Division of Informatics, University of Edinburgh

Institute of Perception, Action and Behaviour

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Co-operating LEGO robots in the 1999 Five Universities "Volleyball" Competition at Sheffield

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Abstract. Having taken part in the September 1999 LEGO robot Volleyball competition at Sheffield between five university teams, we describe the benefits and limitations of these competitions, especially those involving co-operative behaviours, as a testing arena for robot architectures.

1 Introduction

There exists a variety of open robot competitions around the world (e.g. MicroMouse, RoboCup, AAAI[3]Robot Competition, Kephera, BEAM[4] AUVS[5], FIRST[6] Competition,etc). The main goal of some competitions such as BEAM, FIRST[10] is to improve the quality in science and engineering by bringing together schools, universities, business and therefore provide an exchange of resources, clever ideas, problems and mutual needs. Others such as RoboCup [9] and MIROSOT [13] are an attempt to encourage Artificial Intelligence (AI) and Robotics research by offering a good test-bed for the design of Autonomous Robots, Multi-agent Collaboration, Strategy acquisition, Real Time Reasoning, Learning and Sensor-Fusion. MIROSOT is however, more focussed on building robots and less in AI. Depending on the difficulty and goal of the competition, they may require a certain educational level (PhD, Master,Undergraduate, High School) and expertise (hardware, software). For instance successfull AAAI competitions have strong software oriented solutions and teams mainly consist of PhD and Master students. On the other hand BEAM competitions are mainly composed of undergraduate and high school students interested in designing and implementing hardware solutions [13].

In Universities such as Edinburgh [1] and MIT [2], the mobile robot groups organise internal LEGO Robots competitions. The aim of these competitions is to provide experience to the students in building and programming robots, learning the difficulty of integrating together sensing, control and acting by taking their own ideas to the stage of design and implementation.

In general this kind of game competition can be seen an opportunity to promote AI research specially in the area of co-operative multi-agent systems. Team games introduce the advantages of co-operation. One of the most important issues for co-operative behaviour is communication [5] [6]. Robots may communicate by implicit or explicit mechanisms. The costs of communication are balanced by the advantages of co-operative multi-agent systems including reliability, flexibility, fault tolerance and scalability.

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[3] American Association for Artificial Intelligence.
[4] Biology, electronics, aesthetics, mechanics.
[5] Association for Unmanned Vehicle Systems.
[6] For Inspiration and Recognition of Science and Technology.

2 LEGO

For years LEGO Technic construction materials have been used as a child's engineering toy constructionism and as a tool for education and research in mobile robots.

From an educational point of view its flexibility and modularity permits easier and quicker expression and testing of ideas. Also it permits a student without too much engineering background to assemble different body plans directly. Educational experiences have been used by Fred Martin and Henrik Lund to outline two different approaches: Unguided constructionism and Guided constructionism. The former [12] claims that that learning is achieved more effectively by participating in the construction of the artifact. In contrast Guided constructionism [10] claims that pedagogical methods are also needed.

In the area of robotics LEGO has often been used to built robots, and has inspired robot competitions. Robots are easily assembled with the well known LEGO system of clicking bricks together. This use has inspired further research in LEGO [11] to enhance its structural principles, including the best use of some parts, size of the brick, and gear train and box designs. These considerations led LEGO building plans, design principles and textual descriptions to be compiled in a Constructopedia developed at the MIT media lab [11].

For many years the teaching and research laboratories using LEGO robots have used their own designs of programmable controllers and sensors [1]. LEGO themselves have recently issued their own programmable controller (brain brick or RCX) system, which has been reviewed in engineering journals [7].

3 The Context

On the 13th of September 1999 was held a LEGO robot competition between five of the top LEGO using Robotics Universities in the British Isles: Trinity College(Dublin), Cardiff, Edinburgh, Manchester and Reading. For the competition all the teams were provided with 2 LEGO MINDSTORM Kits [3], 2 Robots expansion sets, RCX Bricks and 2 ultrasonics sensors provided by Reading University from which to make a team of robots to win a game of 'volleyball'.

The game was played by two teams of Lego Robots, one to two players each. The pitch as can be seen in figure 1, was a 2.4 metre square bounded by wooden black walls 100 mm high. A central gray line (dowel) divided the pitch in two parts. The function of the dowel was to separate the two halves and to stop the ball standing in the centre. To orientate the robots each half of the pitch was covered with a grey gradient poster print (see figure 2).

