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Letter to the editor

# Long-term assessment of a service robot in a hotel environment

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## HIGHLIGHTS

- Long-term evaluation in real environment under unsupervised conditions.
- The evaluation methodology includes both qualitative and quantitative aspects.
- A set of metrics are analyzed concerning social interaction and navigation.
- Improvement of the robot's performance through assessment feedback.

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## ABSTRACT

The long term evaluation of the Sacarino robot is presented in this paper. The study is aimed to improve the robot's capabilities as a bellboy in a hotel; walking alongside the guests, providing information about the city and the hotel and providing hotel-related services. The paper establishes a three-stage assessment methodology based on the continuous measurement of a set of metrics regarding navigation and interaction with guests. Sacarino has been automatically collecting information in a real hotel environment for long periods of time. The acquired information has been analyzed and used to improve the robot's operation in the hotel through successive refinements. Some interesting considerations and useful hints for the researchers of service robots have been extracted from the analysis of the results.



## 1. Introduction and background

Service robotics has had a major presence in research centers in recent years. However, there are few applications where robots are part of our daily life activities. A number of problems arise in the development of robots (localization, navigation, planning, interaction, etc.) which have been addressed extensively in research centers and have been successfully solved to a significant extent. However, there has been limited success in adapting the solutions reached to the development of robots that can operate in real situations for long periods of time.

There are two main requirements that a robot must meet to be brought to the market: it must offer a good service at an affordable price, and it must perform the tasks with a minimal, tolerable failure rate. A relevant example of a robot that has successfully fulfilled both requirements is the vacuum robot, led by iRobot Roomba [1]. In addition, social service robots have to interact with humans and the environment in a user-friendly and socially-compatible way. This requires robust and versatile perception systems and solid interaction strategies to be developed. To date, much work has been dedicated to these research areas, looking for easy-to-use interfaces through which humans can communicate with robots in a natural way [2–5].

Usually, such criteria as the ability to get and hold the user's attention to the proposed service, evaluated through direct observation, are used to assess the quality of the social interaction between robots and people [6]. Several studies have focused on the underlying reasons for the acceptance of social robots in different scenarios; their usefulness, adaptability, enjoyment, sociability, companionship or perceived behavioral control have been identified as important parameters for potential users' acceptance [7]. In [8] it is suggested that, in addition to this qualitative assessment, metrics assessment should be used to provide feedback mechanisms aimed at improving the general performance of the robot. Benchmarking in robotics [9] has emerged as a solution to evaluate the performance of robotic systems in a reproducible way and to allow comparison between different research approaches. However,

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benchmarking is rather difficult in service robot applications [10], given that humans and real environments must be explicitly considered in the benchmarking methodology.

While many works have focused on analyzing robots working in controlled environments [11], where they interact with few users, e.g. in Physically Interactive RoboGames (PIRG) [12], only a few long-term studies have begun to appear over the last few years. In this sense, an increased effort has been made to understand the particularities of prolonged interactions with robots.

In [13], one of the first long-term studies in a real-world setting involving a social robot is reported. The robot was dedicated to a target impaired user, and was evaluated over 3 months. Results showed that it is important for robots immersed in public spaces to provide clear instructions on how to be operated. The results have also raised some issues such as the personality of the robot, the dialog between users and the robot, and the relevance of group collaboration.

Another relevant example is the robo-receptionist Valerie developed by Gockley et al. and installed in the CMU campus. Results from a first study [14] indicated that, after a certain period, only few users interacted with the robot for more than 30 s. To avoid this, the authors proposed some design recommendations such as proper greeting and farewell behaviors, more interactive dialog or a robust way of identifying repeated visitors. A second long-term study with the same robot [15] was carried out over nine weeks, in which the robot was able to display different moods. Results indicate that interactions were different depending on the level of familiarity and the robot's mood: frequent users interacted more often when the robot was in a positive mood, but the amount of time they dedicated to the robot was higher when it was in a negative mood.

In [16] the robot Robovie is evaluated in a shopping mall. The robot had the ability to adapt its dialog to previous interactions with each user, while it was also capable of offering directions and advertising specific shops and services in the mall. Their results suggest that user perception towards the robot was positive, not only in terms of perceived familiarity, but also regarding intention of use and guidance. Also, better results were obtained from repeated visitors. In addition, the study also concluded that people's shopping behavior was influenced by the robot's suggestions.

