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Interactive Tele-Presence in Exhibitions through Web-operated Robots

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Abstract

The current paper presents techniques that facilitate mobile robots to be deployed as interactive agents in populated environments, such as museum exhibitions or trade shows. The mobile robots can be tele-operated over the Internet and this way provide remote access to distant users. Throughout this paper we describe several key techniques that have been developed in the context of relevant EU-IST projects. The developed robotic systems have been installed and extensively operated in the premises of various sites. The use of the above techniques, combined with appropriate authoring tools, has resulted in drastic reduction in the installation times. Such demonstrations ascertain the functionality and reliability of our methods and provide evidence regarding the effectiveness of the complete systems.

1 Introduction

Mobile robotics technology and its application in various sectors is currently an area of high interest. Research in this field promises advanced developments and novelties in many aspects. Applications of mobile robotics technology in public spaces can be found in a field that we informally term "robots in exhibitions". In this context, robots offer alternative ways for interactive tele-presence in exhibition spaces.

Two recent EU-IST funded projects, namely TOURBOT[1] and WebFAIR[2] address this goal. TOURBOT pursued the development of an interactive tour-guide robot able to provide individual access to museums' exhibits over the Internet. The results of TOURBOT were demonstrated through the installation and operation of the system in various organizations. WebFAIR is an ongoing project; it builds on TOURBOT results and attempts to extend relevant developments to the more demanding environments of trade shows. Additionally, WebFAIR introduces tele-conferencing between the remote user and on-site attendants and employs multiple robots, enabling simultaneous robot control by multiple users.

In this paper we present highlights of the techniques developed in the above mentioned projects. They cover various aspects of robots that are deployed in populated environments. Among them is a feature-based technique for mapping large environments, a method for tracking people with a moving mobile robot, and an approach to filter spurious measurements coming from persons moving in the environment while the robot is mapping it. Furthermore, we describe new aspects of user/robot interaction and user

[1]http://www.ics.forth.gr/tourbot
[2]http://www.ics.forth.gr/webfair

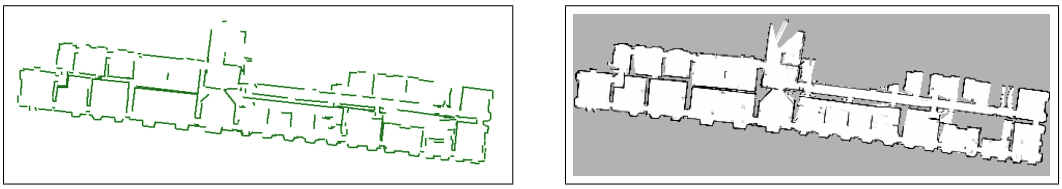

Figure 1: Line feature map (left) and occupancy grid map (right) of an exhibition site generated by the robot

interfaces. Among them are a speech interface for on-site users and a flexible web-interface with enhanced visualization capabilities for remote users. Additionally, we report on the demonstration events that took place in the framework of TOURBOT and argue on the drastic reduction of the system set-up time that was achieved.

2 Related Work

Over the last decade, a variety of service robots were developed, designed to operate in populated environments. Example cases are robots that are deployed in hospitals, museums, trade-fairs, office buildings and department stores. In addition, a variety of Web-based tele-operation interfaces for robots has been developed over the last years. Three of the earlier systems are the "Mercury Project", the "Telerobot on the Web", and the "Tele-Garden" [8, 9, 18]. These systems allow people to perform simple tasks with a robot arm via the Web. Since the manipulators operate in prepared workspaces without any unforeseen obstacles, all movement commands issued by a Web user can be carried out in a deterministic manner. Additionally, it suffices to provide still images from a camera mounted on the robot arm after a requested movement task has been completed. The mobile robotic platforms Xavier, Rhino and Minerva [17, 4, 19] can also be operated over the Web. Their interfaces rely on client-pull and server-push techniques to provide visual feedback of the robot's movements; this includes images taken by the robot as well as a java-animated map indicating the robot's current position. However, their interfaces do not include any techniques to monitor changes of the environment. 3D graphics visualizations for Internet-based robot control have already been suggested by Hirukawa et al. [12]. Their interface allows Web users to carry out manipulation tasks with a mobile robot, by controlling a 3D graphics simulation of the robot contained in the Web browser.

