Collaborative Emergent Actions between Real Soccer Robots

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Abstract We discuss how to induce a set of collaborative emergent actions between two soccer robots. Cooperative abilities, like exchanging a ball, can be achieved through the use of efficient collision avoidance algorithms implemented on two players able to frequently swap their roles. These algorithms have been tested on Bart and Homer, designed at IAS Lab. of Padua Univ., that played quarter, semifinals, and finals with ART at RoboCup'99. The interaction with the ball was made easy by a directional kicker which allowed to hit the ball both frontally and laterally.

1. A Directional Kicker.

An *intelligent multi-robot system* can be contructed by some mobile robots that cooperate to solve a given complex task thanks to *communication* among individuals, and a dynamic *group reconfigurability*. If we indicate with the term *cooperative behavior* a collective behavior that is characterized by cooperation [4], then a behavior is *emergent* if it can only be defined using descriptive categories which are not necessary to describe the behavior of the constituent components [12]. In [5] a cooperative ability without communication is obtained through the use of a BDI approach, while, in [14] the same ability is obtained by using explicit communication. In [8], and [9], we have illustrated how to induce some emergent cooperative behavior through an implicit communication. In this paper, we discuss the problem of how to give cooperative abilities to the individual robots in the group through the use of emergent behaviors, by illustrating the solutions that has been adopted to control the two robots *Bart and Homer,* designed at IAS Lab. of Padua University, that played very successfully in the ART Team on RoboCup'99, by scoring a total of 5 goals in 9 games. Homer won also the Technical Challenge against Friburgh University.

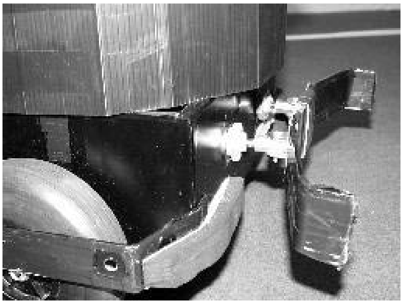

Fig 1

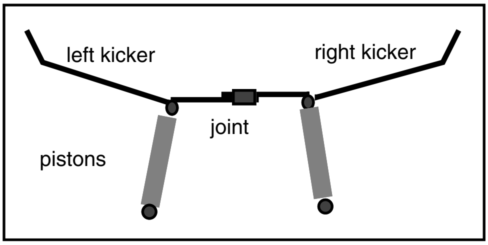

Fig 2

P. Stone, T. Balch, and G. Kraetzschmar (Eds.): RoboCup 2000, LNAI 2019, pp. 297-302, 2001.

In these games, a very effective emergent cooperative ability was achieved by Bart and Homer through the use of efficient *collision avoidance algorithms* activated while they were mutually exchanging their play roles. Basic behaviors, like *find_ball, go_to_ball,* and *carry-ball*, were used in conjunction with a smart *collision avoidance* ability, that was the reason why the collective emergent were induced into the two robots. In particular, the carry_ball behavior was able to carry the ball along a path hitting it only when a full contact between the left and/or right kicker was detected.The most effective tools which made easier to control the ball, during robot actions, was the *directional kicker*, the only one among all competing teams. The kicking system, Fig. 1., is composed by an air tank, a couple of pneumatic pistons, and a directional effector, which allows to kick frontally or laterally, depending on the activated piston (both for a front kick, or left or right, only for a lateral kick). The effector is composed by two separated symmetric pieces with a small corner to facilitate the control of the ball. The two pieces may slide one on each other allowing high flexibility and accuracy of contact with the ball, Fig. 2 The accurate ball control allowed to carry the ball without loosing it, along the direction detected by the collision-avoidance algorithms.