A wider survey that addresses the particularities of prolonged interactions with robots can be seen in [17]. This survey addresses a total of 24 papers organized by their application domain: Health Care and Therapy, Education, Work Environments and Public Spaces, and the Home. The experimentation described in the said survey varied from paper to paper, but has usually been done over several sessions and days. However, few works have extended over several months. Analysis has been carried out in several ways: video and direct observation, system logs and post-trial interviews and questionnaires. Some drawbacks have been found that limit robot performance: (i) Robots lack perceptual capabilities to enable rich social interactions and engage sporadic users, (ii) robot autonomy is often limited, thus preventing the robot from operating for long periods of time, and (iii) platforms often suffer from limited robustness and reliability, which results in weak supporting evidence of the robot's effectiveness, while technological acceptability is sometimes considered as one of the last design steps.

The present paper provides the results of a long-term assessment of a service robot in a hotel environment. Experiments have been carried out using Sacarino, an interactive bellboy robot [18], aimed at providing different services in a hotel: walking alongside the guests, providing information about the city and the hotel (restaurant hours, menus, etc.), and providing hotel-related services (calling taxis, guiding guests to the restaurant or other rooms, etc.). Sacarino is designed to stay connected to a charger in the hotel lobby when it is not doing a specific task (so it can continuously provide effective services) as well as to navigate autonomously through the hotel facilities. The approach proposed in this paper involves being aware of current limitations, avoiding universal solutions and restricting the application domain to a concrete use case, focusing on an iterative design process. Our main aim is to take some of the technologies involved from the laboratory environment to higher technological readiness levels.

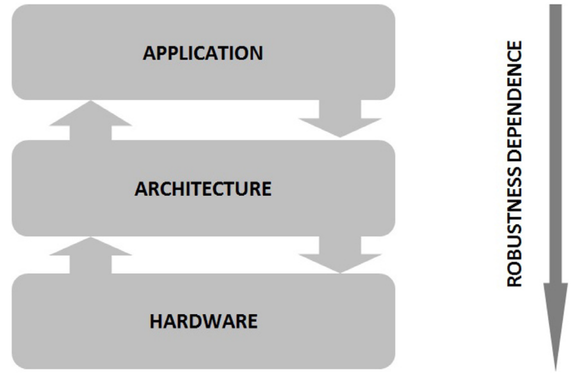


**Fig. 1.** Infrastructure levels of a service robot.

The rest of the paper is organized as follows: A description of our robot is presented in Section 2. The methodology used to assess the quality of the services is presented in Section 3. The following Sections 4–6, describe the different stages of assessment, including procedure and feedback based on the analysis of the results in each one. The dependability of Sacarino is analyzed in Section 7. An enumeration of lessons learned is reviewed in Section 8. Finally, Section 9 includes the conclusions and future work.

## 2. Context of our research: Sacarino

In this paper, the assessment of Sacarino is presented [18]. This robot has been designed to operate in a hotel. In general, three levels can be identified when defining the structure of a service robot (Fig. 1). The first level is the hardware and the mechanical structure, including sensors and actuators. The second level comprises the robot's control architecture. Architecture design has attracted the specific attention of the scientific community over the last few years, where different architecture paradigms have been developed (e.g. reactive, deliberative and hybrid [19]). Architecture design is a difficult task as it comprises different software components, programming techniques and modeling approaches: navigation techniques, simultaneous localization and mapping SLAM [20], planning [21], interfaces, human–machine communication systems including dialog systems [22], recognition systems [23], cognitive modeling [24] and knowledge representation [25].

The third level is the application one. It is a key level, given that it specifically concerns the services to be provided by the robot. However, little effort has been devoted to this level and few results have been obtained towards the development of service robotics. The main reasons can be found in:

- A lack of robustness in previous levels and the hierarchy across them, which hinders the development of service applications with the desired degree of autonomy. For example, a failure in the robot localization may cause goods to be dropped during loading and unloading, as well as navigation errors, collisions and crashes. While a certain failure rate may be acceptable in systems where a human is included in the control loop, the permissiveness is practically zero in systems that must operate autonomously.