The TOURBOT and WebFAIR systems use video streams to convey observed information to the user. Additionally, they provide online visualizations of their actions in a virtual 3D environment. This allows the users to choose arbitrary viewpoints and leads to significant reductions of the required bandwidth.

3 Feature-based Mapping

In order to navigate safely and reliably, a robot must be able to find its position within its environment. For this purpose, the creation and maintenance of suitable representations of the environment is necessary. Two alternative mapping techniques have been developed, that produce feature maps and occupancy grid maps, respectively.

The feature-based mapping algorithm utilizes line segments and corner points which are extracted out of laser range measurements [3]. During mapping, the pose of the robot is estimated via a hybrid localization approach, namely a switching-state-space model [2]. At each (discrete) state, an Extended Kalman Filter (EKF) is used for accurate pose estimation.

To close loops during mapping, the algorithm interleaves localization and mapping just like other techniques which rely on the popular EM-algorithm [20]. During the E-step, our algorithm uses the EKF to provide a maximum a-posteriori estimate of the robot pose given all available measurements; in the M-step the mapped features are recalculated. The left image in Figure 1 shows a typical map of an exhibition site resulting from this process. During mapping the robot could successfully close several cycles.

To perform several navigation tasks, such as path planning and obstacle avoidance, the TOURBOT and WebFAIR robots employ occupancy grid maps [13] and apply the probabilistic algorithms described in [4]. The right image in Figure 1 shows a typical occupancy grid map that is learned from the same data and used for the navigation while the robot provides tour-guides.

4 People Tracking

Tour-guide robots operate, by definition, in populated environments. Knowledge of the position and the velocities of moving people can be utilized in various ways to improve the behavior of tour-guide robots, e.g. by enabling a robot to adapt its velocity to the speed of the people in the environment, by improving its collision avoidance behavior and by facilitating human-robot interaction.

The TOURBOT and WebFAIR systems apply probabilistic data association filters (SJPDAFs) [15] to estimate the positions of people in the vicinity of the robot. A set of particle filters [14] is employed to keep track of the individual persons. The particle filters are updated according to the sensory input, using a model of typical motions of persons. In the adopted approach, we compute a Bayesian estimate of the correspondence between features detected in the sensor data and the different objects to be tracked. The update phase uses this estimate to update the individual particle filters with the observed features.

5 Mapping in Dynamic Environments

Learning maps has received considerable attention over the last two decades. Although all approaches possess the ability to cope with a certain amount of noise in the sensor data, they assume that the environment is almost static during the mapping process. Especially in populated environments, additional noise is introduced to the sensor data which increases the risk of localization errors or failures during data association. Additionally, people in the vicinity of the robots may appear as objects in the resulting maps and therefore make the maps unusable for navigation tasks. Our mapping system is able to exploit the results of the people tracking process during the mapping procedure [11]. This has several advantages. First, by incorporating the results of the people tracker, the localization becomes more robust. Additionally, the resulting maps are more accurate, since measurements corrupted by moving people are filtered out. Figure 2 shows maps of the Byzantine and Christian Museum in Athens that were recorded with (left) and without (right) incorporating the results of the people-tracker into the mapping process. Both maps were actually generated using the same data set. While the robot was acquiring the data, up to 20 people were moving in this environment. The left image shows the endpoints of the laser-range data after localization. Obviously, a corresponding grid map would be useless, since it would contain many spurious objects that might have a negative effect on several standard navigation tasks such as localization and path planning. The right image of Figure 2 shows the map resulting from our approach. As it can be seen from the figure, our technique is able to eliminate almost all spurious objects so that the resulting map provides a better representation of the true state of the world.

