MICRO-RATO ROBOTICS CONTEST: TECHNICAL PROBLEMS AND SOLUTIONS

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Abstract: The Micro-Rato Contest of the University of Aveiro is a competition among small autonomous mobile robots that is organized by the Electronics, Telecommunications and Informatics Department of that institution. The contest aims at promoting, in a festival-like environment, the practical and integrated use of several topics typically taught in electronics and informatics courses. The contest takes places annually since 1995, and a software-based counter-part, the Ciber-Rato contest, started in 2001. The total participation has been significant, not only of local students but also from other schools and even ex-students. Along these years a substantial amount of related literature was produced, covering the main technical issues that need to be dealt with when participating in the contest. In this paper we put together such literature and review those main technical issues, namely related to sensing, motor control, behavior programming and coordination.

Keywords: Mobile Robotics, Robot Competitions, Robotics in Education.

1. INTRODUCTION

Using autonomous mobile robotic competitions to aid teaching electronics and informatics has currently become common place in Portugal. Since 1995, when the Micro-Rato Robotics Contest of the University of Aveiro (MR) was deployed, the number of competitions in the country has progressively increased, aiming at different levels of education. The Micro-Rato Contest is now on its way to the 12th edition, with a steady participation around 30 teams and more than 100 people, divided between the original competition and its software counter-part, the Ciber-Rato Contest (Figure 1). Other national events include the ROBOTICA 200x (National Robotics Festival), started in 2001, and the Robô Bombeiro (Fire-Robots) contest (RB) started in 2002, among others. The reasons for this success are related to the appeal of the application area, i.e., autonomous mobile robotics, and also to the appeal of competition. The application area has shown to be very well suited for the purpose of complementing the formal technical education, as it requires the integration of concepts that range from D/A electronics, microprocessors (system integration and programming), power electronics, instrumentation, digital control, signal processing, artificial intelligence, etc.

The use of competitions to aid teaching is not, however, free of risks, as it may lead to the erroneous generalization of actually narrow solutions, and to the hiding of technical solutions to keep competitive advantages. L. P. Reis (2002) identifies these risks but also recognizes a positive overall effect given the strong motivation from competing. We add (Almeida etal., 2000) that the negative effects of competition can also be softened by providing sufficient resources, by promoting the contact among teams and through publication of successful approaches.

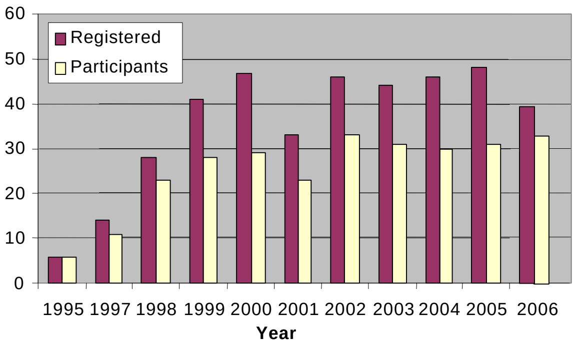

Figure 1. Registered and participants, 1995 to 2006.

Along the previous 11 years of the Micro-Rato Contest a relatively vast set of literature was produced, accessible from our website (MR). Such literature, both in English and Portuguese, covers most of the technical aspects involved in the construction of Micro-Rato robots or Ciber-Rato robotic agents, and it is a good complement to general literature on building small autonomous mobile robots (Jones etal; Wise 1999). In this paper we go through the literature produced in the scope of the Micro-Rato contest, organizing it according to the technical issues of sensing, motor control, behavior programming and coordination. The following sections are devoted to these topics, complemented with a section about the hardware and software support provided in the scope of the Micro-Rato / Ciber-Rato contests. Section 7 concludes the paper.

2. THE CONTEST AND ITS RULES

The Micro-Rato Robotics Contest inherited its name from the Micro-Mouse Contests organized since 1984 by the IEEE Computer Society (Tetta, 1986) and later also by other technical institutions. However, the technical options taken in this contest make it significantly different from the original micro-mouse competitions as explained further on. In fact, it is more like the contest organized in the scope of the MIT 6.270 course on Autonomous Mobile Robotics (MIT). General descriptions of previous versions of the contest can be found in (Almeida etal, 1999; 2000; 2003; Lau etal, 2002).

