An Autonomous Tour-Guide Robot for Public Places

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Abstract: - In this paper, we present our recent experiences with QuiXote, a mobile robot for guided tours inside public buildings. The most relevant results obtained during last year are presented, underlying learned lessons during experimentation. The purpose of the work presented here is to deploy a feasible autonomous robot for tour guiding, interacting directly or remotely with visiting people.

Key-Words: - Mobile robotics, visual localization, human-robot interfaces.

1 Introduction

Mobile platforms had been used since years as a suitable test bed to experiment with complex autonomous systems [6, 9]. Our main interest is focused on using a mobile robot, called QuiXote, as a challenging application of sensors fusion, advanced control and other mechatronics related issues. Among the main challenging aspects of our research we remark:

(1) Navigation in dynamic environments. Exhibits displayed inside public places like museums are highly dynamic indoors environments. In such environments would be possible that people wandering around behave in unforeseen ways, for example, blocking the robot's paths. Under such conditions localization could be achieved by active beacons, landmarks recognition, etc. With QuiXote is being tested a new approach based on artificial landmarks recognition. That innovative algorithm obtains the tridimensional location of the robot from the information encoded on visual colored patterns [2].

(2) Service robots with long duty cycles request a high level of autonomy. Such autonomy only could be attained with robust control systems and batteries with a longer life. Focusing on the aspects of autonomy related with the power supplies, our work is addressing to equip the robot with auxiliary devices for autonomous self recharge. Rather than use specific adapted docking stations for battery charge like other robots do, we face the challenge of docking at the regular power outlets existing all around inside a building.

(3) Human-Robot interaction [1, 3, 11]. That is specially interesting in an scenario where even remote communications empower new capabilities of interaction. In our work we proposed different ways to achieve the interaction between humans and the robot.

- *Gestures* of the robot's body and face can express internal states of the robot and its 'motivations'.
- *Natural speech* for voice control of robots is an appealing capability in applications where physically handicapped people need to be assisted by the robots.
- *Web Graphical User Interfaces* also makes feasible the telepresence for people at remote locations from where exhibitions are being played and guided by the real robot.

Although this paper does not describe aspects such as, software architectures, path planning and tasks planning, they are truly crucial ingredients on autonomous robots and they have to be taken on consideration [6, 9].

1.1. Related works

QuiXote has a set of remarkable predecessors in Rhino, Minerva [3, 11] and Sage [10]. They all had been developed in the field of mobile robotics with astonishing demonstrations, respectively at the Deutsches Museum (Bonn, Germany), the Smithsonian National Museum of American History (Washington, USA), and the Carnegie Museum of Natural History (Pittsburgh, USA).

The internal representation of the world for all of those three robots are build using *occupancy grids* [4] where errors derived from odometry have to be removed. In that context the main issues developed were the navigational related problems, where it should be remarked the *localization problem*. That is, to know instantaneously the robot's coordinates (x, y, θ). Rhino and Minerva solve the localization problem by a modified version of Markov [5, 7, 12]

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localization method using a bayesian approach to integrate sensors reading along time. In this approach the robot's location is obtained as the place where a probability density function is maximized. The proposed strategy displays a good accuracy and robustness, suffering from being computationally expensive and requiring filtering of the sensors readings derived from dynamic obstacles like humans.
Rhino and Minerva were equipped with onboard computers and auxiliary off-board workstations to alleviate computational loads. Rather than to pursue an accurate localization inside a building, Sage uses visual recognition of a geometrical pattern located on walls beyond people reach [10]. With such strategy Sage was able to approximately recognize its location inside the museum. The main limitation of Sage derives from the peculiar environment where it was running into, because it moves along corridors seen as highways with safe widths.