6 The Web Interface

In addition to interacting with people in the exhibitions, a main goal in our projects is to establish tele-presence over the internet. Compared to interfaces of other systems such as Xavier, Rhino and Minerva [17, 5, 16], the web interface of the TOURBOT system provides enhanced functionality. Instead of image streams that are updated via server-push or client-pull technology, a commercial live streaming video and broadcast software [21] is used. This software provides continuous video transmission from the robot's cameras to the remote user.

Additionally, web-users have a more flexible control over the robot. They can control the robot exclusively for a fixed amount of time (typically 10 minutes per user). Whenever a user has control over the robot, he/she can direct it to either (a) arbitrary points in the exhibition or (b) particular exhibits in the exhibition. Furthermore, the user can select from a list of predefined guided tours. At each point in time, the user can request a high-resolution image. This way, the interface combines the properties of previous systems. In addition, the user can look towards arbitrary directions by controling the pan-tilt unit of the robot. Last but not least, the user can request the robot to autonomously move around an exhibit in order to view it from all possible directions.

7 Enhanced Visualizations

Since the robots operate also during opening hours, the robot has to react to the visitors in the museum. This makes it impossible to predict the robot's course of action beforehand. Therefore, it is highly important to visualize the environment of the robot and the moving people therein, so that the web user gets a better understanding of what is going on in the museum and why the robot is carrying out the current actions.

A typical way of providing information to the users is video streams, recorded with static or robot-mounted cameras. This, however, has the disadvan-

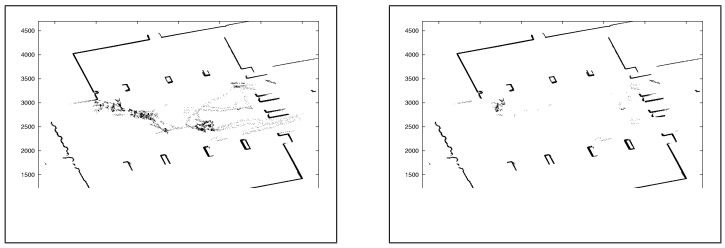

Figure 2: Maps of the Byzantine and Christian Museum in Athens created without (left) and with (right) people filtering.

Figure 3: The enhanced 3D visualization allows arbitrary view-points. The left sequence shows the real and the virtual view through the robot's cameras. The right images show the robot guiding three people through the museum and a bird's eye view of the scene.

tage of limited perspectives and high bandwidth requirements. For these reasons, we developed a control interface, which additionally provides the user with a virtual reality visualization of the environment including the robot and the people in its vicinity. Based on the state information received from the robot and our tracking algorithm, our control interface continously updates the visualization. Depending on the level of detail of the virtual reality models used, the Internet user can obtain visualizations whose quality is comparable to video streams. For example, Figure 3 shows two sequences of visualizations provided during the installation of the system in the Deutsches Museum Bonn in November 2001 along with images recorded with a video camera and with the robot's on-board camera. Within the graphics visualization, people are shown as avatars. As can be seen, the visualization is almost photo-realistic and the animated avatars capture the behavior of the people in the scene quite well.

8 System Demonstration

In the framework of the TOURBOT project a number of demonstration trials was undertaken in the premises of the participating museums. These demonstrations were combined with relevant events in order to publicize and disseminate the results of the project to professionals and the broader public. Factual information of these events is as follows:

- Foundation of the Hellenic World, Athens, Greece, May 28–June 2, 2001 (see Figure 4(a)). Exhibition: "Crossia, Chitones, Doulamades, Velades - 4000 Years of Hellenic Costume." The exhibition area comprised 2000 square meters. During the trial the robot operated approximately 60 hours covering a distance of 14 kilometers. More than 1200 web users observed the exhibition through TOURBOT.

