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System design of a litter collecting robot

G. Maarten Bonnema a*

Laboratory of Design. Production and Management, Faculty of Engineering Technology, University of Twente, P.O.Box 217, Enschede, NL-7500AE, The Netherlands

Abstract

Litter in public places is a serious problem. Not only because of the obvious dirtiness, but also because litter attracts more litter and can cause the winding down of an area leading to large negative financial and social consequences. To avoid this, public areas have been kept clean by humans. In this paper, we apply systems architecting and engineering techniques and among others a tool from TRIZ in a multidisciplinary student project. Goal is to develop a Litter Collecting Robot for operation in public places. Through an investigation of the litter problem and subsequent development of a product vision, we plan four scenarios for robotic cleaning. The paper treats the litter problem, the architecting phase, and will show innovative technical details, including a working integrated result: a proof of principle of the robot. The project was executed by students from various disciplines, supervised by two University staff members.
On a meta-level –regarding systems design and engineering– the combination of systems architecting and engineering principles, TRIZ tools, FunKey architecting and multidisciplinary communication will be treated.

Design; Architecture; Robotics; Application; Student work

1. Introduction

This paper treats the development of an autonomous litter collecting robot as a vehicle for combining several systems design and engineering tools in a real multidisciplinary student project. Maier and Rechtin [2] describe architecting in several situations, the prominent one being where the architect combines many aspects of the product's life cycle to meet the client's interests. The architecting phase is a search process where the output is a set of requirements and abstracted designs including performance estimates. In this paper we use a tool from TRIZ [3] to assist in putting the system under design (SUD) in the right perspective and the recent FunKey architecting approach [4] to find performance estimates and system partitioning. The third tool we combined in is the A3 architecture overviews [5] for easy communication.

* Corresponding author. Tel.: +31 53 4892548; fax: +31 53 4893631.
E-mail address: g.m.bonnema@utwente.nl.

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In the paper, we will first look at the need and the problem by focusing on causes and consequences of litter (Section 2) to formulate a coherent vision for the robot. From that the architecture is developed in Section 3. With the goals and the decomposition, the constituting modules for the robot are developed. Each of these modules will be dealt with in Section 4. Finally, the overall result in terms of the robot, and the SE related result, is described and discussed together with conclusions and future work in Section 5.

Table 1: Most prominent litter locations, perceived by the public. Percentage indicates the share of people indicating the location as most heavily littered [1]

Location	Percentage
Shopping Mall	27
Beach	15
Parking Lot	13
Park	10
Petrol Station	9
Street	8
Forest/nature reserve	8
Bus or train station	5
School	5
Snackbar/restaurant	3
Motorway	3
Sport areas	2

2. Problem exploration: Litter and Safety

First, the issue will be explored by investigating the nature, the magnitude and the consequences of the litter problem. Litter is created everywhere people pass or spend time. It can be created in many situations and due to many causes, and regulations only help partly. Most obvious is someone throwing something on the street, which is in general not accepted (except for cigarette butts). Another cause is when people put something in a trash can, but it falls out when the can is full, due to wind, or when other people add something later. Studies show that most litter occurs near sporting facilities and parking lots. However, the public sees most litter on the locations shown in Table 1. Combining this with a broad study on annoyances of the (Dutch) public where litter is rated as more annoying than noise from neighbors and cigarette smoke, one can state that litter is a serious problem.

Litter should be regarded in context to come to a balanced product architecture. To this end, the *9-window diagram* (part of TRIZ) was used to stimulate hopping between hierarchical and temporal viewpoints. The SUD is part of a hierarchical chain; it forms a context for its subsystems. Also, the SUD is part of a "system of systems" (in the literal sense). This is shown in the *columns* of the 9-window diagram. The other view is that of time. A system often is an evolution of a previous incarnation. One sees this development in the *rows* of the 9-window diagram from a stakeholder's viewpoint. It is recommended to develop several scenarios, each with a 9-window diagram. Table 2 shows one for litter, based on increased individualism and reduced social pressure: the litter-forming process (the bottom row), the people and process involved in creating litter (top row), the past of litter (leftmost column) and the future results of littering (rightmost column).