2.1- The Micro-Rato rules

Although the contest rules have evolved since the first edition, the fundamental aspects still remain the same. Basically it provides a localization and navigation problem within an enclosed area called maze, with fixed and moving obstacles. The robots compete in rounds of three looking for a goal area with an infrared beacon. The maze configuration is unknown and its area varied from 5x5m (1995-2000) to 10x5m (2001-2004) (Fig. 2) and 7.5x7.5m (2005-…).

Figure 2. A maze used in 2002.

The robots objective suffered a major change in 2001. Originally (1995-2000), it consisted in going from the start point to the goal area, as fast as possible, and without colliding with the obstacles in the way. Once in the goal area, the robot had to stop and stay there until the round was over (i.e. when all the three robots finished or the maximum time elapsed).

Figure 3. A robot from 1999.

Later (2001-…), a second objective was added: coming back to the start point without any extra help beyond the knowledge acquired in the way to the goal. When arriving at the start point the robot has to stop and signal its arrival. The classification is sorted according to the distance between the point where the robot stops and the real start point. The obstacles, the robots and the ground outside the goal area are reflective to IR light. Since 2004, color marks have been added to the maze corners and goal, and the ground color was changed creating a contrast with the walls and obstacles, allowing vision-based navigation approaches.

Robots must fit within a square box 30cm wide and 25cm tall, with a cylinder of 15cm diameter extending up to 40cm height (Fig 3).

Finally, it is important to refer that the organization always lents a limited set of robot kits to develop Micro-Ratos. This kind of support has been restricted to our own students, though. The kit has evolved over time but always included a platform with motors, a minimal set of sensors and a microcontroller.

2.2- The Ciber-Rato rules

The Ciber-Rato contest started in 2001 as a software simulation of Micro-Rato (Lau etal, 2002). Other early attempts to simulate the Micro-Rato contest are reported in (Capucho etal, 2001) to allow simple testing control strategies for Micro-Rato robots.

This contest currently follows very similar rules in what concerns maze, obstacles, objectives and game organization. The simulated hardware is, however, alike for all robots (agents), providing a similar set of sensors (obstacles, beacon, compass, goal and bumper) and motors on a circular platform (Fig. 4). A simulator manages the state of the simulated world moving the robotic agents according to their motor commands and providing sensory inputs to them according to their position in the maze. This approach allows focusing on the programming issues letting aside all typical hardware nuisances. For equity, the competition is carried out in a distributed environment over an IP computer network, with one computer dedicated to each robotic agent and to the simulator. A graphical front-end provides a global control panel and shows the current state of the simulated world, the robot penalties and the score.

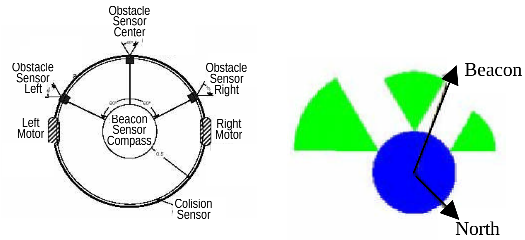

Figure 4. The virtual robots of Ciber-Rato (left) and their sensing capabilities (right).

3. SENSING

The sensing in Micro-Rato relies mostly on infra-red light (IR) detectors, either for obstacle, beacon and goal area detection, although a few robots used ultra-sound distance detectors. Vision based sensing was successfully demonstrated with Sony Aibos in 2004 and 2005 and in a mini-ITX based robot in 2005. Localization in the maze includes the use of compasses, incremental encoders and optical flow sensors. The virtual robots of Ciber-Rato are provided with sensors that resemble those used in Micro-Rato (Fig. 4). Obstacles are detected with proximity sensors. Since 2005 agents may define the angular positions of all sensors. To improve the realism of the simulated sensors, their response is affected by random gaussian noise. The sensing infrastructure is predefined and it is not an object of work for the teams. A brief description can be found in (Lau etal, 2002; 2004). Further data is available in the simulator documentation in (MR).

