Sacarino, a Service Robot in a Hotel Environment

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Abstract. This paper presents Sacarino, a service robot whose purpose is to work in a hotel providing information for guests about the hotel services and accompanying them through the hotel spaces. The article describes the three levels of the development of Sacarino: the hardware level, with the sensors, actuators and robot performance; the architecture level, which describes the different functional blocks; and the application level which describes the services offered by Sacarino. Finally, we show some preliminary results of the evaluation of Sacarino in the hotel environment and the way these results have been used to improve the robot.

Keywords: Service Robot, Social Robot, Robot Architecture.

1 Introduction

Robots with social skills have seen a boom in recent years, although their application has not yet made the leap from research centers to the consumer society. These robots must be able to provide services to citizens in a natural way and interact with them like humans do. Applications that are expected of these robots include luggage or mail transportation and help for disabled and elderly people. According to Dauthenhahn [6], social robots are customized agents that are part of a heterogeneous group (a society of robots or humans), able to recognize each other and engage in social interactions. They perceive and interpret the world in terms of its own experience and communicate by learning from each other. To accomplish these goals, a robot has to be able to display certain characteristics: embodiment, emotion, dialogue, personality, human-oriented perception, environment modeling, social learning and intentionality. Furthermore, it is very important that the robot has a natural interface with some degree of anthropomorphic representation, such as a head (personification) to produce facial expressions to convey moods and emotions [2, 4].

Social robotics requires the integration of a variety of techniques related to the fields of electronics, computers, mechanics, communications, localization, navigation and the study of the psychological, sociological and biological aspects. Many of the

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techniques required for the successful completion of a social robot have still not been fully developed and require further research and experimentation, especially in the fields of environment perception, visual and voice recognition and knowledge representation of mind models, among others.

The solution to addressing real problems in the context of social robotics passes through simplification, i.e. limiting the functionality of each subsystem while ensuring proper integration of all subsystems. For example, the solution to a complex problem, such as maintaining a conversation with the robot, can be bounded by limiting the actual dialog context. This contextual clustering can be applied to other aspects such as visual recognition or emotional control.

The ultimate goal of the robot is to serve people by providing information or helping at home, in hospitals, hotels or industrial environments. Losing sight of this ultimate goal is the main reason why many robotic research projects do not reach the market. Often, technical objectives are proposed but social or practical objectives are set aside, therefore the robot has no real use that people demand. Keeping this in mind would allow social robotics to be gradually integrated into society and become more widespread and accepted, while pending technological problems are solved.

The present paper presents Sacarino, a robot with social skills whose mission is to provide bellboy service in hotels. This mission includes such features as providing information about the hotel services and accompanying guests through the hotel spaces.

2 Architecture

The infrastructure of a service robot can be defined in three levels (Figure 1). The first level is the hardware and mechanical design, including perception systems (sensors) and movement systems (actuators). The second level is the robot control architecture. This level has received major attention during recent years. Several architectures have been proposed: deliberative and hybrid architectures [11] which include navigation techniques, map location and simultaneous generation SLAM [8], planning [5], human-machine interfacing and communication which include dialogue systems, automatic recognition systems (voice, face), cognitive models and knowledge representation, etc.

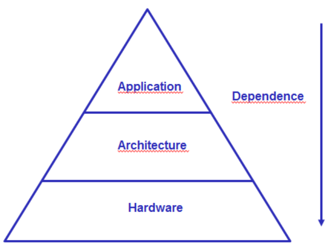

Fig. 1. Infrastructure levels of a service robot

3 Hardware Level

Sacarino's base (Figure 2) is controlled by four double wheels arranged in a synchrodrive configuration. This configuration has greater mechanical complexity than others (e.g. differential or tricycle), but allows the linear and angular velocities to be decoupled. The four wheels pull and rotate at the same time, driven by two motors: one responsible for the traction and the other one for the turn. A platform on the drive system, which turns synchronously with the wheels, supports Sacarino's body in such a way that the social part of the robot faces the direction of motion. The base is responsible for housing the control electronics and the robot navigation sensors.

The base of the robot includes the following elements (figure 2):

- Two Longway brushless motors (80W/24V, 6.2N / m) (one motor for rotation and the other one for translation).
- LiFePo4 26V/40Ah battery providing 3 to 5 hours power autonomy
- Doors damped with contact system to detect collisions.
- Ring of 16 ultrasonic sensors to detect obstacles.
- Sick LMS100 Laser for localization, obstacle avoidance and map building.
- Drawer slides with motorized door for carrying snacks, newspapers and other items.