Table 2: TRIZ 9-window diagram used for investigating the littering system

	← Past	Present	Future →
Super System ↑	Sale of open food High social coherence	Humans, shopping mall, food wrapping, food marketing	Low social coherence, Food marketing more important than food itself
	Little littering	**Present day littering**	Increased littering
Subsystems ↓	Cigarette-butts	Cigarette-butts, cans, PET-bottles, flyers	Same types, more in number

Litter has more consequences than just an untidy view and annoyance: *e.g.* pests (rats, roaches, flies etc.) and resulting diseases; harm to animal life; increased use of fossil fuel instead of recycling; reduced sense of safety, and more litter. Visible litter results in less care by other people to prevent littering. Increased litter suggests people do not care, resulting in a reduced sense of safety, and eventual loss of value of properties. To prevent this, based on the "broken window theory" in [6], public places have to be *kept clean*. At present this involves mainly manual labor. The cleaners have a hard job with low profile despite the importance. Relating to the 9-window diagram, we can conclude that (a sense of) safety is on a higher level than litter. Only focusing on reducing litter may result in worse safety. Litter and safety have to be considered simultaneously.

3. Architecting

This section treats the architecting process as combining social, ergonomic, managerial and technological aspects. It consists of three steps: a philosophy/vision, project organization, and the robot architecture.

3.1. Philosophy and Vision

Based on the above, four subsequent scenarios are devised to guide the development. The first one is a single robotic assistant to the cleaner. In the second scenario multiple robots are controlled by one human cleaner. It can be extended with autonomous communication between the robots where all robots contribute to mapping the environment. The final scenario shows full autonomous behavior where the human supervision can be done from a distance. This scenario conflicts the vision outlined below and will not be pursued actively. The remainder of this paper deals with development of a *proof of principle* (POP) for the first scenario.

Starting from the results from section 2, and extending those with research of stakeholders (including interviews with them), history, market, opportunity and requirements [7], we aim at reducing litter without removing the social aspect of the presence of human cleaners. In close cooperation with the main project partners: Stichting Nederland Schoon, and industrial partners: Hako-Werke GmbH and Demcon advanced mechatronics, it was decided that the robot will assist the human cleaner. The robot will do most of the heavy and dirty work to keep the area clean: not sweeping large areas, but *maintaining cleanness*. The human cleaner is supervising the robot, indicating where litter not recognized by the robot is located. Also, he will attend to hard to clean litter. This way the human cleaner is not replaced, but his task becomes physically easier, the cleanness is improved while freeing time for the social aspect of being in the area.

This vision has far-reaching consequences for the robot development, of which the most important are: (1) Spotcleaning instead of area cleaning: only the items that are most prominent as litter will be collected (cans, bottles, and if possible paper). (2) Not using suction for cleaning. Suction is mostly used in present day cleaning equipment, yet it causes noise, requires much power, and picks up a lot of sand and dust. And (3) Electrical operation to ensure quiet operation among the public.

3.2. Project Architecture

The work in the project was executed as Master, Bachelor and individual research assignments carried out by students from Industrial Design, Mechanical and Electrical Engineering and Mechatronics. The author served as one of two coaches/supervisors. One of the project partners requested frequent public exposure. Therefore, the project model was that of spiral development, Fig.1 [2]. This meant a sequence of three public presentations (at events organized by Stichting Nederland Schoon) with increasing complexity and functionality. The following subprojects have been completed:

- System design and interaction between robot, cleaner and public;
- Collection mechanism and mechanical framework;
- Sensors and electrical framework;
- Mapping and navigation;

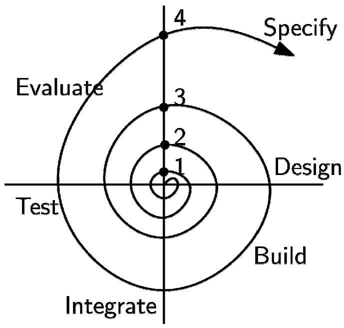

Fig. 1: The development spiral [2]. Points 1-3 are the public presentations. 4 is a future prototype.

- Image recognition and software framework; and
- Locomotion and control.

Through combined management of milestones, project and risks in combination with even shorter cycles in between the public milestones, the stakeholders involved were kept informed and involved.

