MOBILE ROBOT COMPETITIONS: FOSTERING ADVANCES IN RESEARCH, DEVELOPMENT AND EDUCATION IN ROBOTICS

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Abstract: Mobile robot competitions are events well suited to experimentation, research and development in many areas concerned with science and technology, ranging from material science to artificial intelligence. Aware of this fact, and for several years now, some Portuguese Universities have been involving some of their Engineering and Computer Science students in such contests, namely those of international level. The performance has been improving both in terms of the results and prizes obtained and the increasingly elaborate technical solutions developed by the teams. The importance recognised in these events has led the authors to submit to the Portuguese Government a proposal for an annual Festival of this kind in Portugal. This paper points out the advances in research, technology and education, which result from this type of events. *Copyright CONTROLO 2000.*

Keywords: Mobile Robots, Robot Competition, Robotics in Education.

1. INTRODUCTION

Robotics, especially in what concerns mobile robots, is widely accepted as a multidisciplinary approach to combine and create knowledge in fields as diverse as mechanics, electronics, control, computer science, communications, and even psychology or biology. Teaching Robotics in its full extent is therefore a demanding and always incomplete task. Therefore, every opportunity should be taken in order to strength students' (and also teachers') knowledge in any or all of those areas. This is a main reason that justifies why so many people, the authors included, welcome and participate in robot competitions. The other reason for practising Robotics, and possibly the strongest one, is enjoyment! Mobilisation around robot competitions, such as inter-department co-operations, sponsoring, and involvement of interested but non-expert audiences, are further advantages that also justify part of the interest and success of this kind of events. The contributions of robot contests for the development of research are also recognised by a growing scientific community [1] [2].

Depending on the model of participation and objectives of each team, the work to conceive, build and program the robots is integrated in final graduation projects or inserted in post-graduation activities. A third category, also carried out with notorious success, is to propose the job to selected students as a part-time, extracurricular activity.

Portugal has been represented in international Mobile Robot competitions since 1995, through students and faculty from Instituto Superior Técnico (IST), Universidade de Aveiro (UA), Universidade do Minho (UM) and Faculdade de Engenharia da Universidade do Porto (FEUP). These institutions participated in two major events: the Festival International des Sciences et Technologies - FIST, and the RoboCup - The Robot Soccer World Cup Initiative. As a result of the interest raised, the FIST has also taken place in Portugal twice, and there are plans for an edition of RoboCup in 2004. In parallel, the UA has been organising since 1995 the Micro-Rato (micro-mouse) contest with an increasing success among Portuguese Universities (http://event.ua.pt/microrato). The authors believe there is now potential to motivate University and High-School students and teachers for a regular event of this kind in Portugal, and are engaged in this commitment, which also includes a proposal recently submitted to the Portuguese Government with those objectives in mind. In this paper we point out the advances in research, technology and education that result from these events, as well as the potential drawbacks one must avoid.

The paper starts with a brief description of the two international competitions referred above. Section 3 includes more detailed descriptions of past participations as well as lessons learned by each of the Portuguese Universities involved, and finally, in Section 4, some conclusions and perspectives are drawn.

2. CONTEST EXAMPLES

2.1. *FIST - Festival International des Sciences et Technologies*

This event, organised by the French private company *Découverte et Communication*, has been running annually since 1994 in France, plus two extra editions in Portugal in 1997 and 1998 (the former also co-organised by IST and UA), as well as two other editions in Moscow, in 1998 and 1999. This is an international event involving several countries world-wide.

The competition has several categories, with new ones appearing almost every edition. The most participated so far have been the *monotype* and *open* categories whose purposes are nevertheless much alike (with small complexity variations for the *open* category). The main difference is that, whereas in the *open* class the designers only have limited (geometric) restrictions to build their robots, the *monotype* robots are subject to common constraints, such as the base platform, number and capacity of batteries, motors and wheels. These restrictions are nonetheless not a deception; it is very interesting to see, despite these impositions, how the teams reach rather different but competitive solutions. It then becomes easier to compare approaches and that is a major compensation for the developers of every robot.