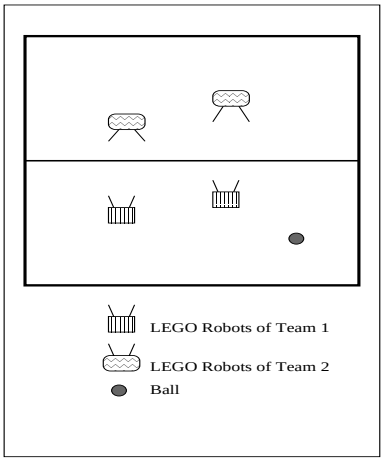

Fig. 1.: A schematic diagram of the task.

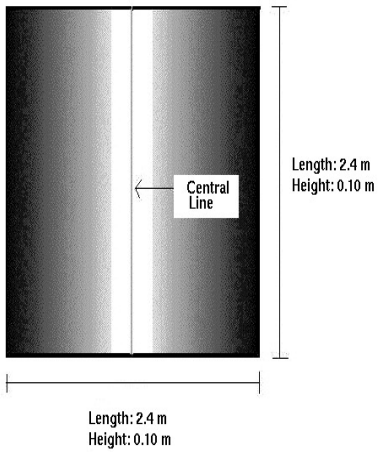

Fig. 2.: Poster print

The game started by placing one ball in a random position of the pitch in front of one of the team robots. The main objective for each team was to find and push the ball out of their area into the opponent's area within 60 seconds. Each game had a duration of 5 minutes. Points were awarded for each ball pushed over

the line and penalties levied for dropping parts, protruding into the opponents area and interfering with the messages of the other team. The task proved difficult.

4 The Implementation

4.1 Capabilities and constraints: testing the hardware and software

To design and build the robots for this LEGO competition the first consideration was that their capabilities would be constrained by the control system, communication system, and morphology. Hence experiments were carried out with the sensors and actuator provided by the LEGO MINDSTORM Kit [3] and its communication system. Also further investigations were done with the software provided to see how much the capabilities of the sensors and actuators were exploited.

The switches and light sensors were accurate and consistent although the light sensors had to be used for close range work (less than 1cm) and were very dependent on the battery state. The ultrasonics sensors, provided by Reading University were not reliable and consistent particularly when looking at the ball. The motors were the only actuators provided by LEGO. Although they showed a good range of speeds and torque when supplied with variable power, the software speed-settings limited this availability. That is, the software interface did not allow a full exploitation of the capacity of the motors.

Communication played an important role for the design of the robots, as not only had the robots to communicate between themselves, but due to he limited number of sensor ports and motor ports in each brick, two control bricks had to be used on each robot, which themselves had to communicate. Hence careful experiments were needed to identify potential problems. The major problem that the IR communication system presented was the failure of reception of messages, due to the fact that there was no tx/rx[7] protocol. An immediate solution was to introduce an acknowledge protocol but this presented drawbacks: delay in the reactions of the robots, and as before, loss of acknowledgement messages. Hence, the compromise adopted for this was to have on the same brick the two driving motors and critical sensors (e.g. poster-print watcher) required by the faster (e.g.detect dowel) and more frequent behaviours of the robots (e.g. navigate); it did not matter, if for instance, there was a delay when the robot hit a wall (e.g. wall sensor). The IR tx/rx ports were too directional. To improve omnidirectional communication, IR scattering sticky silver paper was placed near the IR ports.

Not only does the morphology of the robot influence its capabilities but also the control system. Our robot architecture was inspired by the behaviour based approach [4]. This exploits behaviour emergence from task parallelism. Although the design of LEGO's RCX brick was influenced by MIT's and Edinburgh's research in this area, they limited the maximum number of parallel tasks to 10, a limitation for experienced roboticists implementing this kind of game.

4.2 Cooperative strategy implemented

For this LEGO competition the benefits of reliability, fault tolerance, and time, suggested the use of cooperative behaviour. As one cooperative strategy based on one defender and one attacker robot satisfied most of these requeriments we (Edinburgh [8] [14]) decided on this strategy. The basic idea behind this strategy is that one robot took the role of an attacker, responsible for locating, collecting and releasing the ball into the opponents' area, while the other robot took the role of a defender robot whose aims was to block the ball rolling back into our area and confuse the enemy attacker. In order for the strategy to succeed as a whole the defender and attacker robot had to cooperate by the IR communication system.