3.3. Robot Architecture

Based on the work mentioned in above, the functions to perform can be derived. Also, the stakeholders' main performance items can be derived. We will call these key drivers. With the FunKey approach presented in [4], it is analyzed which function contributes to which key driver. The result is used to create system budgets. Further, the functional interfaces are identified and managed using N^2 diagrams based on these functions.

The architecture created involves the modules shown in Fig.2 and their interaction. Apart from the functional modules, three utility –or infrastructure– modules were identified: the mechanical, software and electrical frameworks. Overarching all is the system design. Now the modules are known, the functional N^2 diagrams can be transformed into modular N^2 diagrams (shown at the right in Fig.2) representing the interfaces between the modules. Several representations (e.g. Fig.2 and 3) of the architecture were created. In addition to the FunKey scheme and the N^2 diagrams, an A3-architecture overview of the system was created (Fig.3) [5]; and a roadmap to plan the development of the robots for the scenarios mentioned in section 3.1. Balance in the performance is created using system budgets [4]. In section 4, some achievements in the individual modules, and the system as a whole will be summarized.

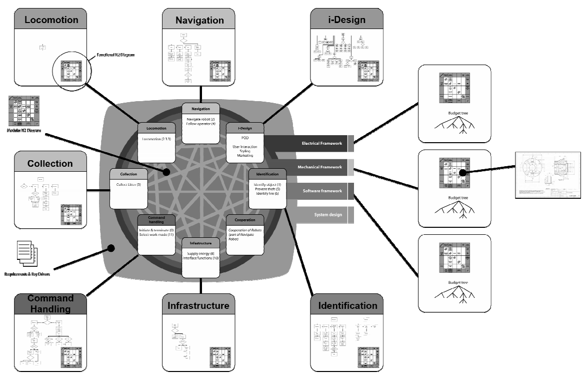

Fig. 2. Architecture view of modules and interactions.

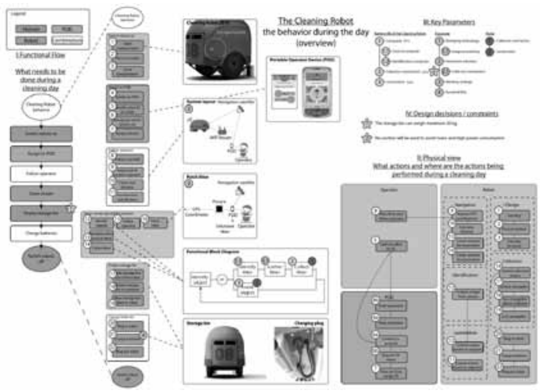

Fig. 3. A3 architecture overview [5] of the robot.

4. Results

In the architecture presented above the interaction between robot and human cleaner is crucial. For this the *Portable Operator Device* (POD) is created. It provides, a.o. learning input to the image recognition module: Any new type of litter identified by the human cleaner, is photographed, and wirelessly sent to the robot.

As this robot uses spot cleaning instead of surface cleaning, and suction was not preferred (Section 3.1), a new way of collecting litter had to be devised that leaves no marks where cleaning has taken place. Instead of a continuously sweeping brush, more rigid *plastic fingers* just stay clear from the floor (Fig.4). When a piece of litter, the can in Fig.4, is detected, the flap (normally in the horizontal position) will close and push the can between the fingers. The rotor will start and transport the can over the rotor into the hopper. This has been tested to work for cans and plastic bottles with a not too large diameter. Optimizations are required for robust picking up of all regular cans and bottles.

The robot has to be aware of its surroundings, has to detect stationary and moving obstacles and litter. The detection system bases on a map, information from a scanning laser range finder (SLRF) and a camera. The SLRF continuously detects objects within a range of several meters. Objects tagged as possible litter are approached. The camera then takes a picture that is analyzed by the image recognition software. Main challenge of the image recognition was to avoid false positives. We used the metaphor of a Chihuahua caught by the robot to discuss this. After analysis of alternatives, we chose feature recognition (FR). FR can identify a cola can that is crushed or in different positions (Fig.5). Feeding the feature database only with known litter minimizes the chance of false positives. Also, the robot learns from images of known litter from the POD.

