Problems and Solutions in Middle Size Robot Soccer – A Review

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ABSTRACT

A review of current scientific and technological problems encountered in building and programming middle size soccer robots is made in this paper. Solutions and solution trends to the problems, as presented by different teams, are also examined. Perceptual systems of individual robots, in particular with respect to object location, communications between robot players, decision making with regard to game strategy and behaviour generation, and, finally, actuation, are the topics dealt with. This makes for a wide perspective on the actual state of the art of middle size soccer robots.

KEYWORDS: Robot Soccer, Artificial Intelligence, Image Processing

1. INTRODUCTION

Robot soccer poses a bunch of difficult and exciting problems in Robotics, Artificial Intelligence (AI), and Mecathronics, both of theoretical and technological scope.

The aim of this paper is to review a set of selected problems, the solutions used and the solutions trends used by the teams that participate in the RoboCup Middle-size League, one of the versions of world championship of hardbots soccer teams. Also, a more general framing of these problems in the robotics and AI fields, in general, and in the other two leagues, in particular, is sought.

In our perspective, the important problems to be considered and that we selected for reviewing are: perception, communication, decision-making and actuation. Following this introductory section, section 2 will briefly describe robot soccer and in particular the characteristics and challenges to be met at the Middle-size League. A review of the solutions to these problems, available in the literature is presented in section 3.

Section 4 considers the trends and conclusions summarising the results obtained in this review.

2. THE ROBOT SOCCER CUP

Though looking just like a game where winning is the main aim, the *Robot Soccer Cup*, or *Robot World Cup Initiative*, or just *RoboCup*, is much more than that (if it is that, at all) because some of its most important objectives are research related, both providing stimulus and a results test bed (Kitano, Asada et al. 1995; Federation 1998; Bräunl 1999). Robot World Cup divides into three leagues: the simulator league, the small robot league and the middle size robot league. In this paper we will focus in middle size robot league, although some comparisons are done with other leagues.

Some of the research topics applicable to Robot Soccer are (Kitano, Asada et al. 1995):

- Design of robot players, their control and actuation, including all electronics and mechanics;
- Vision and sensor fusion – or perception, which is one of the key issues of Robot Soccer
- Learning robot soccer playing behaviours – or decision, where researchers expect the greatest advances in the next years.

(Kitano, Asada et al. 1995) also refers that RoboCup "can be viewed as a co-operative distributed real-time planning scheme", due to its dynamic changing environment, distributed decision making (each player should *think* its next movement) and same shared objective to the players – winning the game.

In the middle size league, four players (robots) compose each team. The maximum height of each robot is 80 cm (Kraetzschmar 1999). The constrains to robot width are set through limiting the robot area. Usually a robot that fits in a circle with 50 cm diameter, or a square with 45 cm side length, meets the necessary conditions to play. The maximum weight of a player is 80 Kg. The robots must be all black with a space for a coloured mark (for team distinction purposes) and a number. Communication between robots or between robots and remote computers is permitted, but at any time the teams are not allowed to jam the opponents communication or sensor systems. It is strictly prohibited the use of global vision or the use of landmarks. Aside the previous restrictions, any kind of sensing systems are allowed.

At RoboCup 99 the teams played in a field with the dimensions and colours shown in Figure 1 (Kraetzschmar 1998). The field surface was green, with blue and yellow goals, and white field lines. The walls were white, with text in large letters. Another specification was brightness, which was between 600 and 1000 lux (this is very important because the colour detected by cameras is greatly dependent on lighting conditions). The colour of the ball was red.

The game playing rules follow those of FIFA (Kraetzschmar 1999), although some (temporary) adjustments are made to adapt them to the current state-of-development of the players. Rules such as offsides, corner-kicks, goal kicks, etc. currently do not apply to RoboCup. Each match lasts 20 min divided in two equal parts. The team that scores more goals wins the game. A goal is made when the ball enters completely the opponent's goal.

Since the first one in June 1993, several cups have taken place together with conferences or workshops where new developments were presented. When a committee of researchers considers that some of the current targets for the competition, or for the players, are overtaken, they push the limits establishing a new partial objective, always looking at the long turn (total) objectives. These objectives are known as *RoboCup Challenges* (Federation 1998). Presently the RoboCup Challenges are set to ball controlling (moving, catching, passing and kicking).