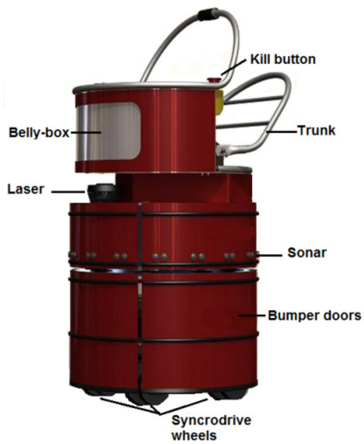

Fig. 2. Sacarino's base

The body is in charge of interactive social communication. This body has a nice, humanoid aspect that confers personality to the robot. The body system combines expressiveness and Human-Machine Interaction. Also, the body can be easily detached from the rest of the robot so that it can be used as an independent system. The robot body includes the following elements (figure 3):

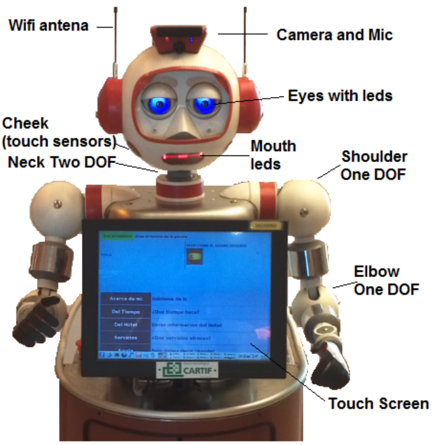

Fig. 3. Bellboy body

- Torso. The torso of robot includes two arms with two degrees of freedom (shoulder and elbow) that are driven by four servomotors. A touch screen in the front of the torso provides information and user interaction. The torso also holds the computer system used for social behavior.
- Expressive Head. The head is the component that provides more expressiveness to the system. It is responsible for supporting the HMI interaction sensors and transmitting the robot "emotions" to the users. The head, jointly with voice and arms, provides the robot with personality for a pleasant interaction. The head has two direct-coupled servomotors (providing pan and tilt movements) in order to look at the user in a natural way.
- Camera and microphone. A (Playstation-3) camera is placed at the top of the head. This camera provides face recognition and tracking for a comfortable face to face interaction. A microphone array is included for noise filtering and voice recognition.
- Eyes. The eyes can be lit up and the brightness can be adjusted by pulse width modulation. The eyelids are controlled by two servomotors for robot blinking and for adding expressiveness.
- Mouth. The mouth is shaped by an array of LEDs that can show different gestures according to the emotional state of the robot and simulate the lip movement during robot speaking.

3.1 Electronic Design

The electronics is also divided into two parts: one for controlling the robot navigation systems (motors and sensors used exclusively for navigation) and the other one for controlling the social functionality of the robot. Figure 4 shows a diagram of the electronic components of the system and their connections.

Sacarino's base is controlled by a specific microcontroller board called GPMRC (General Purpose Mobile Robot Controller). This controller has two dsPIC microcontrollers dsPIC30F6011A in a master-slave for closed-loop motor control and security device management (e.g. emergency buttons or bumpers). The GPRMC includes an LCD display for status notification, a game port for connecting a wireless playstation joystick and several buses (I2C, CAN and RS232) for connecting different elements. The board provides a number of functions:

- Monitors the system power. To do this, the GPMRC continuously measures the battery level and notifies the navigation computer. If the level falls under a critical threshold, the board executes an emergency stop and produces an alarm sound.
- Run-Stop. The board runs emergency stops and activates various alarms to detect the activation of emergency buttons, critical battery level and watchdog timer.
- Reads the bumper signals.
- Monitors the robot state and shows information on the LCD display.
- Performs motor PID control loops according to the linear and/or angular speed references provided by the computer system (or the joystick).
- Monitors the computer system. The board is in charge of the computer on/off switching. Also, an alarm is activated in case of a board-to-PC communication loss.
- Computes odometry estimation. Based on the information provided by the motor encoders, the robot's pose is estimated by dead reckoning.
- Centralizes all the information regarding the robot status and auxiliary boards (e.g. sonars) and transmits it to the computer.