3.1- Detecting obstacles

To detect obstacles teams usually use IR sensors, although a few robots, noticeably Made-in-Agueda and Gabiru, used ultrasound sensors operating as sonars, based on pulse reflection and time of flight. Used IR sensors are mainly of two different types: The first type is based on a hacked Sharp GP1U58. Obstacle detection is active in the sense that the robot emits IR light, and looks at the reflection received by the detectors. This allows a gross measure of the distance of a given obstacle, as the output voltage increases with the intensity of the modulated IR light (at 40KHz) received by the detector, which is inversely proportional to the distance between the robot and the obstacle. The voltage/distance relationship is approximately quadratic. Obstacle detection typically uses 3 of these sensors (Fig. 3) given their relatively wide aperture (+/-30º). To improve detection efficiency, Silva and Santos (2001) suggest to use more than one IR LED/sensor in order to better illuminate the detection area. In some robots, e.g. (Santos and Silva, 2001; Paulo and Dias, 2000; Pinto etal, 1999), the obstacle detection was also improved using more than 3 sensors.

The second type of IR-based obstacle sensor uses a distance measuring device, the Sharp GP2D12. It uses the triangulation principle to compute the distance between the sensor and the obstacle being useful in the range 10-80 cm. The sensor output is a voltage that varies with the position of the spot as captured by the position sensing device (PSD), being inversely proportional to the distance between the robot and the obstacle (Ruas and Azevedo, 2005) (Fig. 5 left).

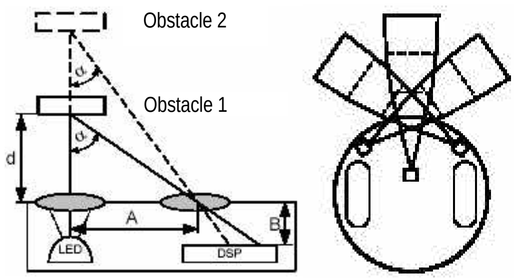

Figure 5. The GP2D12 sensor (left) and to its use to detect obstacles in the Voyager II robot (right).

One strong limitation of this kind of sensors is the very limited detection aperture, which has been experimentally found to be roughly +/-5º @ 40cm. Such a limitation has been circumvented by placing the 3 sensors so that the detection area covered by each one intersects the detection areas of the remaining two (Ruas and Azevedo, 2005) (Fig. 5). This scheme significantly increases the detection efficiency, avoiding the use of a large set of sensors to reliably detect obstacles in front of the robot.

3.2- Detecting the beacon

The goal area is signaled by a 30cm high omni-directional infra-red beacon standing in its center. Beacon detection is therefore very important for reaching the goal. The IR beacon used until 2003 emitted a 25 KHz modulated signal. This frequency was chosen so that the beacon light would not interfere with the obstacle detection based on the Sharp GP1U58 sensor, which was tuned for 40KHz. The output of the sensor (the GP1U583), when the beacon is visible, is a voltage that increases with the intensity of the modulated IR light received by the detector and, in this case, decreasing roughly linearly with the beacon distance (Lopes etal, 2000). Some of the approaches used to detect the beacon direction are discussed by Capucho and Parente (1999), e.g. sets of 4 or more fixed sensors (Pinto etal, 1999), one pair of fixed sensors (Martins and Pedreiras, 1999; Capucho and Parente, 2000), a single sensor rotating, either free (Oliveira and Melo, 1999) – Fig. 3 – or limited rotation (Silva etal, 1999; Silva and Santos, 2001), and even a fixed single sensor (Lopes etal, 1999; 2000 - detection was done by rotating the robot).

Since 2003, the IR beacon emits a 40 KHz carrier frequency, modulated with a digital 600 Hz 30% duty-cycle signal using on-off keying. This creates a potential for interference with the obstacle sensors based on the GP1U58 but these have been largely replaced by the GP2D12, which are insensitive to the beacon light. On the other hand, detection has been carried out by common IR remote control receivers which provides the 600 Hz digital output modulation signal. To determine beacon direction one such detector is placed inside a narrow opaque tube mounted on top of a servo rotating +/-96º. This solution is discussed in (Ruas and Azevedo, 2005) achieving a detection precision of +/ 5º (Fig. 6).