Due to the unreliability of the sensors, and their limited capabilities for localising the ball, a blind ball searching strategy was programmed. These constraints also influenced the design of the grabbing ball mechanism of the attacker robot.

The grabbing ball mechanism consisted of one small soft ball on a rotatory axis driven by two motors as can be seen in figure 3. The purpose of this was to pull the competition ball into the robot by turning the soft ball very fast. The main advantage that this gripper mechanism presented was its facility to get the ball from the corners. Also, it increased the chances of catching and keeping the ball during the game by having it activated all the time.

[7] transmission/reception.

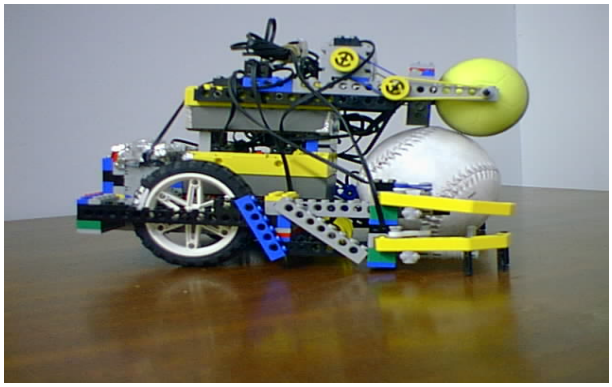

Fig. 3.: Side view of the Edinburgh attacker robot holding the ball

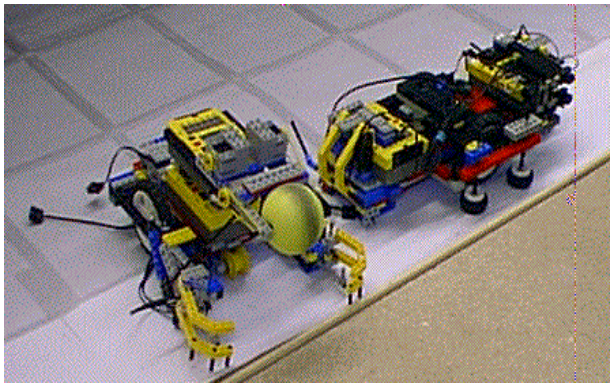

Fig. 4.: Attacker and defender robots of Edinburgh University

The blind searching strategy adopted by the attacker was to run around the walls, looking for the ball, then when it reached the central dowel, to reverse, turn and search the rest of the pitch in a random way. There was no need for searching the ball along the central dowel as if the ball was there, the defender, moving parallel to the line, would have pushed the ball into the walls. The communication system played an important role in the cooperative strategy. It was decided that to avoid collisions between robots, the attacker robot would signal the defender when the ball had been caught. The defender robot could then move to one side and wait until the ball had been pushed into the opponent's area. After releasing the ball the attacker robot would send a message to the defender robot signalling that it may continue with its defender activity. Given that a single message 'got ball' might be missed, the attacker robot also sent a message every time it hit something, saying either 'no ball' or 'got ball', so the defender robot had more chances to learn the ball state. This improved co-operation by reducing robot collisions.

5 The Competition

The team of Trinity College (Dublin), who won the competition, used two dimorphic robots, one defender which tried to block entering balls, and one attacker which collected and fired balls back. The defender robot threw down a large sweeping tail to push the ball into the attacker's back half of the pitch. Then the attacker robot fired the ball with a bulldozer-like shovel which rotated forwards and upwards to throw the ball. The construction of the robots can be seen in figure 5.

The university of Manchester, placed fourth, used two homomorphic robots. One that swept along the sides of the field to pick up balls that were resting against edges, and one that would move in a criss cross manner around the field. Both robots had a strategy of moving towards the centre once they had captured a ball. They implemented this strategy since observations showed that balls often laid near the edges. The robots caught the balls in pincers and had a powerful paddle to throw the ball as can be seen in figure 6.

The robots had all been developed int home laboratories on locally built pitches. On arrival at Sheffield the competitors were allowed about an hour to calibrate to the competition pitch under daylight and room ligth conditions and then about an hour to calibrate under the proper competition lighting. This was barely adequate and some suffered from poor adjustment to competitions conditions.

In the competition each team competed against the other four teams for five minutes each. The most significant problem presented to our team was to navigate around the walls as the height of these had accidentally been changed from the original specifications, which affected the wall searching strategy of our robot. Also the light poster print sensors were affected by the powerful orange (sodium) lights of the environment and the grey gradient level of the poster print.