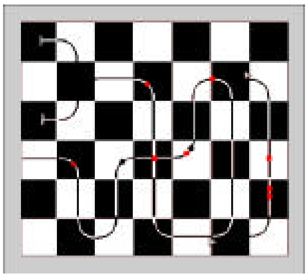

Figure 1 - The running track for the 1998 FIST edition

The main idea for the *open* and *monotype* categories is to present a robot that is supposed to execute a path drawn on the floor with a line alternating in a black and white chessboard-like background (Figure 1). Furthermore, the robot must collect and sort billiard balls spread throughout the path. Parameters to evaluate the classification of robots have been modified over the various editions, but robot path execution time, handling track interruptions and ball picking performance are the most significant items considered. On the technological side, perception (including vision) and path following control, along with electro-mechanical solutions to handle the billiard balls, are the most relevant matters to deal with. Obviously, integrated control of the system is also a relevant concern. IST, UA and UM altogether have participated with teams on both categories with important results as described further.

Since the 1998 edition, the category *footballeurs* (soccer players) has been present and counted with the participation of the IST and UM teams, which achieved relevant rankings, as well. The main idea in this category is to have a team of co-operating robots playing against another team of robots. The goal is to drive (by pushing, kicking or otherwise moving) a colour contrasting ball into a specific region at the border of a playing field, emulating therefore the real soccer game (European football). This category is much more complex than the remainders since, besides the problems of perception and motion control, we must add interfacing with a dynamic environment including actuating on the rolling ball and, for realistic performance, ensuring a co-operative behaviour of the team.

In some editions of the FIST there have also been demonstrations or limited competition categories, such as walking machines, where no Portuguese teams have participated so far.

2.2. *RoboCup*

RoboCup, or the Robot World Cup Initiative, has began in 1997 with a demonstrative pre-launching edition at the 1996 IROS Conference. The purpose is fairly the same as described above concerning the *robot soccer game*. However, RoboCup presents several categories: **small-size** (F180) league, **middle-size** (F2000) league, **simulation** league and, lately, **SONY legged** league. The simulation league runs entirely on a computer with 11 virtual players for each team. The SONY legged league is a still restricted competition based on the SONY AIBO robotic dog. The small-size league uses teams of up to 5 robots with a global vision based system. The medium-size uses up to 4 robots per team without a global vision system. Other leagues are emerging, such as the Humanoid league for which there are plans of live matches in the 2000 edition, to be held at Melbourne, Australia.

Figure 2 – RoboCup: Middle- (left) and Small-size (right) league fields.

Clearly, this competition, at the topmost levels, points to the ultimate challenge concerning mobile robots. Technically, RoboCup robots are complex pieces both in hardware and software. Much is still to be done in all fronts (miniaturisation, autonomy, perception, fast processing, etc.), but actual robots already show impressive behaviours. The list of problems to solve is so vast that some teams have chosen to select a standard commercial mobile platform with custom adaptations, and invest largely on software and image processing.

So far, three Portuguese teams (IST, UM, FEUP) have entered this competitions with variable success.

3. THE PORTUGUESE EXPERIENCE

3.1. *Instituto Superior Técnico - IST*

IST was the first Portuguese school participating in international Mobile Robot competitions. A team of 3 final year students and their professor competed at the 1995 FIST, held at La Ferté Bernard, France, in the open class. Most of the effort put since then on those participations was oriented towards continuous innovative solutions [3]. IST was the first team to use a video camera and image processing to detect the track and recover from interruptions. A catadioptric (camera + mirror) system which allowed the 1997 IST robot to follow the track, recover from interruptions and accelerate/decelerate in real time, based on the track geometry, resulted in an innovation prize from the jury, and the system has been patented in Portugal recently. Different kinematics structures (differential drive and tricycle) were also tested and built from scratch. A collaborative effort between the Electrical and Computer Engineering and Mechanical Engineering Departments put together students and professors from the 2 Departments and proved the possibility of joint work, often overlooked. The two mobile platforms that resulted from these participations are now being used at IST by final year and post-graduate students.

The team, renewed every year, won the 1998 open class category, and was placed 2nd in 1999, getting also the jury prize for the best robot in its class. This robot is described in another paper in this session.