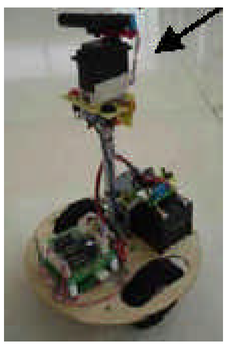

Figure 6. A Micro-Rato platform provided since 2003 and its beacon detector mounted on a servo (arrow).

In Ciber-Rato the beacon sensor delivers the angle between the robot heading and the beacon, affected by Gaussian random noise. Several virtual robots use complex strategies to determine the beacon position. For example, the YAM agent (Ribeiro, 2002) builds a map with the probability of each point to hold the beacon. This map is updated based on its self-position estimation and the angle difference between the points in the map and the measure of the beacon sensor. After a few cycles the agent can estimate the beacon position quite accurately. The RAO agent explored the uniform noise used in the 2003 competition to cut the space in the possible and impossible beacon positions. This cut would merge with previous cuts providing a polygon that became smaller as time advanced.

3.3- Self-localization

To fulfil the second objective of the contest the robot must come back to the start point without any extra help beyond the knowledge acquired in the way to the goal. This heavily depends on an accurate position estimation of the robot. The position and orientation of the robot in a reference coordinate system is determined using adequate sensors. Open-loop estimation (commonly referred to as dead-reckoning) has been used by several teams. The robot Spark (Duarte and Peixoto, 1999) used incremental encoders on the wheels to accomplish a set of missions combining a reactive behaviour (e.g. avoiding obstacles and other robots) with a sequence of pre-programmed short and simple trajectories. D. Dinis (Lopes etal, 1999) used absolute spatial information based on the combination of an electronic magnetic compass and beacon readings (direction and intensity) to estimate its position in the maze. It also used odometric information achieved by integrating the speed commands issued to the robot during short paths. The Bulldozer robot (Silva etal, 2002) determined its position by combining instantaneous orientation (from an electronic magnetic compass) with the elapsed distance provided by an optical flow sensor. Location of the sensor is important as it does not provide angular displacement. Another limitation of these sensors is the maximum distance between the floor and the sensor - less than 2,5 mm. This restricts the use of optical flow sensors to smooth surfaces.
In Ciber-Rato most agents do self-localisation in open-loop by keeping track of the orders sent to the motors. Based on the physics model that governs the movement of robots and apart from the noise they can estimate their position with fair accuracy.

4. MOVEMENT CONTROL

The almost single approach to movement control within Micro-Rato and Ciber-Rato is the use of differential drive with two independent electric motors placed symmetrically in the body platform, being the walking Aibo the only exception.
Regarding selection of motors, the main choice is, by far, the use of radio control servos, hacked for permanent rotation. This is the most economical and practical solution, providing an easy setup. However, after 2003, the basic robot set provided by the Micro-Rato organization included new DC motors (12V, 200rpm) replacing the hacked servos. These motors also include reduction gears with a lower reduction factor, allowing a higher top speed. Moreover, the efficiency of these motors is substantially higher, with less than half the current for the same load conditions.
The motors speed is normally controlled with PWM signals generated by the microprocessor, with the directions controlled with a pair of H-bridges (L293).

5. BEHAVIOR

Probably the most important aspect in Micro-Rato or Ciber-Rato robots since it determines their efficiency in reaching the contest objectives. In this aspect, Micro-Rato and Ciber-Rato robots are alike, except that the former ones are still subject to more physical constraints, e.g. computing capacity and memory, and non-foreseen interferences than the latter ones. Therefore, in Micro-Rato, reactive approaches are predominant, with little state knowledge kept by the robots. In Ciber-Rato, however, hybrid approaches with reactive behaviors being complemented with learning and planning capabilities are more common.

