking the human user for permission through the user interface.

ii. Mower must be stored in a secure location with a fueling station (for internal combustion engine mowers)

A. Mower shall be able to identify the location of the fueling station at any time

B. Mower must be able to monitor and report its own fuel status in real-time

C. Mower must be able to return itself to the dock once the mowing job is completed

D. Mower must be able to return itself to the fueling station if its fuel level becomes too low before its job is completed. An automatic fueling system may be used or the mower may call the user through the user interface to come and refuel it before it can continue with its tasks.

E. Mower must be able to return itself to the secure storage area if it determines that the yard conditions (humidity, wetness of grass, etc.) makes it difficult or impossible to continue the job. The under interface should allow modes where this could be done automatically or after asking the human user for permission through the user interface.

(h) The mower system must be able to provide analytics on the mowing job and machine health to the user before, during, and after completion of a job

i. Mechanical condition of the mower

ii. Weather conditions

iii. Yard conditions and status

iv. Power/fuel status

v. Intentional deviations from original path plan (such as done after encountering an unexpected obstacle)

vi. When possible, amount of drift or error from plan

3. **Non-functional requirements**

(a) Mowing system must be cost-effective

(b) Mowing system must be supportable

(c) Mowing system must be serviceable

(d) Mowing system must be future-proofed

(e) Mowing system must be reliable

(f) Mowing system must be durable

(g) Mowing system must be scalable

(h) Mowing system must be well-documented

i. Full instructions for set up and operation of the system shall be provided to the user, even if the installation and maintenance is provided by the manufacture

A. Full documentation to set up the hardware shall be provided

B. Full documentation about setting up the yard boundary shall be provided

C. Full documentation related to the user interface shall be provided

ii. Full instructions for resetting the system (after a power surge, extended period of non-use, etc.) shall be provided to the user

4. **Software and user updates**

(a) Mower system software must be updatable and upgradable

(b) Mower hardware must allow updates and upgrades

5. **Safety and security requirements**

(a) The mowing system must be as safe as possible to use, both for the users and for any by-standers or animals, and any safety issues must be clearly specified.

(b) The developers/manufactures of every part of the mowing system must provide safety training and materials, including on safe maintenance and system disposal, with the original delivery of the system or any of its parts.

(c) The mowing system must have a remote method for the user to take control or shut the system down if needed

(d) Only a secured internet connection shall be used to operate and communicate with the mowing system; the system must be secured with strong passwords or bio-metric security systems. Two-factor authentication should be used if feasible.

(e) Since the mowing system will be connected to the internet or mobile network during use, on-line/IoT security is vital and must be built into the system

(f) The mowing system must be segregated or partitioned from the main internet service to the home it served in order to prevent personal damage to the user in case the system suffers an external attack

(g) All commands from the user and the mower system must be encrypted and tagged so the system cannot accept external commands or interference from 3rd-party actors

(h) All commands and electronics must satisfy federal requirements for signals and interference

(i) All signals and communication with the mowing system must not interfere with any local navigation or communication systems

(j) In addition to the secure storage and management area for the mowing system hardware, all of the hardware and software components must be securable and recoverable if stolen from the user