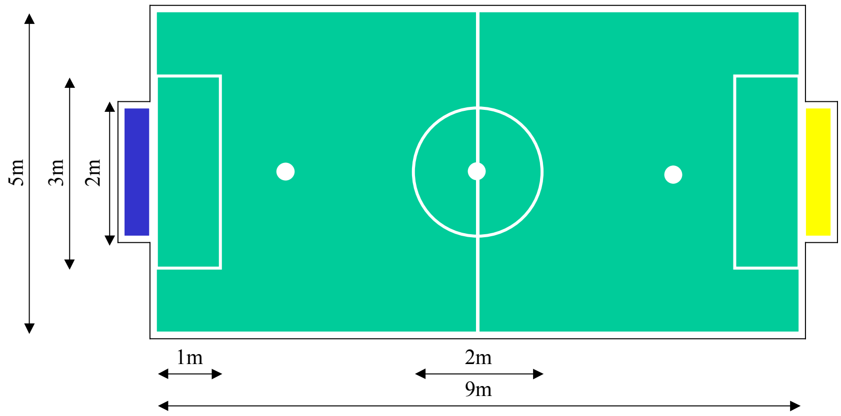

Figure 1 - Schematic of the play field used in RoboCup 99.

3. SOLUTIONS

3.1. Problems and Proposed Solutions

As mentioned in previous sections, researchers, in order to validate their assumptions, solutions and implementations, are increasingly using Robot Soccer. This happens because this kind of application brings many difficulties in several domains, making it a complex multidisciplinary problem to solve.

The essential problems to overcome can be divided into two different categories: one at a more theoretical or structural level, and the other dealing with sensor (actuator) information extraction (generation) and its pre-processing (post-processing). The first kind of difficulty relates to general robot control, i.e. its actions. At this level, Robot Soccer can be viewed as a multi-agent environment. To succeed in this environment, various attributes are needed. These attributes can be summarised as co-operation and opposition. In fact, each team, or multi-agent system, is embedded in a dynamic environment, where the environment continuously (in real time) tries to neutralise the first team's objective. This happens because to the environment of one team belongs the opponent team, which has objectives that are exactly the opposite of the first. Winning multi-agent systems should have good reactive, deliberative and also predictive control, not only at global (team) level, but also at local (single agent).

Noisy perception and actuation falls into the second group of problems. Regarding perception, this noise can be seen in several ways: inaccuracy of sensor readings (odometry error propagation), actual noise (lighting conditions for an imaging system) and limited perception capabilities (communication with limited bandwidth). What concerns actuation, this noise can be seen as an inability of the actuator to perform some of the controller commands. Most of team's efforts aim towards solving this kind of problems, in order to achieve the desired robustness that allows them to try to solve the problems in the first category.

3.2. Perception

In order to be able to choose between one or another movement, with some degree of confidence, it is necessary to have valid information to support that decision. This information should reflect as faithfully as possible the players surrounding environment. In this sense, *possible* is relative and not absolute possible, because it is only necessary to know the relevant information, which might not describe the whole environment (Russel and Norvig 1995).

This observation of the player's surrounding environment, also called perception, can be obtained in several ways: own sensory system (Ribeiro, Machado et al. 1999), world map actualisation (Gutmann, Hatzack et al. 1999), and information sharing with colleagues or with a trainer (Jonker, Corten et al. 1999), etc. Although the existence of high diversity in information sources and processing, there exists one sensor type used by all: vision. Due to its enormous importance, being probably one of the most scientific investments for the teams, and because of the very diverse approaches taken, it will be given particular emphasis to this subject all along this text.

Some solutions used by teams in competition will be described in the next paragraphs, regarding the perception of the player-surrounding environment.

As said before, there are many types of sensors being used, many kinds of quantities being measured, as well as the conclusions withdrawn from it. Essentially, the objective is to detect the presence of objects – walls, team mates, adversary team players and obviously the ball – as well as to give some information about the localisation and orientation of the robot. When possible surrounding objects information is also mostly welcome.