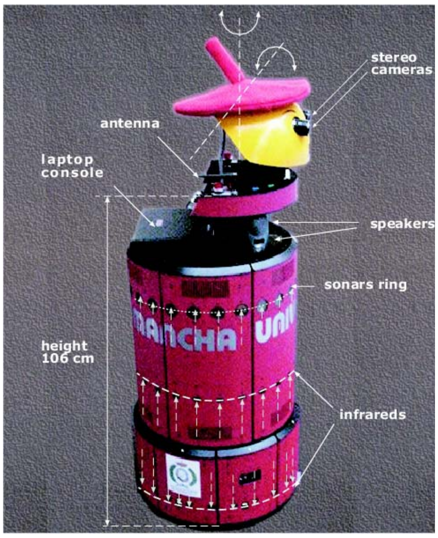

Fig. 1: QuiXote.

In the previous works autonomous self recharge only had been addressed by Sage. It detects a low charge state for immediately go to a docking station where it can plug up an electrical terminal into an ‘adapted’ power outlet. The docking task is controlled by visual alignment with an auxiliary external mark. In this case the outlet ‘adaptation’ consist on the AC/DC adaptor needed to connect the batteries.
In those depicted cases, at the museums, the interaction between humans and robots is reached by physical touch from human to robot's interfaces (buttons and touch screens). All of them have the ability to emit sound as a way to make people figure out what is going on. Those robots have an straightforward model for ‘mood’ states, that guarantees a kind of realistic *‘situated robot’*. In addition, Rhino and Minerva had web interfaces that allow limited interactivity through Internet [11].

1.2. Quick overview of the mobile platform

QuiXote consists in a B21 mobile platform by RWI (now integrated at irobot Corporation) equiped with the systems listed below.
■ *Sensors:* 48 sonars, 24 infrared and 56 tactile.
■ *Onboard controllers*: two PCs running Linux OS and the main control software architecture called Beesoft.
■ *Motors:* a four wheel synchronous drive able to provide a max. speed of 90 cm/s (translational) and 167 deg/s (rotational).
■ *Communications:* a wireless RF Ethernet bridge.
■ *Power supply:* four batteries of lead acid and 1440 W-hr.
■ *Accessories:* a pan-tilt turret with an stereo vision system.
This basic platform has been retrofitted with several auxiliary systems: a laptop computer with attached microphones, and speakers for running voice commands recognition and voice synthesis software. Also we build a face for increasing the robot expressivity and friendliness by gestures. Fig. 1 shows the main systems and physical features of QuiXote. Beesoft provides a basic architecture to integrate software modules into the robot's global control. The architecture consists on a decentralized set of servers and clients running under an Unix-like OS communicating each to other by TCX, a socket's based protocol [12].
Next sections describe our implementation for a first version of a tour guiding robot inside public buildings.

2 Visual localization

Due to nature of the environment where QuiXote must operate, the initial internal representation of the world is based on the architectural plans of the buildings. This is an available a priori well structured information, and an easily way of representation. With that supplied information the robot knows the relative dimensions of rooms, halls and corridors inside the building and that information is sufficient for global path planning. For local navigation and collision avoidance, QuiXote builds a non-persistent representation of the immediate surrounding world called the *local map*. That map use an approach based on *occupancy grids* with a probabilistic fusion strategy [4, 7]. Unlike mapping, where little new contributions we had done so far, QuiXote's localization is reached by a novel visual recognition method [2].

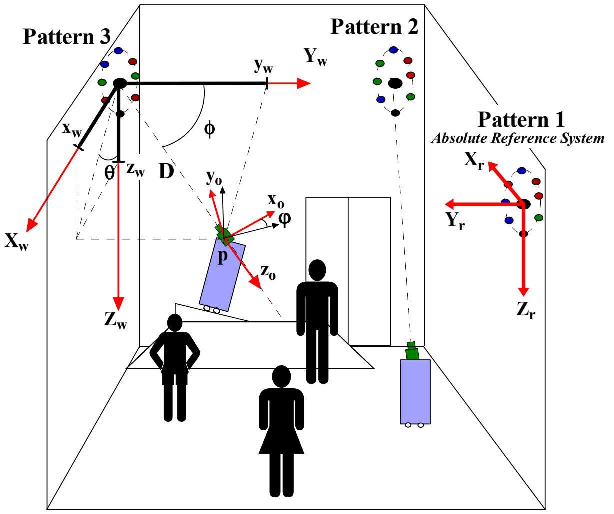

Fig. 2: Visual localization: Pattern and Ref. sytems.