Cardiff's strategy was to employ one large rectangular robot which could search the entire pitch very rapidly for the ball and had no inter-robot communication problems. However the co-operative strategy of Dublin proved marginally superior in the competition (Dublin placed first, Cardiff placed second). Edinburgh's strategy was the same as Dublin but Dublin had better morphology (Edinburgh third).

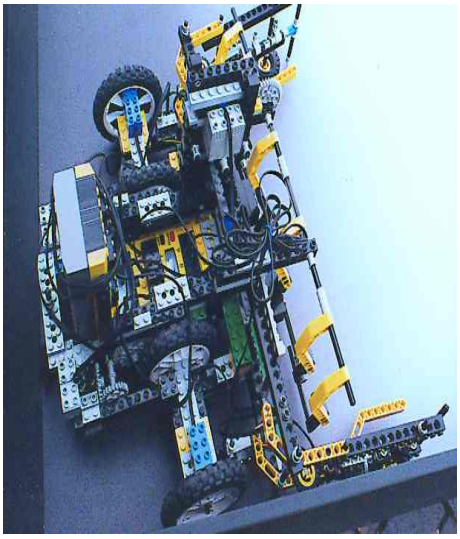

Fig. 5.: Dublin's attacker robot

Fig. 6.: Manchester robots

Manchester was limited by the difficulties with the unusually high friction and strong lighting (Manchester placed fourth). The high friction of the pitch unabled the robots to turn the right angle.

Reading was also affected by the lighting conditions. To overcome the problem a black paper was attached close to the light sensor. Even so they still had problems to orientate themselves, and were placed fifth.

6 Lessons learned

Learning, the most important issue of the competition, was achieved before, during, and after the competition.

The experience of the competition aided to highlight important issues: Adaptable sensors not fixed on particular environment conditions are preferable. For instance, to achieve the dessired turning angle wheel revolutions sensors are more reliable than timing sensors. During the game, timing sensor proved to be very dependent on the states of the batteries and friction of the pitch (e.g: Manchester University). In contrast, revolution sensors, based on distance measurements, kept track of how far the robot moved. Dublin used revolutions sensors to know how far the sweeping robot was from the wall. Also, to tackle lighting environmental problems, self calibrating sensor routines had been quite useful.

It is useful to minimize the number of sensors by taking advantage of the natural dynamics of the robot interacting with the environment. One remarkable example is Cardiff University. Their robot took advantage of this by smashing the robot into the wall in order to align itself. Edinburgh and Dublin teams took advantage of the natural slight curve of any robot attempting a straight line to keep the defender robot tight against the central line while moving by attaching two small rotating wheels to the robot at the same height as the central dividing line and placing the two driving wheels in the right position. If the robot touched the dividing line, these wheels rotated around, so that friction was minimized, but the robot was pushed into line to run parallel to the central dowel. Also Dublin minimized the use of sensors when sweeping and striking the ball into the opposite area. Neither of the Dublin robots looked for the ball. The cooperation of the sweeper and striker robot was enough to push the ball into the opponents area within the allocated minute.

It is not only a case of robot design but also environmental design matters. The rules of the game and equipment of the robots should be fairly and clearly specified with proper time in advance. We felt that this competition had lack of management and commitment: some rules and pitch specifications were determined in the last minute. As a result none of the teams performed at their best, some poorly, and a bad impresion of the competence of these students roboticists was given to the public, when the culprit was competition management.

7 Conclusions

Overall the competition provided a challenge for AI, specially it was useful for testing different approaches to multi-agent coordination. Although due to the size of the team, the resources available, the limitations of the sensors and bricks, the LEGO competition was not the best arena for multi-agent robotics research. Changes of rules, proper construction of the pitch and resources available could led to a most interesting game. Furthermore, whether the MINDSTORMS Kit is suitable for serious robotics research is questionable, mainly due to its lack of sensory abilities, number of outputs/inputs ports of the brick, and limited parallelism. Hence in order to become a useful research platform, more sensing capabilities such as range and vision should be provided by LEGO in the future. Also we felt that for research work (as opposed to a child's toy) the capabilities of the RCX (a Hitachi micro-controller with 32K of external RAM) should be more accessible.

However the competition proved a good way of exchanging clever ideas, problems and mutual needs and learning how difficult it is to cope with the unexpected change of the environment and rules.

8 Acknowledgements

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