In order to shoot successfully to the goal, one should be able to know if there is a direct free path to the goal, or if a robot player blocks the way. In the same way, collisions with other players must be avoided, and when the available information about robot localisation is not precise enough, collision with walls must also be avoided. The decision whether the obstacle is a ball or an adversary, resulting in different robot behaviours, will be made by the image processing part, being explored in following chapters. Only collisions with adversaries are mentioned because, the teams where a co-operative game is played can significantly reduce collisions between their team mates, although in some other teams, without co-operation between players, all the robots are taken as adversaries. To detect objects in a robot's neighbourhood the following kinds of sensors are typically used: laser (Nardi, Adorni et al. 1999; Nebel, Gutmann et al. 1999), ultra-sound (Jonker, Corten et al. 1999; Teoh 1999) and infrared (Costa, Moreira et al. 1999; Teoh 1999; Ventura, Aparício et al. 1999) and Image Processing (Ribeiro, Machado et al. 1999), although this technique will be raised again later in this paper. These sensors detect objects at distances in the range of a few tens of centimetres up to a few meters. Generally, all the robots are equipped with a set of these sensors all around them, in order to detect objects in several directions. Another used solution employs two or three laser sensors (range finders) that sweep in several directions instead of just one.

Detecting object contact is normally a simple problem and is usually solved with some kind of bump-sensors (micro switches) all around the robot body (one of the participating teams does so using an old computer keyboard). However, contact can make the robot loose its position information for those who use encoders on the wheels to know its position.

One of the other kinds of sensors also used by robots are wheel encoders. This sensor establishes the feedback to control, among other things, speed and robot direction. Knowing wheel rotational speed and its diameter, one can also estimate robot location. This type of localisation (further described) lacks precision, for two reasons; because all the errors are accumulated through time, so periodic calibration (with laser range-finders (Oswald, Becht et al. 1999), for instance) is advised to improve readings precision; and because in case of collision or wheel slippery the encoders loose its control.

Depending on the strategy used and implemented control, there can be players that knowing their position do not know which direction they are heading. The most serious problem occurs when the own goal is detected as being other's team goal, and thus score a goal in the wrong side. To prevent this situation, some robots are equipped with digital compasses that are calibrated before game start, with all the robots at initial positions (Nardi, Adorni et al. 1999; Teoh 1999).

Using some of the described solutions, it might be possible to improve robot's travelling, which will contribute to a successful game.

Vision is the main source of information for a robot soccer player. Some the teams use vision as the only resource for perception (Brusey, Jennings et al. 1999; Ribeiro, Machado et al. 1999). It is used to, among other things, detect and locate team mates, other team players, the ball, goals, walls and field lines. It is, thus, one of the team's attention focus for improvement. Those who have the best image acquisition system, guarantee some advantage over the others. This called "best image acquisition system" should, preferably, have:

- High frame rate - there are teams with systems capable of rates higher than 50 frames/sec. All these high rates are achieved both improving hardware and software (by low-level programming, like using assembler to do the hard work); however the frame grabber has a limit on the number of frames;
- Good image resolution – it can go up to 768x288 pixels (in some special cases even more), with cameras and frame grabbers that support it. Higher image resolutions result in better precision to all image supported calculus, for instance, the calculus of distance from robot to objects; but also increases the time to process each image since the bigger the image the longer it takes to be analysed.
- High immunity to environment lighting conditions – usually the team programmers change the colour space mapping from RGB to HSI, HSV, YUV, etc. that contains information about light intensity, but this continues to be one of the greatest problems to tackle;
- Good image segmentation algorithms – helps when locating objects with different colours;
- High immunity to detection of false objects – some of the used imaging systems detect in their field of view some regions with the same colour attributed to known objects, so they think that region is that known object (the ball, for instance), when in reality that region refers to a, let's say, spectator shirt.

Although all the teams possess different vision systems, they also share one common ground: colour imaging. Since all the game entities have known colours, all the vision systems use colour cameras. So, identifying regions of the image with one particular colour, is the first step to recognise the existence of a ball, player or goal.