A PZT camera is set up on the robot for grabbing images from artificial patterns located at known places inside the building. The proposed pattern consists on nine circles arranged in a circumference in such a way that eight of them are at the perimeter and the ninth at the center. The main information provided by the localization algorithm is:

A.- Robot's local coordinates inside a room.

B.- Room identification inside the building where the robot is located.

For getting an identification for the rooms, the customized pattern is composed by a fixed sequence of color, among four possible colors (red, green, blue, and black). That encodes floor, room and pattern. The floor id. is encoded by the central point and the eighth circle of the pattern what gives us until 12 possible floors. That is quite enough for the purposes of this particular application. Rooms in a floor must be determined by the encoded id. on second, third, fourth and fifth circles of the pattern, what provides until 81 possible codes for rooms at each floor. Finally the code formed by the sixth and seventh circles are used to make location easier because a room may have several patterns.

The experiments offered a pretty good performance getting a typical error for angles smaller than 1% and less than 2% for cartesian coordinates. In addition, the final results show the little effect of lens distortions [2].

Summarizing, the localization method employed offers a new strategy for a quite cheap real-time computation of local 3D cartesian coordinates of mobile robots. Furthermore, the method provides a global positioning information inside a public building composed by floor-room ids. where the robot is guiding a tour.

3 Autonomous self recharge

One of the most challenging problems to deal with on autonomous robotics is power consumption. That is, how to keep running the robots as much as possible without any human technical assistance. That means a reduced duty cycle for the robots at indoors applications, limited by the lifetime of power batteries. On QuiXote the self recharge problem is being carried out with the following strategy. Self recharge should be done by an autonomous task for docking an onboard electrical terminal into a regular, without any external adaptor, power outlet. The main benefit from that approach is the high availability of unmodified power outlets inside the buildings. Several hardware systems are required to achieve our purpose:

- *An small AC/DC adaptor*. This adaptor must supply the DC current for recharging the four lead acid batteries of the robot. The main constraints for that system are the maximum size and weight because it has to be located inside the robots' enclosure.
- *An auxiliary docking manipulator*. This manipulator will carry out the electrical terminal to be plugged into the power outlet located on the wall. Like the previous system, that one has severe constraints about its size and weight.
- *A sensorial system for feedback to the controller of docking tasks*. The sensorial systems provided by the manufacturer into the mobile platform are directed to feedback of motion controllers and navigation tasks, thus, it makes necessary to retrofit the robot with an specific sensor for the autonomous self recharge task.

So far, the first prototype for the electrical adaptor had been implemented. It consists on a DC/DC converter where a non regulated DC voltage is transformed in a regulated DC voltage well suited to the required recharge cycle. That converter uses a half-bridge galvanically isolated configuration obtained with a very reduced set of components compared with other topologies [9]. The efficiency reached with this first prototype is established around 85 % with a supplied power of 300W and current of 6A.

4 Human-Robot interfaces

One of the most interesting capabilities for a tour-guiding robot must be the interactive component provided by the human-robot interfaces. Interaction allows humans, with no skills on robotics, be able of

friendly interplay with complex robots and be interested on them [1]. Furthermore, at the context presented here, interfaces allow unusual interaction in such a way that handicapped people are able to experiment with robots. Moreover, Internet provides links between remote places around the world.
To obtain a rich and friendly human-robot interaction, the robots should synthesize an 'artificial' understandable behavior by humans. That understanding only can be reached when a natural synchronization exists between internal states and external actions displayed to the interlocutor. In the next sections we describe several types of interaction implemented on QuiXote.