Recently, IST has moved its main motivation to the RoboCup contest. This is a very challenging problem, where not only the rules change every year to foster increasing research advances, but also the opponent teams get better solutions, posing different and often more difficult problems.

IST participation in RoboCup has started in 1998 within the framework of a joint project of the Intelligent Control and Artificial Intelligence groups of IST's Institute for Systems and Robotics, named SocRob (Soccer Robots or Society of Robots). The larger goal is to develop methodologies for teams of co-operative robots capable of handling real-world problems. Recently, the SocRob project has also turned towards Robot Rescue problems, including the establishment of contacts with the Portuguese Civil Protection Department to identify areas of potential useful intervention of robotic teams in case of large-scale disasters, such as earthquakes. This is, actually, one of the new challenges of RoboCup, as the motivating goal of building a team of soccer playing robots capable of defeating an human team is just part of the most relevant goal of using co-operative robots to solve problems of significant social impact.

Concerning the robotic soccer competitions, IST has participated in the middle-size league only. This is the league where greater autonomy is required to the robots, as no global vision exists. Even though external processing power is allowed, IST IsocRob team has never used such possibility, as the goal is to achieve the largest possible autonomy. This means that the robots must co-operate to achieve global goals, not only their individual goals. IsocRob has attempted to handle this problem through the usage of on-line wireless communications among the team robots. This allows, e.g., the whole team to know the location of each of its composing robots or prevents two team-mates from trying to reach the ball simultaneously.

The work developed so far includes i) the definition of a functional architecture for the team, from which the individual level has been implemented, ii) the development of a software architecture comprehending a distributed blackboard to handle inter- and intra-robot communications [4], iii) the implementation of a self-localisation algorithm based on an omnidirectional catadioptric system (a camera plus a convex mirror, specially designed to provide by hardware the bird's eye view of the soccer field), and iv) the construction of a population of 3 autonomous robots. A robotic soccer field following RoboCup rules is available for training of national teams at the premises of IST's Institute for Systems and Robotics.

Recently, the ISocRob team acquired four Nomadic SuperScout II robots, which replaced the original "home-made" robots. The Scouts' increased reliability and availability of new sensors plus software libraries (e.g., sonars and odometry) allowed the refinement of self-localization, obstacle avoidance and teamwork methodologies

The IsocRob was among the best 8 (out of 16) teams in the Paris RoboCup98 edition and was placed 9th among 21 teams in the Stockholm 99 edition.

Its is important to point out that, out of all this effort of participations in FIST and RoboCup, 14 students concluded their final year projects with grades ranging from 19-20 and an MSc student defended his thesis successfully. As a result of the experience gained, some of those students helped deploying the CIÊNCIA VIVA RODITAS project, that is now in its 3rd year of considerable success teaching electronics, mechanics and programming to high-school students through the construction of a small and simple mobile robot. Continuous efforts are made to enlarge the participation in the SocRob project of higher level students, including foreign and national PhD and Post-Doc students, and this is becoming a reality in the short term.

3.2. Universidade de Aveiro - UA

The UA started to participate in the *FIST – Championnat du Monde de Robotique Mobile* in 1996, either in the *open* (1996, 1997) as well as in the *monotype* (1998,1999) categories. The technical specifications for both cases are based mainly on floor painted line tracking. The initial aim was twofold: to motivate electronics engineering students to exercise their technical knowledge in an integrated and informal way, and also to promote interest in the field of mobile robotics. The teams were formed by 2 to 5 different students every year, backed by 2 to 4 teachers.

The technical solutions used in the 1st participation were chosen so that the robot could be built as an extra-curricular activity in less than 3 months. The option was for simplicity, either in the mechanical structure as well as in the control system. The result, called *Moliceiro* (the name of a typical boat of Aveiro) was the smallest and lightest robot among all the competitors [5]. It used active infrared light analog detection either for line tracking as well as for reflector tracking (during line breaks). The billiard balls were captured passively by running over them and then sorted out by means of visible red light reflection. The motors used were hacked radiocontrol servos, which would allow for a top speed of 0.3 m/s (however, the effective speed under contest conditions was never above 0,23 m/s). Total weight without canopy was 1.8Kg and 2.3Kg with canopy. The supply was a single 12V 2Ah NiCd battery. The control algorithm, executed on a 68HC11 processor, was based on fuzzy logic but using only the actual error (aprox.

proportional control). The motors' speed was not controlled in closed loop. The control loop was closed by the tracking error with respect to the line, only.

