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EXPERIENCES WITH A REMOTE LABORATORY IN A ROBOTICS AND COMPUTER VISION SUBJECT

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Abstract

This paper presents the experiences with a remote laboratory we have implemented to carry out training with mobile robots. These practices are developed in the fourth year of the studies of Industrial Engineering, in the Miguel Hernandez University, within an optional subject which is structured around two main fields: robotics and computer vision. The main goals of the subject are to analyse the kinematics and dynamics of serial manipulators and mobile robots, and to study several techniques to extract the most relevant information from the images. To deepen in these objectives, several practical sessions have been scheduled with the aim the student improves his knowledge of these fields and the relationship between them, in an applied way, using real robots and computer vision systems. The students can carry out these practical sessions using a remote laboratory that allows programming the robots in an intuitive way and the monitoring of the implemented task. This system empowers the autonomy of the student and constitutes a powerful tool in the adaptation of the studies to the European Space for Higher Education.

Keywords
Remote laboratory, Mobile robots, Distributed platform, Computer vision, European Space for Higher Education.

1. INTRODUCTION

In engineering education, it is essential to provide the necessary resources that allow the student putting into practice all the knowledge he acquires during the theoretical study of the different subjects. As an example, in a robotics and computer vision subject, is it desirable the student can test the algorithms he learns over real robots and computer vision systems.

Traditionally, these practical sessions have taken place in the robotics laboratory, where the teacher exposes the principles of the robots used and the objectives of the sessions and then, the students have to create their own algorithms to extract the necessary information from the images and control the robot using this visual information. However, this situation presents several disadvantages. The number of robots is limited, so the students have to work in group and sometimes, some students do never train with the robot directly. Also, it requires the presence of the students and lecturers in an established timetable, and the time to carry out the sessions is limited so, some groups may not be able to reach the objectives of the session in the expected time. Also, most of the problems that arise during the development of the training are not related with the contents of the subject but with the functioning of the robots (software architecture, problems with the hardware, implementation details, libraries…).

To avoid some of these problems, different universities have developed, during the last years, some kinds of remote laboratories. They provide a distributed environment that permits the students to access in a remote way through Internet to the equipments available in the laboratory. Thanks to them, the student can access to real equipment, from his house, and with a very flexible timetable. In this sense, students are highly motivated to make use of and benefit from the resources available in remote environments through Internet [1].

Also, we must take into account the fact that the higher education is now under a process of change in Spain with the adaptation to the European Space for Higher Education. The new system is expected to be centred in the learning of the student, trying to foster his autonomy and reducing the time the teacher uses to present the theoretical concepts at the lecture rooms. This is expected to be a less rigid system with regards to the lectures and timetables. Remote laboratories are definitely going to help to the establishment of this new system in the technical studies.

The present work presents the use of a remote laboratory we have implemented in a subject of robotics and computer vision. With this laboratory, the students can build their control algorithms and test them in a real working environment. Several previous works haves shown the power of Internet applied to the field of control systems education, as [2] or [3] show. In the area of robotics, we find several works that present different ways to operate robots in a remote environment. Candelas et al. [4] present a virtual laboratory to carry out robotics practical lessons. This platform is capable to simulate a robot arm and also, students can teleoperate the equivalent real robot. The work in [5] presents a remote laboratory that allows controlling a Lego mobile robot through a web browser. The student can make the design of several kinds of controllers using the MATLAB/Simulink environment. The objective is to carry out a path planning and to test them on a real robot. Khamis et al. have developed the 'Developer' architecture to teleoperate and control the B21r robot [6]. [7] presents an interactive tool for mobile robot motion planning to enhance full understanding of the students. At last [8] presents a platform for the monitorization and control of a team of heterogeneous robots and [9] presents an application of this platform in the field of behaviour-based multi-robot formations using computer vision.

The platform we have built permits the access to the robots available in the laboratory, in a transparent way for the user, in a free timetable and with no limitations of time. The students can access the platform from any computer through Internet, independently of their operative system and with a very simple installation. There is a common graphical interface to access all the robots, and the students can monitor and control the robots in an intuitive way, without needing a deep knowledge of the architecture of the robot they are using. This way, the training is centred in the objectives of the subject, and the students take more profit of the educative process. Also, the students are provided with some templates to develop their algorithms and many examples of use.