What concerns the use of cameras, there are mainly two types of players: those who see in only one direction (directional vision) and those who can see in several directions (omni directional vision).

Those players who see in just one direction are equipped with one camera heading towards one direction (mostly his direction of travel). The exceptions are the goalkeepers, of some teams, whose camera is aligned perpendicularly to his course movement, because these only move parallel to the goal line (Yong, Ng et al. 1999; Ribeiro, Machado et al. 1999). The other exception to this rule are those teams who mount the camera in a motorised platform, that permits viewing in several directions although just one direction can be seen at a time (Nakamura, Terada et al. 1999). This last approach falls in between directional vision and omni directional vision. The main disadvantage of directional vision is the narrow field of view achieved. In order to minimise this problem, some teams mount their cameras with special lenses (eye-of-fish lenses) that broaden the field of view, but at the same time they cause image deformation (Demura, Miwa et al. 1999). Using two cameras forming an angle between them is another potential solution. Although improving field of view, this approach has the disadvantage of higher image processing complexity (and doubling required hardware).

To achieve omni directional vision the technique used by a large number of teams is based on viewing the image of the field reflected by a mirror (Nardi, Adorni et al. 1999; Ribeiro, Machado et al. 1999; Ventura, Aparício et al. 1999). The camera is mounted with lenses facing upwards and pointing to the mirror. The main variation used by teams relies on the type of mirror used. While some use a regular convex mirror, that causes image distortion, others advocate the use of mirrors with hyperbolic, or conic, shapes specifically designed to reduce image distortion. The latter strive for as near as possible the human eye, while the former advocate that this kind of distortion is welcome because gives higher relevance to close objects. One of the alternatives to the use of mirrors is the use of two cameras with eye-of-fish lenses, mounted back to back. This solution is more complex than the use of a single mirror and cannot cover all the robot surroundings. Anyway, all these teams share the opinion that knowing what goes around the player, as opposite to know just what is happening in front of him, is advantageous (Nardi, Adorni et al. 1999): backwards movements are easier and done with higher certainty; monitoring simultaneously several object positions becomes possible.

There is another simple solution which also uses two cameras; one to see the field (like all other teams do) and another one to see just in front of the robot, in order to get more control of the ball (Ventura, Aparício et al. 1999).

3.2.1. Object location

Player self-location and object locations, being either the ball or goals, are key points to team success. Used methods should be as fast and precise as possible. To do so, the teams rely mainly on information from three different sensors: wheel encoders, laser sensors and imaging systems. Simultaneous use of these three kinds of sensors is not usual, but when self-location based on wheel encoder information is required then a sort of sensorial fusion is performed to calculate or recalibrate player location.

As said in 3.1., for self-location purposes, wheel encoder and laser sensor are the primary sources of information. Wheel coupled encoders output a number of pulses proportional to wheel rotation. Knowing wheel diameter and calculating the one rotation associated time, it is possible to extract values such as robot translation speed, its location and heading on the field. The main disadvantage linked with this method is associated to the accumulative nature of related errors, i.e., if associated to each revolution exists an error x then after 100 revolutions the overall error will be $100x$. Periodic calibration of robot location, using data gathered from imaging systems, is one option to minimise these kinds of errors. This calibration is made through identification of game landmarks, such as goals or field lines (Yong, Ng et al. 1999).

With the use of laser sensors, more precise information is collected, but with higher costs. Each of these sensors is made of laser beams: emitter and receiver. Spent time from emission to reception is directly related with distance to the beam-reflecting object (Nebel, Gutmann et al. 1999). When self-location is the issue, then the important reflections are those with field walls, so all occurring with other objects are neglected. Some of the used self-location solutions take advantage of data coming from a digital compass to resolve field-heading information. The orientation system should be calibrated with the compass reading before game start with the robot at a predefined position. Self-location based on imaging input is also possible if one can find three reference points (landmarks) to perform a triangulation (Bandlow, Hanek et al. 1999; Ventura, Aparício et al. 1999).