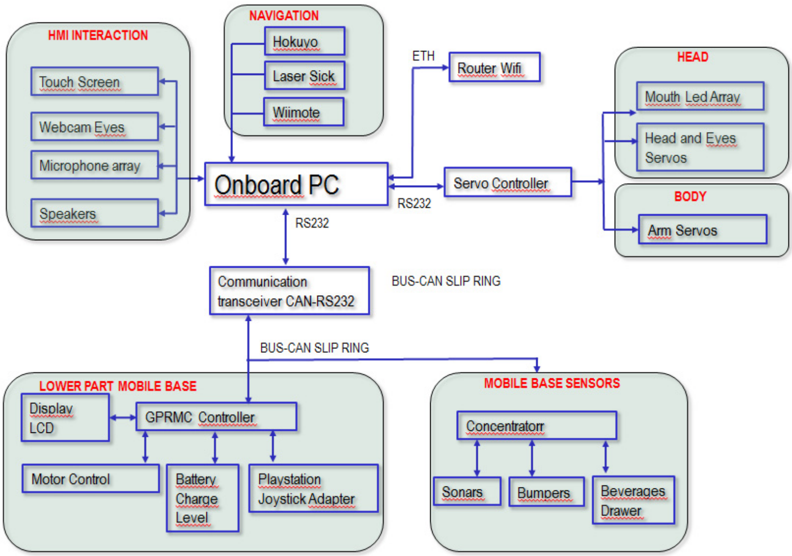

Fig. 4. Component structure and communication

The concentrator board is a specifically designed board used for configuring and reading the sonar ring and the bumpers. This board communicates with the GPRMC through CAN Bus and with the computer through RS232, via a transceiver (see Figure 4). The bus allows the number of wires to be reduced. The GPRMC is located at the robot base (along with the batteries) so that it rotates with respect to the robot torso (housing the remaining elements). A slipping ring is used for connecting the two parts of the robot.

The body of Sacarino is driven by a servo controller that performs head, eyelid and eye movements. The controller receives the position references for each axis from the computer through an RS232/USB communication line.

Finally, the transceiver is a board for converting CAN bus protocol to RS232/USB serial protocol, in order to communicate the low level control system and the navigation computer.

4 Architecture Level

The development of Sacarino's architecture has been conducted under the principle of component-based integration (component-based robotics framework). The component-based approach has several advantages [3], such as modularity, reusability, scalability and especially, the existence of repositories of different implementations of modules that facilitate the integration of systems. There are several frameworks that are enjoying a great acceptance in the robotics community. OROCOS (Open Robot Control Software) is a free software project that includes an application framework. Microsoft Robotic Studio [13] is a framework aimed at robotic design and simulation. It provides support for accessing different types of sensors, but it is neither open source nor portable to different operating systems, which has greatly limited its applicability. CARMEN (Carnegie Mellon Robot Navigation Toolkit) [14] and Player [17,18] are two implementations of open source robotics projects that maintain repositories of verified algorithm implementations in robotics. However, ROS (Robotic Operating System) [15] is undoubtedly the most successful mobile robotics re-use project to date. It provides tools and libraries to help software developers create robot applications. ROS also provides hardware abstraction, device drivers, libraries, visualizers, message-passing, package management, and large repositories of well-tested re-useable implementations of algorithms.

Figure 5 shows a functional block diagram of Sacarino's architecture. There is a set of functional modules, each one in charge of a specific task. Module integration and communication has been done using the ROS framework. Modules are grouped into two major functional subsystems. The sub-navigation subsystem, as the name suggests, is responsible for all on-robot navigation tasks. This subsystem includes the control modules that communicate with the GPRMC board and perform an abstraction of the hardware level (sensors and actuators) as well as the other navigation modules (localization, reactive navigation and planning). The other subsystem is the interaction and behavior one, which includes modules for gesture control, (body control), visual perception, chatbot to generate dialogue and Automatic Speech Generation and Recognition [12] for a more versatile communication.

5 Application Level

The main mission of Sacarino is to inform the guests, show them the hotel facilities and accompany them to the different facilities. Currently, Sacarino can provide the following services:

- Give information about the hotel facilities. This includes audio and visual information about the hotel, meal times and restaurant services. Information about the city, shopping, museums, restaurants, etc. is also given. All interactions are bidirectional and are carried out in a multimodal way (using voice and/or touch screen). Sacarino presents information through spoken and written messages (displayed on the screen), images and maps. Moreover, the user can request information using voice or the touch screen, thus easing the interaction when the environment is noisy or the voice recognition system cannot correctly recognize the user.