The remainder of the paper is structured as follows. Section 2 presents the components and the architecture of the platform. Then, in section 3, the use of the tool is exposed. After that, the practical sessions the students have to solve and some typical results are shown on section 4. To end, the conclusions of the experience are presented.

2. ARCHITECTURE OF THE SYSTEM

The main features of the platform we have developed are the following ones:

- It permits monitoring and controlling a team of mobile robots through Internet.
- The monitoring and control is carried out through a common, friendly and interactive graphical interface. Using it, the students can interact with the mobile robots in a transparent way, independently of their internal architecture.
- We have implemented several libraries so that the students can develop the control program using a high-level language, without necessity of a deep knowledge of the internal architecture of the robot used.
- Independence of the operative system and minimum installation in the students' computers.

With these goals we have designed a communication protocol between the different members of the system using CORBA (Control Object Request Broker Architecture) as a reference model. The robustness and efficiency of this standard for the implementation of distributed applications has been demonstrated in previous works [8], [9]. The platform is composed by three different working environments that allow the simultaneous access of three students to carry out the practices. Each working environment is composed by a WifiBot robot that has a wireless connection to the access point, and an Axis 207W camera, placed in the ceiling, that provides us with a view of the working environment. Each WifiBot robot carries a colour camera on its top, two infrared sensors to measure the distance to the obstacles and the walls, an odometer system and four independent motors (one per wheel). The structure of each environment is shown on fig. 1.

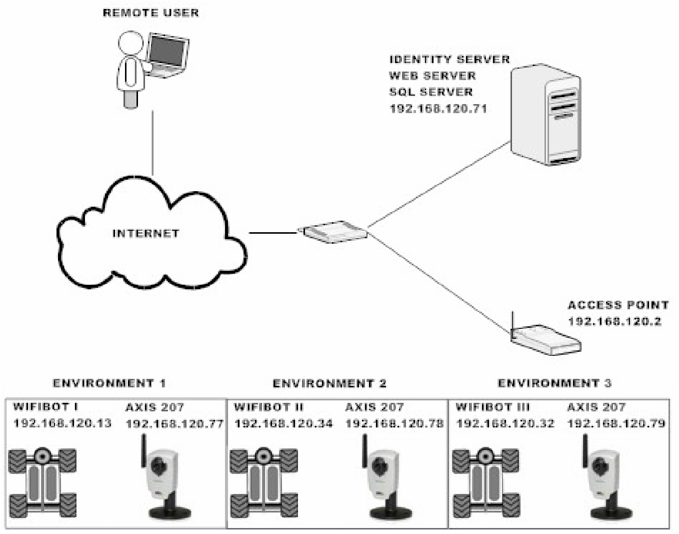


Fig. 1. Working environments that the students can access in a remote way.

The basic components of the platform are:

- **Onboard Servers**. Each robot carries a PC onboard where the necessary servers to access to the sensors and actuators of the robot run (video cameras, infrared sensors, odometer, motors, etc.). Thanks to them, the student can program basic movement actions, read the infrared sensors and the odometer of the robot and obtain snapshots from the camera each robot has on its top and from the ceiling camera. With the images from this camera, this interface also provides us with information of the position and orientation of the robot in the environment thanks to the artificial mark each robot carries on its top.

- **Identity Server**. This server has two main functions. The first one consists in keeping a list of all the robots and the cameras of the environment that are active at each moment in the system. The second function is to carry out an access control from the client applications to the robots.

- **Client Application**. It can run on any computer, independently of its architecture and operative system. This application permits the access to the robot environments to carry out the practical, independently of the location it runs from. The student can access from the computers in the laboratory, but also from any computer that has Internet access. The implementation of the client application has been carried out through Java Web Start. With this technology, it is possible to start desktop Java applications that reside in a web server, checking first if the version of the application the client has installed is the latest one. If not, it downloads the new version and the application will run in local mode. The starting of such applications can be carried out from a web page or through a link in the client desktop. Thanks to this technology, we can be sure that an application is always distributed with its most up to date version.