In most of the teams, when the interest is to identify and locate all other game entities (opponents, team mates, goals, ball and even field lines) all the responsibilities are attributed to image acquisition and processing. In order to permit correct object identification, each type of entity is painted with different colours. Entity identification relies on searching an image for that object colour. Precision in object identification can be greatly improved performing a match up with a model stored in memory (Nebel, Gutmann et al. 1999). Object bearing relative to robot is directly image extracted, while its location is calculated from its image size, i.e., a match up of the image-measured size with a size of the object to a known distance is performed (Plagge, Günther et al. 1999; Shen, Salemi et al. 1999). Knowing object distance, its heading relative to the robot and absolute robot location, makes estimation of absolute object location quite easy. This process is repeated for every object. When necessary, each robot can communicate with its team mates, the ball location and information about the surrounding environment it is aware of. The only variations between teams are implementation related – some teams, in order to improve performance, either search objects in image areas where is most likely to find those objects (Shen, Salemi et al. 1999), or search objects at the last place seen (Plagge, Günther et al. 1999), or perform testing with pixel windows sized to the smallest object (Jamzad 1999) or compare successive images to extract information such as speed of moving objects (Nardi, Adorni et al. 1999). Image processing can also perform self-location. In this case attention should be paid to distinguishing field lines and goal areas, being the remaining processing similar to object location.

3.3. Communication

Soccer is a team game where every player should play according to the same common objective. Being a co-operative game, each player should have some knowledge about his team-mates (if not all, at least some). This knowledge can be about their position, current task, objects seen, etc.

One way of getting information about team mates consists of identifying them in an image where one tries to extract, for instance, that player location. The information achieved by this approach is very limited, due to its external observation nature and to the limitation in perception which machines have.

One form of communication between players is based, mainly, in radio frequency transceivers. These transceivers are connected either to Ethernet interfaces (Jonker, Corten et al. 1999; Plagge, Günther et al. 1999; Ventura, Aparício et al. 1999) or serial ports (Teoh 1999). With Ethernet interfaces one can get rates up to 10Mbps and distances of around about 100m without quality loss, which is enough to cover the entire play field.

But, it's not only between players that exchange of information exists. There are some teams that use either a player (usually the one playing as goalkeeper, because it has a lighter computational load) or an external computer, acting as information server, with functions of a coach (this kind of solution is usually used in small size league, where there is an over field camera connected to an external computer – coach – that commands all robots). The attributed tasks to this coach, being further discussed ahead, include monitoring, communication control and tactical planning (behaviour) individually for each robot.

It must be said that there are also participating teams where information exchange is not implemented at all, neither visually nor radio frequency based. Although, currently at middle size league, such is not absolutely necessary for good overall team performance, as long as each robot is robust enough, because the passing techniques are not sufficiently developed for this league yet.

3.4. Decision-making

Decision-making heavily determines robot behaviour. The algorithms for decision crucially impact robot's playing. It addresses the classical spectrum of criteria from local immediate behaviour to team game strategy (for those who do so).

3.4.1. Game strategy decision support

This is the area where most diverse solutions appear. Each team supports its decision in different techniques, being very little the common points with other teams. Following is a description of some of the most used decision strategies.

One of the differentiating characteristics between teams is related to playing, or not, a co-operative game. There are few, but very important advantages when playing co-operatively:

- Vital information retrieval is simplified – when a player sees the ball, it communicates its location to its team mates, preventing those from wasting time looking for it on all playground;
- Improved game strategy made possible – allows playing a pass based game.
- Improved tactic – the robots will not repeat the actions of other team member and will behave individually like the humans do.
- They will not disturb or obstruct a team member, thinking that they are opponents. In fact this is a major problem form most teams because if all robots have the same program they will behave the same and they all go to the ball even when the ball is with a team member.

Although a pass-based game has already been implemented successfully in other leagues (Matsubara, Noda et al. 1996; Veloso, Bowling et al. 1999), in middle size league it is used only by a few teams. A pass-based game should imply a real co-operative game, where each player performs the thinking and decision. This falls under the problems addressed by distributed intelligence. A difficulty in pass based games is related with kicking devices implementation. These should permit a good ball control, namely shoot strength and damping when receiving it. When these difficulties are overcome then this kind of game should become more successfully used. However, it is important to point out that when a ball is passed, there is an higher probability of the ball being intercepted by the opponent team.