2. Function Q and the Dynamic Role Assignment of ART.

Bart and Homer were programmed by using a *behavior-based* approach, [3], to the aim of obtaining a robotics social organization, [10]. A set of different robot roles has been introduced, according the definition of a role given in [13], by specifying a set of behaviors. An Arbiter activates the basic behaviors according to the data received from the sensor module, based on a simple F.S.M. Each basic behavior is realized as an Expert in the Real-time Kernel Ethnos [11].

A *measure of quality Q,* able to triggers the prop role, was introduced at IAS Lab. of Padua Univ., for evaluating how much work must be done by a robot to get the ball in the best position to score. Q_i *is a weighed linear function* of:

- distance of robot *i* to ball
- relative position of robot *i* w.r.t. a right approaching configuration to the ball
- ball recorded position when the ball is not visible by robot *i*
- presence of other robots on the way of robot *i* to goal
- number of failure of robot *i* to get moving around without colliding
- previous role played by robot *i.*

Each robot i computes independently Q_i based on its local estimation. The robot sends this value of Q_i to its teammates 10 times per second, and decides autonomously how to behave comparing its own estimation of Q_i with the other value of Q_i. Function Q was used in Stockholm by the whole ART Team [6], to distribute among its team members a specific role set depending from its value communicated using Ethnos. Players were able to assume *three different roles:* - *Role* #1 must play the ball, either if it is defending or it is attacking; *Role* #2 must cooperate with robot that has role #1, *Role* #3 must locate itself far from the place where the ball is played.

A generalization of the function Q has been introduced in [7], as a set of *utility functions,* able to give through an explicit communication some *utility values* that indicate the usefulness of each role. Thus, ART robots may decide to distribute among its team members a specific role set depending from the values assumed by some functions transmitted among the members.

Bart and Homer were able to shows a cooperative action, like a *ball exchange*, by coordinating their basic behaviors through the dynamic assignment of the above three roles realized by a set of behaviors that exploit some smart collision-free motion strategies, based on the computation of field vectors. An Obstacle Avoidance module implemented these motion planning algorithms as an Ethnos Expert.

3. Field vector-based collision-avoidance.

Indeed, each ART member was left free to specialize the basic behaviors for the robots of their local team. At IAS Lab of Padua Univ., we developed an original *design of the behaviors* for Bart and Homer, based on collision-avoidance algorithms that use *field vectors* and generate *schema-based behaviors* [2]. Both *target* (the attractor) and *obstacles* (the repulsors) generate their specific vectors. The target generates a purely attractive field, proportional to the distance, while the obstacles generate a rotational field

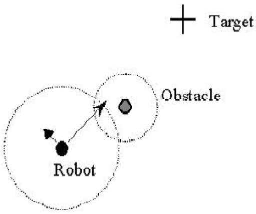

Fig. 3

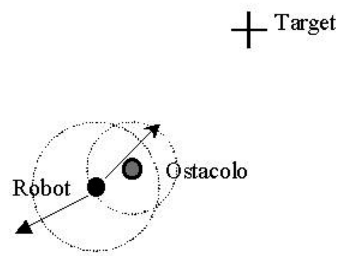

Fig. 4

All active behaviors send to the Obstacle Avoidance ExperT (OAET) the coordinates of a target. The attractive field vector is bounded by the max. robot velocity. Then, OAET realizes the motion towards the target according to the corrections induced by the obstacles on the attractive field vectors. Each obstacle is surrounded by a circular zone that indicates its affected area (OA), equal to 1 meter. The robot-affected area (RA) is computed according to a sum of robot dimension with its instant velocity: OA_ray = 1000 mm; RA_ray = V-robot + Dim-robot (see Fig. 3). The rotational field is computed according to Coulomb Laws: $I = (K * H) / r^2$ where K and H are constants. K was determined experimentally in such a way that its value could be comparable with the intensity of the attractive field, while H is equal to 0, to to 1/Distance-from-object, or to 1, w.r.t. to the Distance-from-obstacle. That is, if the robot is too much close to an obstacle, then it must be forced to make a back-step, as in Fig. 4, since the games rules penalizes a robot if it collides with other robots. Then, obstacle's field vector become repulsive instead of rotational, if the distance between robot and obstacle is ≤ 550 mm. Sometimes two alternative paths can be equally selected to get the target, as in Fig 5, but only one is safe due to other constraints, as in Fig 6. A decision is achieved by blocking a direction on one rotational vector, in order to force all other vector directions to follow. A frequent delicate case is in Fig. 6, where the robot must decide if it is more convenient to turn around the obstacle. Because of the wall, it may turn right towards the free area. But, if walls is considered as a particular kind of repulsive obstacles, then the resultant becomes parallel to the wall itself, as in Fig 7.