3. USE OF THE PLATFORM

Fig. 2 shows the appearance of the client application. From the main window of this application, the student can continuously see the images that both the camera of the ceiling and the camera of the robot capture. Both video panels have a button associated so that the student can capture and save some snapshots during the development of the task in JPEG format.

This window also shows the advance and the steering speeds of the robot. In addition, using the arrow buttons, the student can operate the robot with basic movements. Using the top menus, the user can decide which data he wants to save while the application is running and the name of the files to save these data.

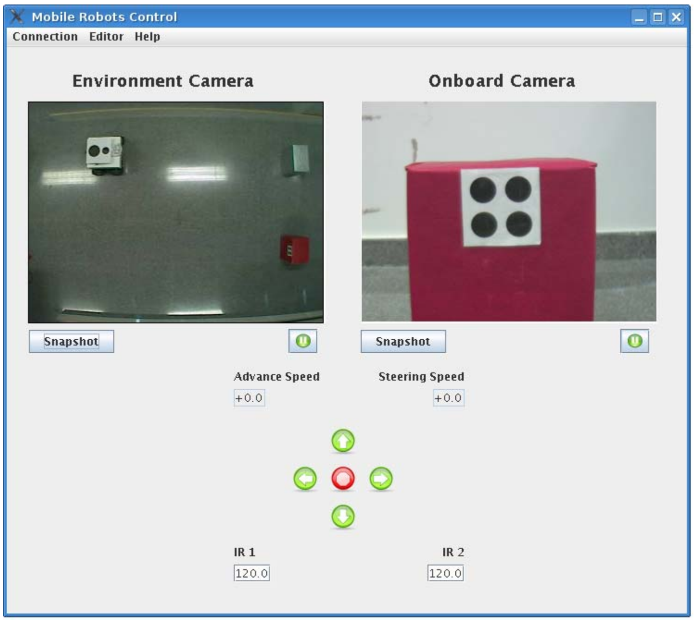


Fig. 2. Appearance of the graphical interface of the client application.

The first step when the student runs this application consists in getting a working environment (if any available). This option is accessible from the menu *Connection* that will show the next window:

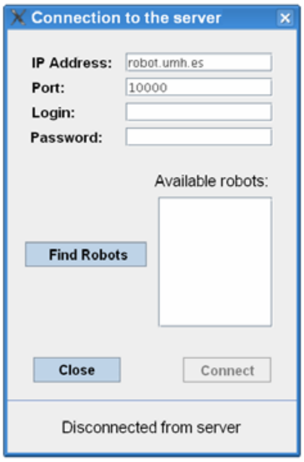


Fig. 3. *Connection* window.

Each student is assigned a login and password to access the system. If these data are correct, when clicking on the button *Find Robots*, the system looks for any available environment and if any existing, the robots are shown in the *Available Robots* textbox. The student will select one of them, and, after clicking *Connect*, he will access the basics navigation window (fig. 3).

When a student accesses one working environment to carry out the practices, he has the exclusive rights to operate with the robot. None of the other students can access this environment until the current user leaves it. Besides, to avoid that only a student can monopolize the environment during a long period of time, a reservation system has been established. Through it, each student can make a reservation during a time slot in a timetable (the maximum period of time is limited to one hour in the current implementation). During this time slot, only the student who has made the reservation can access the working environment. Taking into account the fact that, in this moment, there are three independent environments available, three different students can access the system simultaneously to test their algorithms.

During the practical sessions, the student has to improve his knowledge of the kinematics of the mobile robots and to study several techniques to extract the most relevant information from the images. To do it, the student has to write the necessary program (using a high-level programming language) to control the movements of the robot, depending on the reading of the sensors and the information from the images. Once the program is created, it has to be sent to the robot, compiled and run.

To start this process, the student has to access to the *Editor* window (accessible from the *Editor* menu in the main window), shown on fig. 4, where the student can write, send and compile the program. This compilation is carried out in the server. If the compilation fails, the errors or warnings are shown on the bottom text box of the *Editor* window.