Co-operation towards the same objective can assume various configurations. In a first, more centralised, approach, a workstation comes to play, which can be outside the field, or implemented in the goalkeeper, acting as an online coach. The online coach gathers essential information coming from every player (location, heading, visible surrounding environment, etc.) and calculates the next movement for each player in its team (Costa, Moreira et al. 1999; Jonker, Corten et al. 1999; Teoh 1999). Another coach possible duty is communication medium access control for players (Yong, Ng et al. 1999). An alternative form of co-operation results in the establishment of different competencies for different players. However, this is only possible in big teams (of humans). In this solution, each player has a preferential position, corresponding to a pre-defined playground area, attributed at game start, mimicking the roles of human players. These areas might be overlapping at frontier zones. Depending on the specific position attributed to one player, his observable behaviour might also be different. In this case the position of a player influences its game posture (as in real soccer), although some teams ignore this and program all the players the same way, for simplicity and better control. The existence of different

players in different positions with different behaviours does not prevent that one playing as a *defence* cannot go up to the strike zone and score a goal. This means that game strategy should be flexible for players being able to occupy team mates positions temporarily.
Even with this type of behaviour, somehow globally established, each player should also be programmed with reactive behaviours, i.e., behaviours that permit immediate reaction to some sort of perception, for instance the imminent collision with a player or a wall.
Another issue of decision support deals with the conception and actualisation of a world model, corresponding to the play-field with its entities (Gutmann, Hatzack et al. 1999). The existence of this model might simplify entity search, and, mainly, the generation of a game plan that might include player-passing decisions, or simply, which player tries to take ball possession. There are two kinds of models: global and partial. Global models are kept by the coach or players and store information about the entire field (Nebel, Gutmann et al. 1999). Partial models only have information about each player neighbourhood in last iteration – in this case should each player own a different model (Brusey, Jennings et al. 1999; Sablatnög, Enderle et al. 1999).

3.4.2. *Behaviour generation*

What concerns behaviour specification, usually the choice falls into state machine (Ribeiro, Machado et al. 1999; Shen, Salemi et al. 1999; Yong, Ng et al. 1999) or decision tree (Jonker, Corten et al. 1999; Nebel, Gutmann et al. 1999) based solutions. In some cases (Ribeiro, Machado et al. 1999) they use a little number of states (4 only). In this way, each of the machine states, or tree nodes, corresponds to a determined type of attitude that can be a basic skill or a high-level behaviour – which in turn will trigger basic skills. The transition between states and nodes, respectively for the state machine and decision tree, is commanded by rules based on percepted data.
It is to reference the use of a Markovian decision process to determine robots behaviours (Demura, Miwa et al. 1999). This team determines actions and states stochastically, with the help of a table that maps current states to actions with a probability.
Two other approaches are also to be referred: the use of fuzzy evaluations (Nardi, Adorni et al. 1999) or dynamic-systems based (Bredenfeld, Christaller et al. 1999). One of these teams, rather than having a sequential behaviour organisation, possesses a set of behaviour modules, whose evaluation is performed in parallel. Only the one of these modules that gets the highest trigger level during evaluation is activated. The trigger level calculation takes into account two fuzzy preconditions – *can do* and *want to do* – and two parameters, that are the static and dynamic relevance, that consists, respectively, in a predefined module order and according to situation module order. The other implementation, behaviours are formalised as dynamic systems, by ordinary differential equations. Functioning modes are defined (defence, attack, etc.) that regulate percepted information interpretation. An hierarchy of behaviours is proposed, where elementary behaviours, the ones belonging to the lowest level, are composed by two subsystems: target dynamics (calculates the kind of actuation relevant for this behaviour based on sensorial data) and activation dynamics (resulting in a value in the range 0 – 1 that indicates the activation degree of this behaviour). In this way, one can continuously change the decision point regarding situation and history until then. According to their authors, the major difficulty is associated with the establishment of activation dynamics.
Concerning programming languages, the teams either use conventional programming languages (typically C/C++ or Java) or use languages specifically developed by teams (with specific primitives for their problem), such as

ARVANDLAN (Jamzad 1999) and RUBA (Ventura, Aparício et al. 1999). ARVANDLAN defines a set of nodes (seen as behaviours) that correspond to C source code blocks, linked together by a set of transitions (entered in a file). This language allows the specification of global nodes - executed always when its conditions are met – and also includes the interruption concept. In its turn RUBA language implements a society of communicating agents, between them and to society exterior, by means of a shared medium, called blackboard. This language has a LISP similar syntax and allows the specification of rules, states and events.