The POP uses a simultaneous localization and mapping algorithm (SLAM, [8]), with some a priori information. This method sufficed for the POP. Yet, for a final product further development is needed to deal with moving objects (people and traffic). This is still a challenging subject.

As the robot should be agile, we use mecanum wheels [9] in order to move, and turn on the spot. Detection of the rotation angle of the robot was done with an electronic compass. This turned out to be incorrect as it is sensitive to steel in the environment, causing severe navigation problems. The collection mechanism and all other components are built inside the frame of an existing Hamster 700Electric cleaning machine provided by Hako. Although the driving and sweeping mechanisms were modified, the frame was usable for the POP.

The POP robot was demonstrated for all stakeholders. A movie of this demo can be found on http://www.rtvoost.nl/nieuws/default.aspx?nid=106306 (comments in Dutch).

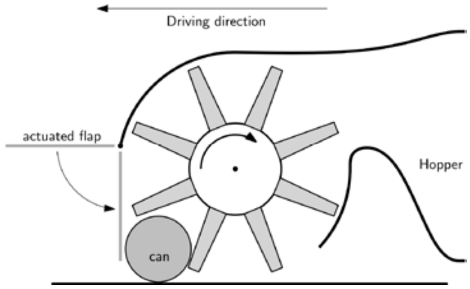

Fig. 4. Plastic fingers collection mechanism.

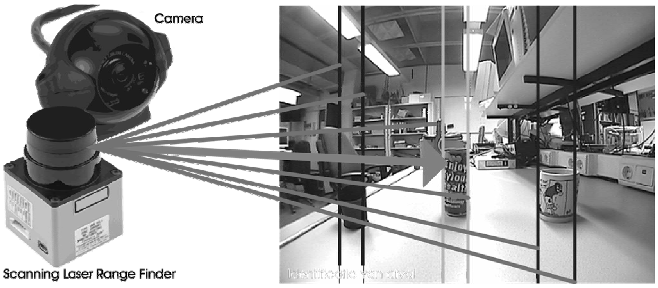

Fig. 5. Scanning Laser Range Finder and Camera working together with the Image recognition software.

5. Discussion, Conclusions and Future Work

The Litter Collecting Robot is feasible as shown by a working *proof of principle*. The architecture uses synergy between human and robot as starting point meaning that together they are expected to provide a clean *and* safe environment for people to do their shopping and leisure.

On a technical level, interesting results have been obtained for the collection mechanism. The rotating drum with plastic fingers solves several issues with one device: reduction of sand and dust collection, noise, and energy consumption. Further results include the cooperation between navigation and sensing, and the cooperation between human and robot using the Portable Operator Device (POD). The result so far is a proof of principle; it is not yet a prototype, see Fig.1. In order to come to a prototype several issues need further investigation. Robustness of the sensing and navigation subsystems is paramount. Also, replacement of the compass with another sensor is required. More development is needed in order to create a robust robot; deal with moving elements in the environment (shopping people, traffic passing by, etc.) and varying weather and lighting conditions. Yet, the project has succeeded in showing that the technology is available, and that a combination of the technologies provides a functioning robot. Other issues that need to be addressed are how people react on the robot. Do they litter less or more? Will the robot attract vandalism, or repel it? What are strategies for swarm behavior when multiple robots cooperate? Unfortunately, partly due to the economic crisis in 2009-2010, the main industrial partner withdrew from the project after the POP.

Regarding system design and engineering, we conclude that the architecture is essential in robotic development projects. The SUD should be considered as an instance in both the temporal and hierarchical chains. The robot to be developed should not be the top of the hierarchical chain. The supersystem; containing the environment, users and other context, should be considered. The *9-window diagram* from TRIZ is helpful in facilitating this type of systems thinking: It showed here that merely replacing the human cleaner with a robot may provide a cleaner environment, but safety, an issue higher in hierarchy than litter, may then be worsened. The spiral model (Fig.1) is useful in student projects because of the regular feedback moments. In the architecting and system design process, the A3 Architecture Overviews and FunKey approaches have helped to maintain the big picture. N^2 diagrams helped to maintain consistency in the interfaces, and system budgets maintained consistent and balanced performance. Frequent visualization of results, and the use of metaphors have helped in communication between the diverse stakeholders and designers.

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