The advantage of this method is that the student does not need to install any library in his computer. However, the depuration of the possible errors during the compilation of the source code becomes a slow process, because the source code must be sent several times until all the possible errors have been corrected

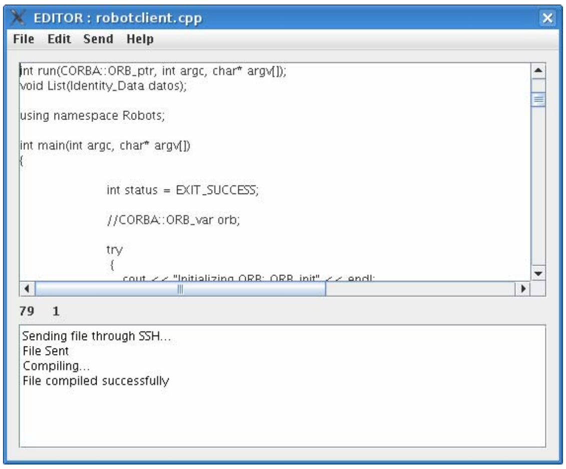


Fig. 4. Appearance of the *Editor* window. The student can edit the program and the text box at the bottom shows the status of the process.

Fig. 5. *Save Data* menu. Before starting the task, the student can select the kind of data he wants to be saved once the program finishes running.

Before running the task, using the *Send* menu of the *Editor* window, the student can select the data that he wants to be recorded and stored in some text files while the robot is running the control algorithm. This way, he will be able to plot these data on some charts to study the development of the task.

To prevent a dangerous use of the tool, a database registers all the actions the users have carried out in the system, from the verification of the student until he leaves the system and the environment is released. Also, a prevention mechanism has been implemented to avoid malfunction and damages on the robots. An independent thread always runs concurrently with the student's algorithm, and it is in charge of monitoring the advance and steering speeds of the robot and the infrared sensors. In case any speed is over a threshold or the robot is near an obstacle, this thread can stop the robot and reinitialize the algorithm.

4. PRACTICAL SESSIONS PROPOSED

4.1. Basic control of the robot.

The student must create a program so that the robot moves forward, describing a straight line. The robot must avoid the obstacles it finds in its way, and it must stop when it has travelled a distance of three meters. The student has to make use of the next sensors to solve the problem:

- Infrared sensors to detect the presence of an obstacle.
- Odometer data to compute the position of the robot and the distance it has travelled.
- Images captured by the ceiling camera to know the position of the robot at each moment and compare it with the results computed using the odometer data.

In general, the robot has to move straight, and it has to describe a 90º arc when it fins an obstacle. The robot must turn to the side where the obstacle is farthest from, and it must stop when the distance it has travelled is higher than three meters. To compute this distance, the student has to make use of a function that integrates the odometer data and that returns the coordinates of the robot with respect to the initial position.

The problem must be solved using a competitive coordination of two behaviours, 'Go straight' and 'Turn'. The students are advised to design a flow chart of the task before writing the program, as the one shown on fig. 6.