Fig 3: Running at the exhibit. QuiXote's face.

4.1. Gestures

Visual perception is one of the richest and primary class for interaction, thus the first human-robot interface implemented on QuiXote was a friendly face. This face was made with a yellow plastic cap covering the pan-tilt turret which provides motion in two axes (pan and tilt rotations). The stereo vision system plays the role of 'eyes' and we built a 'mouth' with an array of leds synchronized with a sound card (see Fig. 3).
The robot's face can show agreement or disagreement by simple motions, moreover the face is able to follow robot's actions driving public attention to specific points of interest. Some interesting experiments had been directed to track, by the face, very close non static obstacles located in front of the robot . With such a tracking behavior, implemented using a subset of filtered sonars readings, the robot displayed a quite natural 'pay attention' behavior.

4.2 Speech

Interaction in QuiXote is obtained through speech generated with a commercially available TTS engine. In particular we used the IBM Viavoice software and its SDKs for TTS and dictation recognition. Using a TTS interface to generate voice allows us easily to increase the list of speeches, and even to adapt additional software to automatic generation of sentences, in the manner of Eliza. Furthermore with this strategy it is possible to deliver the robot's explanations through web sessions with a truly small overload. In addition the speech synthesis by the mentioned TTS software does not require an specific hardware but a conventional sound card installed onboard. With a microphone attached to it, the same hardware also suffices for sound acquisition.

Fig. 4 : Web GUI.

The interfaces created for voice interaction are based on the three following modules:
(1) *Speech server*: It is waiting for requests from other user modules (clients). Each request includes a message to be processed by the TTS engine.
(2) *Commands parser*: It is a module that listen to an speaker understanding a selected set of voice commands. In our first implementation we include motion commands for the body and face of the robot (e.g. *"go two meters left!"*, *"turn right!"*, etc.).
(3) *Mood daemon*: Timely, this module delivers sentences expressing the robot's 'mood'. The first implementation for this module is considering a few mood states (*lonely* -without any task to do-, *busy* -trying to accomplish a task-, *happy* -success achieving an objective- and *frustrated* -fails to completing a task-).

4.3. Remote telepresence

Internet and the World Wide Web are quite well suited to provide a remote access to multiple resources across the world. Somehow the web can allow to remote people follow tours in public buildings. At this context, telepresence assumes visual and perhaps audio feedback from the remote environment to the local user.
A quite modest Web Graphical User Interface (GUI) had been developed in the earliest stages of the

QuiXote project. It consists on a web page (http://fuenllana.ind-cr.uclm.es/Quixote) with a brief explanation about QuiXote and an opportunely refreshed image grabbed from the robot's cameras (see Fig. 4). Due to the web latencies the interface have a console mode which is able to gain direct control over the robot and the motions of the pan-tilt turret. In this console the refreshing period for images is shorter than the images embedded directly onto the web browser.

5 Experiments and learned lessons

The practical demonstration of the work done with QuiXote has been tested inside the building where the ISA group has its laboratories. In that building QuiXote ran along corridors and halls populated with students, teachers, etc. That environment shares some similarities with a museum, however there are also many differences: e.g. number of people around, points of interest, etc. Although it could be possible to adapt that environment to resemble a museum, it was really welcomed the opportunity for a public presentation at the II Salon of Innovation celebrated at Ciudad Real (Spain) during November 2001. During that event (three days) QuiXote was tested in a truly similar environment to the final implementation. Nevertheless, it is planned to initiate shortly a bunch of experiments into The Science Museum of Castilla-La Mancha (Cuenca, Spain).