- Deutsches Museum Bonn, Bonn, Germany, November 6–11, 2001 (see Figure 4(b)). Exhibition: "Part of the permanent exhibition, highlighting scientific achievements that were awarded the Nobel Prize." The exhibition area in which the robot moved comprised about 200 square meters. The system operated about 60 hours, covering a distance of 10 km. Approximately 1900 web visitors had a look around the

(a) (b) (c) (d)

Figure 4: Snapshots of robots operating in various museums and fares. (a) Robot Lefkos operating in the exhibition of the Foundation of the Hellenic World. (b) Robot Rhino operating in the Deutsches Museum Bonn. (c) Robot Lefkos operating in the Byzantine and Christian Museum. (d) Robot Albert interacting with a person at the Heinz Nixdorf MuseumsForum (this picture is curtesy of Jan Braun, Heinz Nixdorf MuseumsForum).

museum via the robot.

- Byzantine and Christian Museum, Athens, Greece, December 3–7, 2001 (see Figure 4(c)). Exhibition: "Byzantium through the eyes of a robot." The exhibition area comprised about 330 square meters. During the trial the robot operated 40 hours, covering a distance of 5.3 kilometers. Given the large number of on site visitors, the TOURBOT team decided to devote more tour-guide time to the on-site visitors as opposed to web visitors.

Additionally, TOURBOT was installed and operated for a longer period of time (Oct. 2001–Feb. 2002) at the Heinz Nixdorf MuseumsForum (HNF) in Paderborn, Germany (see Figure 4(d)). This was in the framework of the special exhibition at HNF "Computer.Gehirn" (Computer.Brain) with a focus on the comparison of the capabilities of computers/robots and human beings. Recently (June 2002), TOURBOT was introduced for one week in the Museum of Natural History of the University of Crete, Heraklion, Greece.

8.1 Installation Time

The large number of test installations ofthe TOURBOT system required sophisticated tools for the setup of the overall system. Obviously, the most crucial part is the generation of the navigation map. However, based on the techniques described above, the overall mapping process could in all cases be accomplished within several hours. To avoid that the robot leaves its desired operational space or collides with obstacles that cannot be sensed, we manually create a second map with artificial obstacles. These artificial obstacles are fed into the collision avoidance module [4] and thus prevent the robot from moving into the corresponding areas.

A further time consuming process is the generation of the multimedia-content that is presented to the user for each exhibit. The TOURBOT system includes a generic Multimedia database including html-pages, images, audio, and video sequences. Material in the database can be changed and/or edited using available software tools. Furthermore, the robot is equipped with a task specification that defines where the designated exhibits are and which content has to be presented.

Most of the multimedia information pertinent to the exhibits can be obtained directly from the exhibition sites, since pictures, text and other relevant material are often already contained in existing Web presentations. The whole setup can therefore be accomplished in less than two days. This is an enormous speed-up compared to previous tour-guide systems. More specifically, while Rhino and Minerva set-up times were 100 and 30 days respectively, the set-up of TOURBOT required only 1.5 days.

9 Conclusions

The goals set for by the TOURBOT and WebFAIR projects are in-line with on-going activities towards the development of fully autonomous robots that operate in populated environments. The mentioned projects aim at the development of interactive tour-guide robots, able to serve web- as well as on-site visitors. Technical developments in these projects have resulted in robust and reliable systems that have been demonstrated and validated in real-world conditions. Equally important, the system set-up time has been drastically reduced, facilitating its porting in new

environments. Current research extends the navigation capabilities of the robotic systems by addressing obstacle avoidance in the cases of objects that are not visible by the laser scanner [1], 3D mapping [10], mapping in dynamic environments [11], predictive navigation [6], and multi-robot coordination [7].

Moreover, in the context of the above projects additional issues are addressed that consider (a) how to adapt this technology in order to fit the long-term operational needs of an exhibition site, (b) how to evaluate the robotic system in terms of its impact to the main function and objectives of the exhibition site (financial impact, accessibility, marketing and promotion, impact on visitor demographic, etc.), and (c) how to evaluate the content and educational added value to museum and exhibition visitors, and generate a feedback to the technology developers in order to improve in the future the robotic avatars and adapt further to the needs of the users.

Acknowledgments

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