The main problem was related to control stability under increasing load caused by the incoming billiard balls. These would represent an increase of about 50% in the robot's total weight along with an even larger variation in the moment of inertia. The robot would typically lose the track after gathering the 2^{nd} ball when running with the canopy on or the 4^{th} ball when not using the canopy. Nevertheless, it ranked 8^{th} among 14 teams competing in the *open category*.

This problem was tackled in 1997. The main idea was to maintain the same simple approach (similar motors, electronics and supply) but to reduce the total moment of inertia in order to facilitate the robot's control. A MATLAB simulator built for this sort of robots [6] allowed to observe a considerable gain in control stability by keeping the moment of inertia as low as possible.

Therefore, the robot named R2D2-v2 used a lift, built just on top of the robot's centre of mass, to store the billiard balls vertically with a minimum increase in the total moment of inertia. Although this solution was innovative and appealing, its implementation revealed low mechanical reliability, raising problems that were difficult to deal with. The total robot weight increased to about 2.5Kg. The control algorithm was a PID type which, together with the reduction in the moment of inertia, allowed for an improved control performance. The result was, nevertheless, a 5^{th} place among 12 competitors. This was probably the best result that could be achieved with those very low power motors (aprox. 5W). The remaining robots used motors at least 10 times more powerful allowing for much higher speeds.

In 1998, the team exchanged categories and entered the *monotype* competition. In this case, the chassis, motors, wheels and batteries were the same for all teams. The motors were hacked windscreen wiper DC motors, which are considerably powerful (aprox. 60W) and allow to drive the heavier robot (aprox. 18Kg) to speeds of up to 1m/s using 12V supply. Furthermore, the team resulted from a co-operation between the mechanical and electronics engineering departments, which allowed to improve the robot structure and its mechanical subsystems.

The robot was named RUA-v3. The electronic systems were built around an 80C188 processor and the line tracking subsystem was also exchanged by an array of 16 digital IR sensors. The billiard balls capturing subsystem was also redesigned using an active approach based on a rolling sponge to effectively catch the balls. However, the overall mechanical configuration had, again, a large moment of inertia that was thought not to be so restrictive due to the more powerful motors. This belief was wrong. Once again, the robot control, which used a PD type algorithm, was relatively unstable, requiring a very precise tuning of the control gains. Moreover, the tight schedule for building the robot did not allow using closed loop control of the motors' speeds, as planned. For these reasons, the robot's average speed had to be severely reduced to about 0.35m/s. Nevertheless, the result was a 5^{th} place among 12 competitors.

In 1999, the same robot was redesigned, mainly by exchanging the placement of several subsystems in order to reduce the total moment of inertia. Furthermore, the closed loop speed control on each motor was also installed. The result, named Zqiub, behaved as expected, tracking the line smoothly with speeds near to 1m/s. It was ranked 3^{rd} on its class, very close to the 2^{nd} robot. Moreover, Zqiub's modular design together with its stable and regular behaviour were rewarded with the Special Jury Award for the monotype category.

In these activities, students had to deal with issues of control, kynematics, dynamics, electronics, programming, etc., in an integrated fashion. Furthermore, there was a constant stress for using modular approaches to ease maintenance, an important topic for students' future engineering activity. The students' interest in the field of mobile autonomous robotics has been clearly improved, not only by promoting their participation in this activity, but also in other ones that we have been developing in the university for large number of students (Micro-Rato contest). Several indications seem to confirm that these activities are contributing to improve student´s technical education, in particular, their practical skills to develop embedded control systems for real machines.