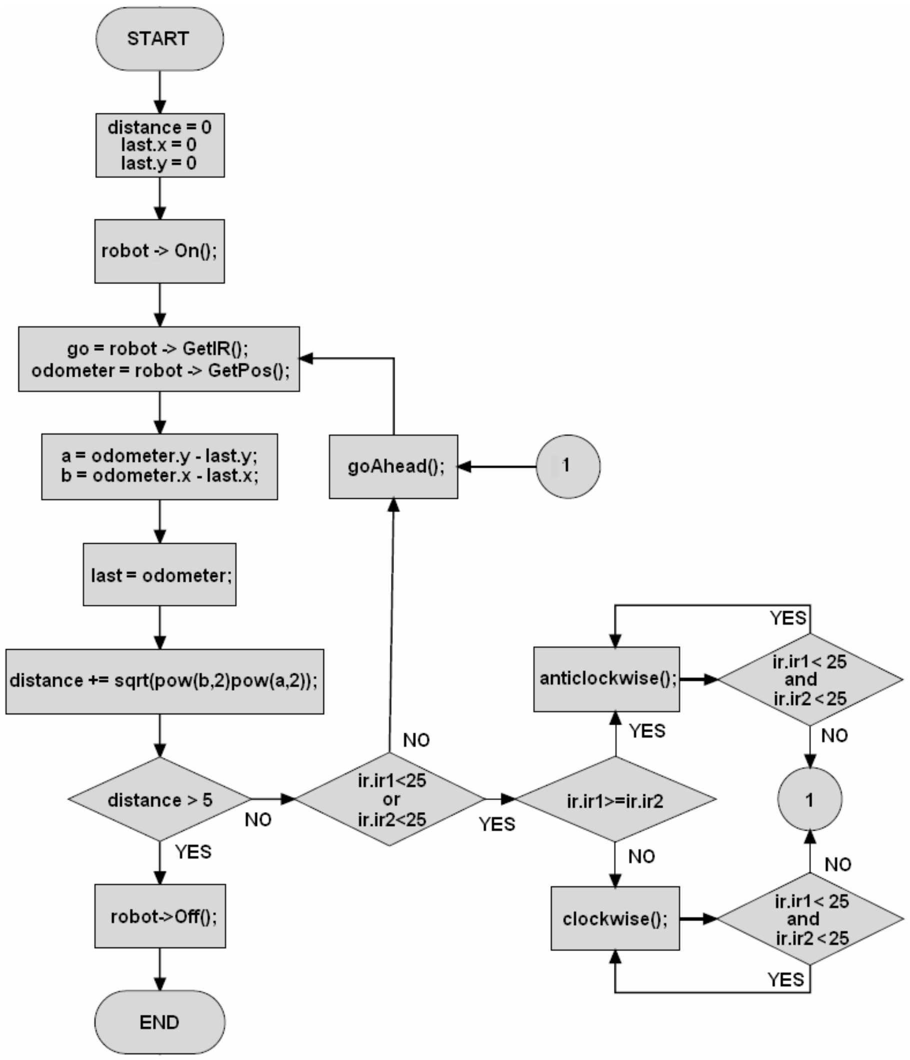


Fig. 6. Flow diagram the students must design to solve the first practical session.

Once the robot has fulfilled the task, the student has to make a graphical representation of the path the robot has followed, using the odometer data. After this, the student must draw the same trajectory, but computed from the information provided by the external camera. A comparison and a critical analysis of the results must be carried out.

As the main objective of these practices is to empower the knowledge in robotics control, we provide the students with some templates to develop the algorithm and with some methods they can use in their programs.

- The measure of the infrared sensors and the linear and steering speeds of the robot are automatically returned as text files when the control algorithm arrives to an end (the student has to tick the corresponding options when he uploads the program).
- There is a specific function that computes the position of the robot using the information of the ceiling camera and the mark the robot carries on it. To know the position of the robot, the student has just got to make use of this function.

Fig. 7 shows the typical results the students get after solving the task. There is a great difference between the true trajectory (fig. 7, b) and the one computed by means of the integration of the odometer data (fig. 7, c). This is due to the fact that the wheels sleep when the robot is describing a curve.