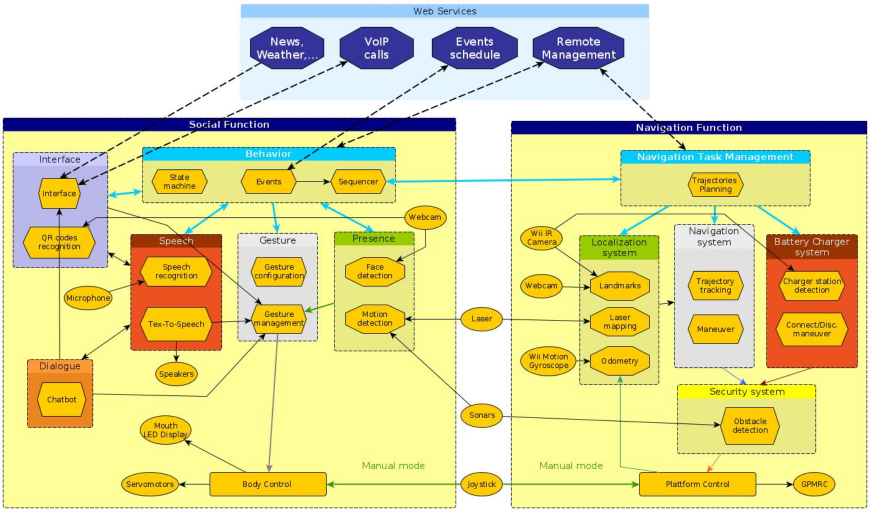

Fig. 5. Sacarino Architecture

- Provide online information from Internet, like weather forecasts, news of the day and other entertainment information such as jokes and proverbs. Sacarino currently has a database of over 5000 jokes and proverbs.
- Give information on events. Sacarino informs about upcoming events (congresses, conferences, presentations, etc.) to be held at the hotel. A dedicated website allows the staff to enter event information (description, meeting room, schedule, etc.).

- Taxi service. When a guest requests a taxi, Sacarino completes a web form to call a taxi. In order to avoid bad practices, the robot requests guest identification, asking the user to show a QR code printed on the hotel guest card, to the head camera.
- Breakfast control. Control of guests who have breakfast every day. It is intended that Sacarino performs this task. The robot will be placed at the entrance of the restaurant and when a guest is detected by the laser scanner, he/she will be prompted to say (or input through the touch screen) his/her room number.
- Videoconference service to the hotel desk. When Sacarino is unable to provide feedback for a user request, it can establish a video Skype conference with desk staff.
- Accompanying guests. Sacarino can navigate through the hotel spaces to accompany guests. Sacarino's navigation is currently restricted to the ground floor (hall, dining room, bar and meeting rooms), but, in the future, it will be able to travel to the rooms in order to guide guests or deliver items (newspapers, snacks, etc.). This task will be addressed as soon as the electronics for calling the elevator remotely have been set up.
- Satisfaction survey. The user answers a simple questionnaire about the interaction (appearance, expressiveness, ease of use) and the services offered by Sacarino.

6 Experimental Results

Sacarino has been tested initially for a two-month period at the Hotel Novotel (Valladolid, Spain). The robot usually stood in front of the reception desk, and moved regularly through the different hotel spaces on the ground floor, main lobby, coffee shop and meeting rooms, according to a certain scheduled agenda. Some services, such as taxi call, breakfast and video conferencing, have been implemented and will be evaluated in a second phase (scheduled to begin shortly). After interaction, users were asked to complete a questionnaire about the features and functionality of Sacarino. The survey questions are shown in Table 1. Visitors were asked to rate the performance on a scale 0-7 and also to fill in an open-ended form to express the reasons for their answers, the constraints encountered and suggestions for possible improvements.

Table 1 shows the mean and standard deviation of the ratings corresponding to 53 visitors who answered the questionnaire.

Table 1. Sacarino assessment survey (scale 0-7)

Question	Mean	Std
1.-Rate 0 to 7 how Sacarino is able to display information clearly.	5.05	1.18
2.- Rate 0 to 7 the ease of use of the touch interface	6.36	0.58
3.- Rate 0 to 7 the voice communication with Sacarino	3.48	1.88
4.- Rate 0 to 7 the overall experience with Sacarino	5.10	0.94
5.- Rate 0 to 7 the Sacarino movement (if you have seen it moving).	4.94	1.36
6.- Rate 0 to 7 the Sacarino usefulness as a helper and guide in a hotel.	5.43	1.10

The evaluation of the survey has been generally good. The highest rated aspects have been the touch interface, which is able to display information clearly, and Sacarino's usefulness as a helper and guide in a hotel. The worst rated question has been the voice recognition. In general, guests report some difficulties to be understood by the robot. This problem has happened due to the ambient noise reaching the microphone during recognition. The second worst rated question concerns Sacarino's movement. This question was answered by only 17 users who were present when one of the scheduled tours was performed. Some of the comments about this issue were that Sacarino should travel at a higher speed.