The previous solution exception is implemented by an Australian team. They use a Java based commercial agent software development tool - Jack (developed by *Agent Oriented Software*). Jack allows the programmer to specify plan or strategies in order to react to different situations (Brusey, Jennings et al. 1999).

Almost every player knows a basic set of behaviours, also called basic skills: search for the ball, move towards the ball, kick the ball, etc. The selection and execution order for basic skills, or the definition of new skill-based behaviours, which will be of a superior level, shall command the player resulting attitude. In this last case an hierarchic or level organisation structure is introduced, which is probably the mostly used kind of structure (Oswald, Becht et al. 1999; Plagge, Günther et al. 1999; Ventura, Aparício et al. 1999).

3.4.3. *Learning techniques*

Contrarily to what happens in other RoboCup categories, sophisticated artificial intelligence algorithms are not yet implemented in the middle size league. This happens because these robots suffer constant changes in their hardware that alters at great extent their dynamics, so making simulator implementation a hard task. These simulators are essential when talking about artificial intelligence in order to validate the best solution. Thus, almost every team supports their decision making process not on artificial intelligence or learning techniques, but on a mapping of observed situations to desired behaviours, being this mapping more or less predefined. One of the few examples on the use of advanced artificial intelligence techniques comes from a team that uses reinforcement learning to classify adversarial actions, in what can be seen as an attempt to adapt its behaviour to the one of the opponent (Nardi, Adorni et al. 1999).

3.5. Actuation

After perception and decision-making it is necessary to apply the game strategy, by robot movements and actions. A good decision strategy, based on a reliable perception, might be ruined if the actuating part of the robot is not effective. The robot should have then actuation systems as reliable and precise as possible, since this is also synonymous of its robustness.

In order to score a goal it is necessary to introduce the ball in the goal. For that, there exist essentially two strategies: either taking the ball up to the goal or finding a way to kick the ball. The first solution guarantees better ball control, but on the other hand requires that the player travel with the ball up to goal area, possibly loosing opportunities to score. Being away from the goal and when travelling to it, the player could have a clean path to shoot, but because it has to take the ball up to the goal area it gives his opponents time to react and block routes to goal. The majority of teams, even with slightly different approaches, use the second solution, with either a pneumatic system based or electromagnetic based kicking devices. A well developed kicking device, besides the possibility of kicking, also gives the possibility of passing the ball to other team mates.

Pneumatic kicking devices make use of a cylinder that stores air under pressure (Demura, Miwa et al. 1999; Jonker, Corten et al. 1999; Nardi, Adorni et al. 1999; Plagge, Günther et al. 1999). This cylinder is connected to a pneumatic cylinder by means of valves. The pneumatic cylinder shaft impels the ball. Pneumatic cylinder air pressure can be controlled by actuating the valves accordingly, thus controlling the translational speed of its shaft. This is a simple and reliable solution. Some participating teams can kick up to 20m with a capacity of replay in 5s and 50 kicks at maximum strength.

Electromagnetic systems kicking devices make use of solenoids, which when driven by electric current produce a magnetic field, thus attracting metal shafts. There are two kinds of implementations: one solenoid or two solenoids based. The first one uses the magnetic field to impel the shaft to kick the ball. When the electric current is cancelled the shaft return is forced by a spring (Brusey, Jennings et al. 1999). The second approach uses one solenoid to impel the shaft and the other one to bring it to home position (Oswald, Becht et al. 1999). These kinds of implementations need well-developed electronics in order to produce the required (relative) high DC voltages.