During the two years of developments with our robot we were encouraged by the learned lessons. Next paragraphs summarize the main learned lessons to be outlined:

I. You need as many skilled hands on as you can afford. During fourteen months the number of persons directly involved was of three. That stage of the process was devoted for tuning the hardware and software systems delivered by the manufacturer with the platform. Here are listed some of the tough obstacles we found: the insufficient documentation supplied, faulty devices (e.g. the network wireless bridge and the batteries charger, etc.). The second stage of the project was accomplished with a number of six new more persons on a full-time dedication for six months. Even with such a number of people working on the project onto diverse fields of expertise, it had been verified how much effort has to be derived to the tasks of maintenance and technical support.

II. Most of times severe faults are due to unreliable hardware and its drivers. Robustness is a key point to deliver truly autonomous robots and we found that faulty hardware (like for example the access.bus) was a persistent source of technical halts.

III. Relying on odometry as little as possible for navigation. In our experiments the errors from encoders are rapidly increasing and that information is used only for rough localization.

IV. Redundancy on perception is translated to reliability in action. QuiXote uses sonars as the principal source of information for safe navigation. However, incorrect or incomplete readings could lead to improper actions. That happens in front of obstacles with a very smooth surface and some 'invisible' furnitures (without reflective surfaces for the robot's sonars).

5.1. Comparison with previous works

QuiXote is a project with a clear inspiration on the precursor works done by two groups at Carnegie Mellon University on mobile robotics, thus we use the same model (B21) as mobile platform. QuiXote share the same software architecture than Rhino and Minerva and the differences can be appreciate on how modules are implemented. In QuiXote localization is being addressed from a different perspective, rather than use a probabilistic model, our robot recognizes artificial visual landmarks in the world obtaining 3D information.

Autonomous self recharge is a key objective working on QuiXote. The solution of that challenging problem requires to blend knowledge from manipulators' control theory, electrical engineering, etc. In previous works, autonomous self recharge had been addressed from an obvious approach. That is, to adapt the electrical terminals to the docking task. Unlike, we are trying a more ambitious strategy adapting the docking task to the standards electrical terminals, which is quite challenging. A significant benefit of that implementation should be derived from the high availability everywhere inside buildings of power outlets.

With QuiXote we also wish to remark the importance of human-robot interfaces. To accomplish that aspect, we tried a flexible use of speech synthesis for explanations and speech recognition for voice commands.

5.2. Next steps

The initial project on QuiXote finished last December, however there are many paths to follow from the obtained results. Below it is enumerated the main lines of action for our group directed to increase the robot's capabilities and its final deployment at a public museum.

(a) Autonomous self recharge. Actually, at this moment, an auxiliary manipulator for docking tasks and a sensor for alignment is being developed.
(b) Localization. We must complete tests for our visual 3D localization method. Furthermore, optional methods based on topological representations should be tested for comparison purposes. Also a supplementary sensor systems are going to be installed into the robot like a laser rangefinder and a non-magnetic compass.
(c) Human-Robot interfaces. Where visual and audio feedback should be done faster enough to be realistic. In addition, more expressivity had to be include on the robot's face.
(d) Software architectures and control algorithms. With the available 'ready-to-run' platform we could do interesting work on new control architectures where robustness, expandability, learning and planning should be the provided main capabilities.

6 Summary

In this paper a mobile robot called QuiXote for tour-guiding at public places has been presented. The main objective of that work is to provide additional capabilities to a commercial mobile platform doing it capable for autonomous navigation and interaction with people during a guided visit to public exhibits. The most challenging aspects for that task are the intrinsic dynamics of an environment usually crowdy, even 'hostile' at times. This kind of applications has a very few precedents around the world and the similarities and differences with our work had been outlined.

The remarkable aspects of QuiXote are:

■ Localization 3D by visual recognition of colored patterns with encoded positioning information.

■ Autonomous self recharge through a controlled 'docking' task to regular power outlets.

■ Human-Robot interfaces to guarantee a rich, friendly and natural interaction between the machine and robotics-non-skilled humans. A first interface allows local and remote interaction by transmitting audiovisual information through a web GUI. Finally, a second one consisting in a friendly mobile face mounted on the robot provides the robot with capabilities for direct interaction with people.

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