Regardless of the numerical scores, the qualitative information provided by users has been a very important feedback element for improvement. In order to improve the speech recognition, a more directional microphone has been set up on the touch screen (on a vibration absorbing mount). This reduces the incoming noise from the motors at the robot head. Also, when Sacarino is continually on alert listening, ambient noise may eventually be recognized as a user request, thus making the robot provide unsolicited information. One solution could consist in forcing the user to start each interaction with the word "Sacarino". However, this would result in a less natural interaction, especially when very short sentences are required. Moreover, this solution does not prevent the recognizer from being continuously active. So, the chosen solution has been a button on the touch screen. The user touches this button to start the voice recognition. This method is providing satisfactory results and is familiar to users, given that it is commonly implemented in smartphones. We are also evaluating the possibility of placing an infrared sensor to detect that a person approaches the microphone to speak, in order to activate the speech recognizer automatically (and inform the user that he/she is being listened to).

Another recurrent observation is that the user does not know what to say to Sacarino. Unfortunately, there are still no universal speech recognition systems able to deal with fluent conversation. Aware of this, users generally do not know how to restrict their speech to be understood by one of these systems. This problem appears for example when interacting with common telephonic voice recognition systems. We tend to express ourselves using monosyllables until we reach a human operator. This is coupled in many cases with the shame that people feel when talking to a machine out loud. We have added the multimodal interface to deal with these circumstances. The touch screen also includes contextual menus which provide the user with information about the discourse universe that can be recognized at the moment. Dialogue and discourse are managed using the chatbot RebecaAIML [16], which provides flexible dialogue and eases user interaction, requesting Sacarino's services (such as hotel information screen, taxi reservation or guiding through hotel spaces).

Regarding robot mobility, the robot may occasionally be unable to move due to the need of recharging its batteries. The limited autonomy of mobile robots is a recurring problem that cannot be solved by simply increasing the battery capacity (especially when robots must provide continuous service). The key idea is to take advantage of times when the robot is idle, for recharging the batteries. We have designed an automatic recharging system (Figure 6) that uses the IR sensor of the Nintendo Wiimote controller for accurate robot positioning in the vicinity of the charging station [9]. The charging station includes four LED emitters and a QR code (bidi). This allows the robot to identify and locate the station at a distance of 3 to 4 meters, and subsequently engage it in an accurate way. The system not only enables automatic recharge but avoids the degradation of the robot localization when operating for long periods of time. This degradation, common in navigation systems based on maps, has happened occasionally in the hotel, preventing the robot from reaching the correct destination. This situation has been mitigated by forcing the robot to couple with the charge station each time a tour is completed in order to reset the robot's position. This has been tested intensively in our laboratory, resulting in more than 100 successful couplings over 100 consecutive times (scheduled every half hour tour, for a week, 8 hours a day), and then in the hotel.

Fig. 6. Detail of Sacarino coupled to the charge station

7 Conclusions

This paper presents Sacarino, a service robot whose mission is to provide added value services in a hotel environment. The goal has been to completely design the robot, from the hardware to the application level, with the ultimate aim of assessing the potential of future technology transfer. At a hardware level, a specific control board has been set up for low-level control and perception. A hierarchical control structure has been developed to achieve an easy integration and maintenance. For example, Sacarino may be manually controlled (joystick) even when the high control system (the computer board) is unavailable. Furthermore, pose estimation based on dead reckoning is performed at a low level, thus releasing the high-level computer system for other activities. The use of the ROS framework has allowed us to generate a component-based scalable architecture and reuse modules already verified and widely used by the scientific community, such as localization [7], navigation and route planning [8].

The application layer should be given the greatest transcendence in a service robot. Robust robot planning and navigation algorithms are of low interest if adequate services have not been defined at the application level. However, it is necessary for this level to be supported by solid principles in the lower levels. A good application cannot be built onto a low-robustness or inefficient hardware architecture. At the application level, special attention must be paid to services that can be offered by the robot. This requires a correct definition of specifications in coordination with the hotel staff, always being aware of the current technological limitations.

Finally, intensive experimentation is needed, not only in the laboratory but also in the place where the robot has to operate. Continuous improvement based on continuous assessment is also required. This paper has made a first assessment of the opinions of guests. The future goal is to continue evaluating and improving the robot by incorporating a set of metrics [1] for the evaluation of navigation (distance traveled, localization faults, most requested destinations), interaction (recognition rates, most requested services) and maintenance (number of assistances, failure rate, etc.).

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