5.1- Beacon following

Beacon following is a fundamental basic behavior because it is essential to navigate efficiently towards the goal area as fast as possible. Basically, it consists in detecting the orientation of the beacon using the beacon detector and turning to the side where the beacon is. All robots should be capable of doing this orientation, using some kind of closed-loop control. The angular displacement of the beacon with respect to the robot heading can be seen as an error, which is used to control the angular motion of the robot. The control can be simply proportional, or it can be a ramp, making the robot turn small angles to the side where the beacon is. More complex control approaches are hardly justified. Some robots explored the ability to “see” the beacon even when it is behind the robot (e,g Zaratustra robot of 1997, Dyno (Oliveira and Melo, 1999) or Insónia (Pinto etal, 1999)). Although this may seem beneficial, it proved to be a source of vicious cycles as it could make the robot come back to a dead end when trying to escape from it. The common solution is to discard the beacon information when is it behind the robot and the robot is escaping from a dead end (e.g. following a wall) but even this approach can still fail in specific maze configurations (Gonçalves etal, 2002).

5.2- Avoiding obstacles

Reliable obstacle avoidance is an essential feature, as penalties for colliding with objects accumulate during every round, therefore punishing the competing robot if it touches objects in the maze repeatedly.
The simplest way to avoid obstacles is to use at least two non-contact (IR or ultra-sound) proximity sensors looking left and right. Detecting an object on the left side of the robot makes it turn right and vice-versa. This can be done by simple proportional control, using directly the output of the sensor, or by quantizing the sensor value in a few discrete levels (close, medium-range and far) (Martins and Pedreiras, 1999). However, most of the robots used at least 3 obstacle sensors with one facing the robot front. This improves obstacle detection area while maintaining the capability to detect obstacles in front. In this case, use of randomization can also be useful. By not turning always to the same side when facing a frontal obstacle, chances of developing vicious cyclic behaviors are reduced (Silva etal, 1999).

5.3- Following walls

Wall following (Fig. 7) is a behavior that emerged as a solution to some traps (dead ends) that may occur when the robot simply tries to follow the beacon avoiding obstacles on the way. A simple approach to deploy wall following is found in Silva and Cardoso (2002), while Cardoso (2002) describes a more complex solution based on a stack of directions.

Problems that can arise in these implementations are discussed in (Gonçalves etal, 2002) A more elaborate discussion can be found in (Luis etal, 2002).

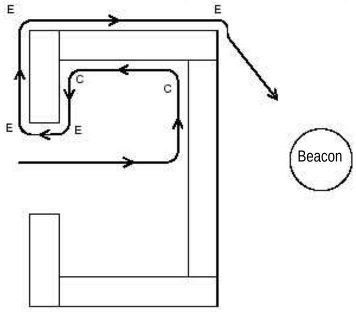

Figure 7. Following walls to solve difficult mazes.

5.4- Returning to the start point

Returning to the start point was introduced for the first time in the 2001 Micro-.Rato competition and the winning robot that year, Bulldozer, successfully achieved the competition goals. The strategy adopted was based in the use of a compass and on an optical flow sensor. The robot returned to the start point using the concept of virtual beacons (Santos etal; Silva etal, 2002; 2002a; Silva and Santos, 2001) which provide the base points for the return path.

In the Ciber-Rato competition most agents build a maze map where they record each point as free, obstacle, unknown or a combination of these. This map is used to derive the returning path using for example breadth-first search (Ribeiro, 2002), or the A* algorithms (Neves etal, 2005).

5.5- Global coordination

One simple way to coordinate multiple behaviors is by means of the subsumption architecture proposed by Brooks (1991). This enforces a hierarchy among behaviors so that some of them in certain conditions would inhibit other lower priority ones. This has been used in a few robots (Paulo and Dias, 2000), Insonia (Pinto etal. 1999). The Spark robot (Duarte and Peixoto, 1999) followed a similar approach but could merge pre-programmed movements within a global reactive architecture for beacon following. This improved the efficiency in following wall corners.

Hybrid approaches were firstly tried in 1998 with the robot D. Dinis (Lopes etal, 1999; 2000), which ranked second in the following year, 1999. This robot was able to combine a planner that searches for the best path with a reactive layer capable of avoiding unknown obstacles (e.g. other robots).