3.3. Universidade do Minho - UM

The Group of Automation and Robotics (known as GAR) from the School of Engineering of the University of Minho, located in Guimarães (Portugal), has been developing a team of footballer robots since March 1998. The first team took three months to build the three mobile autonomous robots from scratch (keeper, attacker and a spare one) and these were prepared to participate in the FIST which took place in May 1998 in the city of Bourges (France).

This work started in March 1998, with a team of students made up of Carlos Machado, Sérgio Sampaio and leaded by Fernando Ribeiro. Since then, it has been been continuously improved by the same persons as described in [7] and [8], and this year will participate in their 5th competition.

Each robot was autonomous and there was no communication between them, and had an arc that could be lifted up or pulled down in order to take control of the ball. Each robot had contact sensors all around itself in order to detect collisions with the opponent team robots and also with the short wall placed all around the field. Contact sensors were also used on the ball controlling arc in order to detect when opponent teams had touched that arc willing the take control of the ball in which case the robot would have to lift the arc to allow the opponent robot to take the ball.

Two motors were used coupled on the two wheels allowing steering by differential which means to stop one motor to turn to that direction. Two contact points were also placed under the robot since it cannot hold itself only on two wheels.

The robots would start and stop automatically when the microphone sensed the referee whistle. Each robot had a computer inside (Intel based microprocessor running at 200 MHz MMX, 16 Mbytes of RAM and a 2 Gbytes hard disk), and a vision system made up of a frame grabber and a convex mirror facing down and a video camera pointing upwards to the convex mirror. With this technique the robot was able to see all around itself and see the goals, the ball and the opponent players. The field was half black and half white, contrasting with the goal area which was the other way round. Behind each goal both teams could place anything they needed in order to recognise the goals or for self-calibration of the robots. The Minho Team used a coloured rectangle with a light bulb in it and used colour sensing through the video camera in order to see the red ball and the green and blue goals. The keeper could keep properly using a simple tactic which consisted of never leaving the goal, except when the ball was near (1 meter or so). The robot would rotate around its waist point always to the ball and only when the ball was near it would move forward and throw it far away. The attacker could score a goal and the keeper could defend a goal, but no teams (from the three that participated) could play an entire game for the expected 20 minutes of a game and therefore only a demonstration of the robots individually was made. With a couple of days programming, these robots would be able to play a complete game. Even though, the jury gave a second place award to this team, awarding the first place to the home team and creators of the competition.

One month after, the robots were improved and able to play a complete game. In October 1998, this team participated again on another competition organised by the same French entity (this time in Loures, Portugal) but no other football teams participated and therefore only demonstration of these robots were made.

The robots were improved in mechanical terms, electronics and software and participated again on April 1999, in Bourges again. This time six other football robotic teams participated but only one other apart from our team could play a complete game. Our team still used the same vision system but with faster image processing routines that were written in Assembly language allowing up to 50 frames to be captured per second. Moreover, a new software approach was used and consisted on a GrafCet type with several stages. The movement and steering was controlled using a special dynamic algorithm approach.

Three games were scheduled with the other team (Nantes) and the results were all wins for the Minho team (5-2, opponent missing represented by 3-0 and 1-0).

A new challenge came up consisting on the participation in the RoboCup held in Stockholm in July 1999. Since this competition was much more scientific than the one in France, several changes were carried out. Firstly, four robots were needed to play a game, which means that due to lack of budget we lost the spare robot. Standardisation of the electronics was also implemented with a common bus in order to have the possibility to implement more electronics without loosing control of the whole system. Each circuit was made in a standard PCB with standard size connecting to that common bus. From then on improvements would mean only to plug in the new board. Also all the contact sensors were removed and replaced by software routines on the image processing system. The design also changed substantially improving significantly the playing performance. Basically each robot was simpler and more efficient. Apart from the encoders on the wheels, one only sensor was used and consisted on the vision system from which every feature was extracted.

3.4. Faculdade de Engenharia da Universidade do Porto - FEUP

Since 1998 a team from FEUP has been entering in the Robot Soccer World Cup organised by the RoboCup Federation. This team, named 5dpo, is composed by post-graduate students and/or lecturers from FEUP and associated with ISR-Porto.