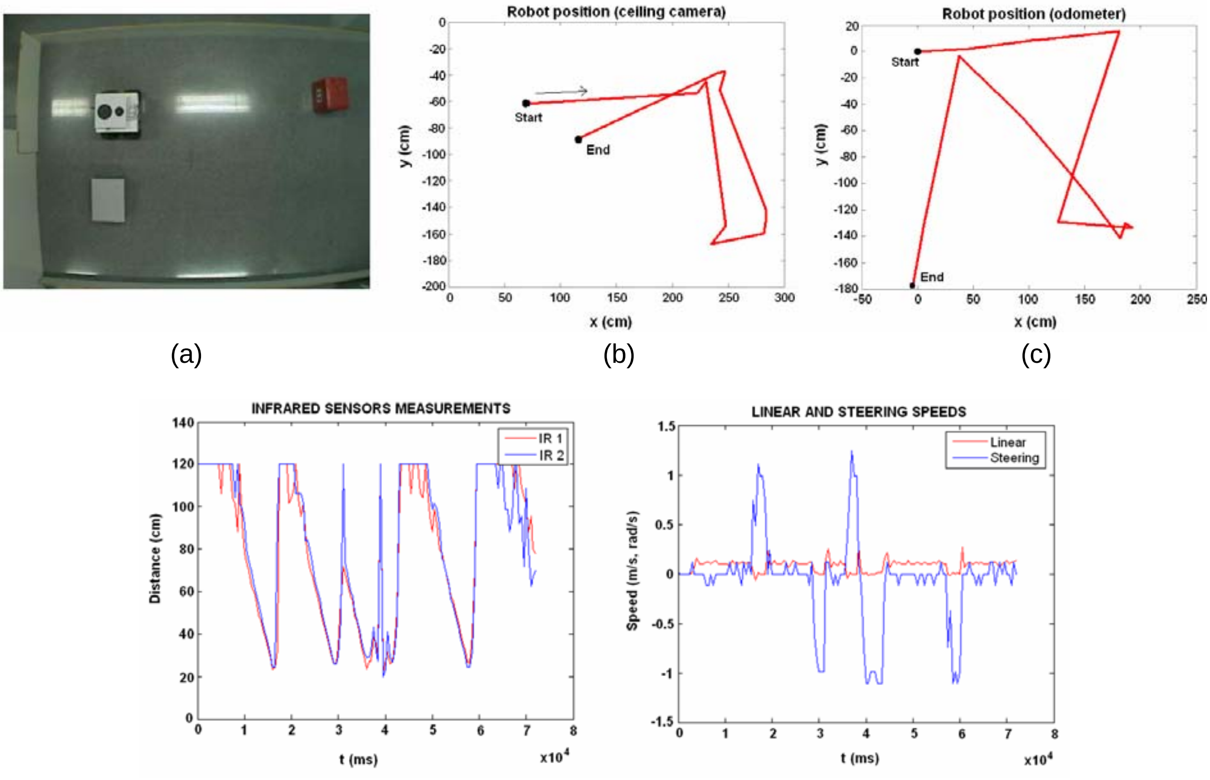


Fig. 7. Typical results after running the control algorithm for practical session 1; (a) initial position of the robot (view from the ceiling camera), (b) robot trajectory during the development of the task, computed by means of the information provided by the ceiling camera, (c) robot trajectory, computed by the integration of the odometer data, (d) left and right infrared sensors measurement and (e) linear and steering speeds of the robot.

4.2. Basic control of the robot.

Taking as a basis the previous exercise, the student must make the necessary changes in the program so that the robot moves from its initial position to a target point, trying to avoid the obstacles it finds. An artificial landmark on the target point indicates its situation. This landmark can be viewed from ceiling camera so, analysing the images of this camera, its position can be inferred.

As in the previous exercise, the robot must move straight to the target point, turning when it finds an obstacle. Once the obstacle has been surpassed, the robot must orientate again to the target point and move straight to reach it. The current position of the robot must be computed using the function that makes uses of the information of the ceiling camera, and the same for the target point.

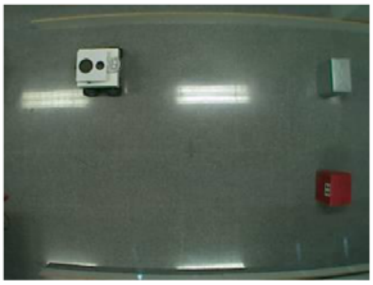
The problem has to be solved through the implementation of two behaviours: ‘Go to destination’ and ‘Avoid obstacle’. At each moment, only one of these behaviours must be active, depending on the reading of the infrared sensors (presence of an obstacle). Once the program has finished its running, the student must draw the path the robot has followed, using the data of the ceiling camera.