Besides the existence of the previous solutions, some teams achieve kicking without using any of the above. What their players do is to impel the ball to goal by bumping on it (Yong, Ng et al. 1999). This is, when a player sees the ball, accelerates to it until collision. The impact transfers trust to ball putting it in motion. As the ball is kicked by rebound (in a billiard-like manner) against the player it is necessary accurate control over player heading when contacting the ball.

A player’s manoeuvring capacity is another factor to explore, as it allows control simplification and spends less time in task execution. Hence, every team pursues characteristics as robot turning capacity among any point in the plane he stands.

To move robots, the most common adopted way uses two wheels with independent motors and at least one other wheel free. Turning is possible with differential actuation in each of the motor wheels. Rotational speeds are normally adjusted by PWM, generated either by a micro-controller or a PC. Other solutions employ omnidirectional wheels, which have the capacity of moving in any direction. Finally, one team besides using independent motor wheels also has independent direction control for each of the wheels (Jamzad 1999).

4. CONCLUSIONS

Any team is free to make their own decisions, and that is what makes this game more beautiful, imprevisible and scientifically interesting. Each team uses his own solutions, most of them work, ones better than others. It is important to keep creating new solutions in order to keep science moving. Rules change are also welcome from time to time, in order to get new challenges, to get a more competitive game and to get a game more human-like. In human football the rules also change from time to time, in order to get more spectacular football.

This competition called RoboCup is a multi-disciplinar challenge are therefore it requires new solutions not only on software but on electronics, mechanics, multi-agent systems, etc. There is not ONE magical and unique solution but many different solutions depending on many things.

To conclude, in order to build a robot football team, some aspects have to be kept in mind and those are following described.

- Computer vision is definitely one of the techniques to gather information with most success, there is one team which uses only one major sensor and it is based on vision. But, it is important to choose the right tools (both software and hardware). The filters to get the colours (entities of the game) have to be as reliable as possible. Some team use RGB other YUV, being the second the ones with more success because they do not depend so much on lighting conditions.
- The hardware should be 100% reliable, just like a washing machine in which a button is pressed and it does the job without maintenance. Our experience shows that most of the time during a championship, many teams are sorting out hardware problems and that should not be the case.
- The choice for faster motors is also another important characteristic to bear in mind. But, even more important is the ability to control those motors. No matter how fast the motors are, if one cannot control them fast.
- Some teams kick the ball by pushing it with their body towards the goal. But, with the improvement of the goal keepers, scoring a goal is becoming more difficult for those teams and therefore the use of a kicking device is advised.
- Localisation of the robots on the field is also used by many teams and although that helps the tactic some teams still don't use it and they also have success. It is not, therefore, a critical point to discuss but having it helps.
- Most teams come to a point where they can play acceptable football. Now it is the time to improve tactics and that will be more successful if co-operation is used, like in human football. Players talk to themselves and they get used (learn) to play with their team mates. Having co-operation means that the robots can pass the ball, know where their team mates are on the field, they can instruct another team mate to do a certain movement, and an enormous number of different techniques can be used (just like human can create an imprevisible movement at any time).
- But, co-operation means that a means of communication is needed. That should be reliable, not get mixed with the other team, not use to much media resources and be as fast as possible. Most teams use wireless network boards (radio frequency). Teams should also be aware that external people to the game (public) can limit those resources by using mobile phones, or other devices, even without knowing that they are interfering with the game. Other interference exist like photographic camera flashes, video camera automatic focus (some use ultrasound), etc.
- Software Optimisation has also to be considered. Low level languages have to be used in order to increase computation efficiency to the maximum. As an example, the software has to analyse images taken by the computer vision system and the more frames per second it can analyse the better for the game, the faster the robot reacts. The routines that are used more often should be extremely optimised.

If all these aspects are taken into account, that is the first step to achieve a good, simple and efficient tactic for the robots to score the maximum of goals.

Many teams can play football, but not as good looking as external people expects. But, we are sure, that is coming in the next couple of years.

As bottom line it is important to say that, RoboCup is a very mediatic event and it is attracting more and more sponsorship. Even though this challenge requires much money, time, and working resources, the scientific community hope that the money will not destroy the science behind the competition.

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