In Ciber-Rato almost all agents use hybrid approaches combining high-level behaviours with reactive behaviours (Lomba, 2002). All of the competitors try to return to the starting point and the best ones finish with an error lower than half the robot diameter.

6. HARDWARE AND SOFTWARE SUPPORT

6.1- Hardware platforms

Many different hardware platforms have been used in Micro-Rato. Early platforms were based on the Motorola 68HC11 microcontroller (Martins and Pedreiras, 1999; Pinto etal, 1999; Lopes etal, 1999; 2000). Since 1997. however, the KIT DET188, based on the Intel 80C188 microprocessor, started being used as well (Duarte and Peixoto, 1999; Santos etal; Silva etal, 1999; 2002; Silva and Santos, 2001). In 2000, the winning robot, TRIPE III, was the first and only one to use a single chip solution based on the AVR AT90S8535 from Atmel (Capucho and Parente, 2000). It was the simplest computing platform ever used in Micro-Rato. Occasionally, a few platforms based on a variant of the well-known 8051 microcontroller were also used. Another singular solution was presented by Dyno in 1999 and Sniffer in 2000 (Oliveira and Melo, 1999; 2000), in which an FPGA was used to boost computing performance.

After 2003 a simple platform based on the PIC16F876 was developed to replace older ones, requiring a lower power. This was used, for instance, in the Voyager robot (Ruas and Azevedo, 2005).

6.2- Software support

Apart from the hardware support, the organization also provides a library of C functions specialized for each computing platform, using the same prototypes to control the motors, read the sensors, create wait times, etc. (Almeida etal, 1999).

Beyond the libraries of functions, support for small multitasking real-time kernels is also provided. The ReTMiK kernel for the 80C188 platform was deployed in 1998 and used by a few teams since then, notably the Bulldozer robots (Silva etal, 1999; Silva and Santos, 2001; Santos and Sargento, 2004). Later, kernels for the PIC16F87x and PIC18Fx58 were also deployed, respectively the PicMiK and the RTKPIC18.

In Ciber-Rato, libraries of functions allowing the interface with the virtual hardware of the robotic agents is also provided. Such libraries are available for different languages, both for Linux and Windows operating systems, granting a good flexibility for the participants in terms of development and execution environment (Lau etal, 2002).

6.3- The Ciber-Rato environment

The Ciber-Rato environment is built on a distributed platform composed by a simulator, visualizer and agent processes. The Ciber-Rato simulator is a specific piece of software that is central in that contest. It communicates with the robotic agents via XML messages transferred via UDP sockets (Lau etal, 2004). This allows a very clear interface, supporting robotic agents running on different operating systems at the same time. Moreover, it also communicates with a graphical front-end that displays the evolution of the competition (Neves etal, 2002). The simulator can make a log of a competition, and a logplayer tool, allowing the visualization of recorded log files, is also available. These can be downloaded from the Ciber-Rato technical archive (MR).

7. CONCLUSION

The 11 years old Micro-Rato Contest has contributed for the promotion of didactic robotics and robotic competitions, in Portugal, as a teaching aid for related technological courses. Many students of different levels have gone through this or similar activities and many more continue to participate. The interest of activities like the Micro-Rato contest includes the motivation to learn more, to relate and integrate different fields of knowledge and to build concrete devices that are subject to constraints as real development projects. The negative aspects related with the competition have been tempered with technical support, promotion of contact among teams during the development stage and the publication of successful approaches. With respect to this last aspect, a relatively large amount of literature has been produced in the scope of the Micro-Rato contest and its Ciber-Rato variant, exposing technical problems felt when developing a robot or a robotic software agent, as well as their solutions. In this paper we revisited this literature and presented in a brief way the most common technical options used in Micro-Rato and Ciber-Rato contests. We believe that this work is a step forward to systematize the body of knowledge and experience developed by these events.

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(RB) Robô Bombeiro: http://

(RCF) RoboCup Federation: http://www.robocup.org

(RCJ) RoboCup Junior: http://www.robocupjunior.org

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