In the Small size League (F-180) each team is composed by five robots that play the game in a field with the dimensions of a Tennis Table. Each robot's convex hull area must not exceed 180 cm^2 and the biggest dimension, taken in any direction, should be under 18 cm. The game is played with an orange golf ball. The goal is 50 cm wide and to ensure that it is not possible to create an impossible to defeat defensive situation (like placing all the robot over the goal line to block it completely) there is a goal keeper area with 22.5 cm, in front of the goal. Inside this area, only one robot from each team is allowed.

While the game is being played it is strictly forbidden any human intervention, that can only happen while the game is stopped. A match consists in two parts with ten minutes each. The complete rules can be viewed in the RoboCup official site: http://www.robocup.org.

The preferred way to acquire the ball and the robots' position is by using a vision system. So, each robot must carry over its top a Table Tennis ball, painted with one of the official colours. One team uses blues balls and the other uses yellow balls. Additional markers are often used to help extract extra information about the robots, like the heading and to identify them.

While some teams have attempted to use some kind of local vision, that approach is not very easy due to the small dimensions of each robot. It is very difficult to place inside the robots the memory and the processing power needed to deal with the acquired image.

The usual set-up is based on a global vision system. For each team, there is a camera placed over the field and near the middle of it. The image from that camera is captured by a PC where it can be processed. Having extracted, from the image, the position of all the robots and the ball, the strategy can be decided, the corresponding control signals can be generated and dispatched to each robot. Usually, that is achieved using a radio transmitter capable of sending short packets to the robots.

Typically, the robots have a small micro controller to handle the radio packets and the control signals for the motors. We use a PIC16F84 in 98 and an AVR90s2313 plus a AVR90s8515 in 99. Almost all teams designed their robots based in some kind differential drive (two motorised wheels in the same axis, one or two free wheels for stability and no steering wheel) allowing the robots to turn around very easily. In fact we have been seeing a convergence in the designs, both mechanically and functionally.

This challenge provides a very interesting environment where we can study and test solutions to the problems of perception, decision and motion control while interfacing with a dynamic environment with co-operative, opposing and independent systems. Some of our solutions to the vision and radio communication problems have already been used in other systems.

In 1998, the 5dpo team participated, for the first time, in the Robot Soccer World Cup that was held in Paris [9]. There were twelve teams qualified for the final phase and in the first round, four groups of three teams played with each other. The 5dpo team won both matches and passed to the quarterfinals. After wining the quarterfinals, the 5dpo team lost the semi-final and then defeated the team from Cambridge in the match for third and fourth place. As a side note, we can stress that the champion team had lost with the 5dpo team in the first round. In result of that participation all the human members of the team became addicted to this competition.

The 5dpo main advantage was the vision system. It was acknowledged that it showed the best performance and robustness. Some of our solutions were adopted by various teams in the next World Cup.

In 1999 the RoboCup was held in Stockholm. Once again the 5dpo team was present, this time with new robots [10]. One of the main handicaps of the 98 team was the robots' maximum speed. Unfortunately, the new robots while faster, were not so robust and a lot of malfunctions prevented the passage to the quarterfinals.

4. CONCLUSIONS

Mobile Robotic competitions are a very motivating way of fostering research, development and education, mainly in Robotics, but also in Science and Technology in general. The increasing challenge difficulties are a typical feature of these events, pushing the participating teams towards advances in their approaches which are reflected in related work, e.g., on navigation systems, mechanical solutions or functional architectures, to name but a few. Students are very motivated, because they can integrate most of the knowledge acquired during their courses. Potential sponsors of the research program are attracted by the usually overwhelming presence of the media, including TV and radio stations.

Despite all these clear advantages, one must be careful not to cross the line between research projects and a competition. A few teams participate in these events with the single goal of winning. However, this hinders the main goal of the events: to foster scientific and technological progresses in Robotics. A team who competes only to win usually chooses solutions well suited for a particular contest, without worrying about the adaptability of such solutions to larger-scale real-world problems. However, this is the real challenge, and everyone who participates with that in mind knows that the real victory comes from what is learned by the students, faculty and general audiences.

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