4.3. Visual control of the robot.

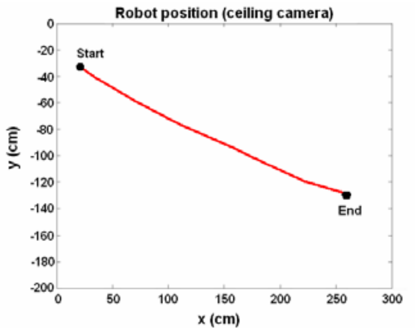
The main goal of this session is to introduce the concepts of visual control of a robot. To achieve it, the student has to make use of the *OpenCV* library that includes interesting functions for image manipulation.

In the working environments where the robots move, there are some visual marks that are visible from the cameras each robot carries on it. Firstly, the robot must move with a random movement, trying to avoid the obstacles, until a mark appears in its visual field. From this moment, the robot has to try to situate to a determined distance from the mark, and it must stop when this goal is achieved.

This problem must be solved using competitive coordination of behaviours. The student must implement two different behaviours: ‘Random movement’ and ‘Go to mark’. Only one of these behaviours must be active at the same time. If the mark lies in the visual field of the robot, the second behaviour must be active and the first one if the mark can not be seen. The lecture of the infrared sensors must be used to avoid the obstacles. Fig. 8 shows the typical results the students get after solving the task.

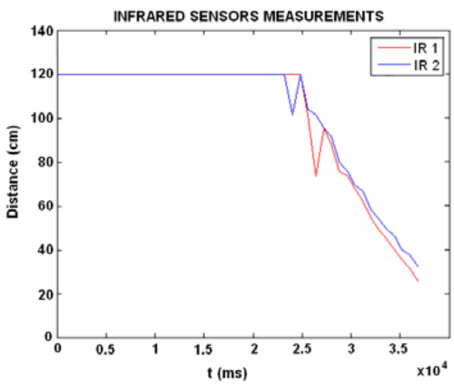


(a)

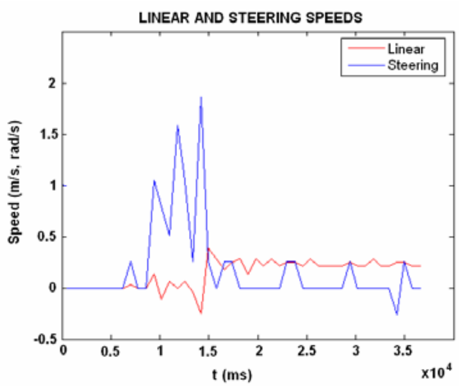


(b)

(c)



(d)



(e)

Fig. 8. Typical results after running the control algorithm for practical 3; (a) initial position of the robot and the destination point (red box), viewed from the ceiling camera, (b) robot trajectory during the development of the task, computed by means of the information provided by the ceiling camera, (c) snapshot taken by the robot camera, where the mark on the destination point appears (four black points), (d) left and right infrared sensors measurement and (e) linear and steering speeds.

5. CONCLUSION

In this work, we have shown an interactive tool we have built to help the students to understand the basic concepts of mobile robots, computer vision and its relationship. The students can deepen in the knowledge of basic sensors in robotics and basic control strategies, using visual information to control the trajectory of the robot. This way, we have centred the learning process of the subject in the practical side, what gives the students a global view of the subject and the applications in the real life. They can study robots with different kinematics, try to avoid obstacles using the infrared measures, perform a visual localization or navigation and study the properties of the odometer data. Besides they can visualize the evolution of the task thanks to the cameras that have been installed along the environment.

The methodology used to build the platform makes it easily extensible to other robots and could also permit communication between the robots so, in the future, the students will be able to test some algorithms that imply collaboration between several robots to solve the task. This tool is independent from the architecture and operative system of the student’s computer; he does not need any installation in his computer. Also, as the compilation is carried out in the remote computer, the user does not need any additional library and the last version of the client application is always available and continuously updated in the user’s computer.

The experience collected during the development of the sessions has shown how the students are much more motivated to learn in this way. The practices are much more fruitful and the objectives of the subject are fully achieved. This system empowers the autonomy of the student and allows a more fair evaluation system, where not only the final goals but also the work they have actually carried out can be taken into account.

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