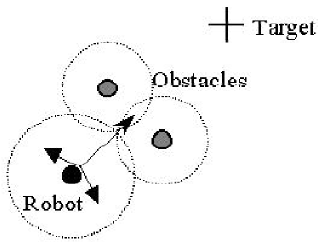

Fig. 5

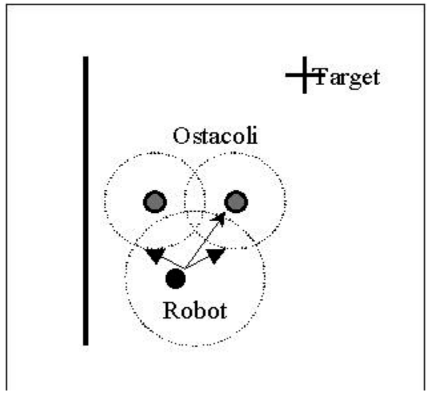

Fig 6

A serious problem may arise if both two opposite directions are blocked due to some difficult configuration like the one of Fig. 8 (and its symmetric configuration where the target and the robot are swapped). We decided the robot does not move for a while, waiting the opponents' move, or a game restart by the arbiter.

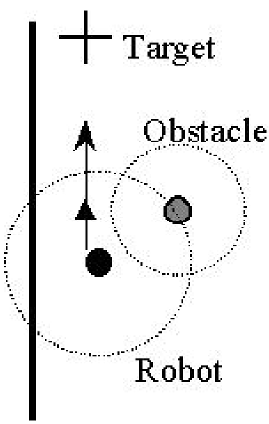

Fig. 7

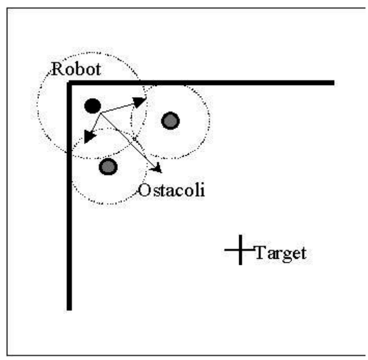

Fig. 8

To enhance role swapping robustness, and avoid the system unstability, Q was made sensitive to the previous role played by robot *i* To make the role #2 very effective, at IAS Lab, we did the following assumptions: - *A):* when a robot plays role # 2, it must never obstruct robot with role #1; - *B):* when a robot plays role # 2, it must try to quickly take the ball if it realizes that robot with role #1 does not succeed to perform its task; - *C):* when a robot plays role # 2, it must keep itself close to robot with role #1 to recover the ball if robot with role #1 looses it; - *D:* when a robot plays role # 2, it must never interfere on the path between robot with role #1 and opponent's goal. To reinforce the robustness of *robot role-swapping,* robot navigation algorithms were based on a different evaluation of the attractive and repulsive potential fields of robot that plays role #2 versus the one of robot that plays role #1. Robot #2 is much more influenced by obstacles than robot #1. Then, robot #2 also moves directly towards the ball, but it does not obstruct robot #1, since it is affected by a stronger repulsive force than robot #1. Indeed, if robot #2 meets robot #1 along its path to the ball, he treats robot #1 as an obstacle, and its repulsive force prevents it to interfere with the action of #1. If, for any reason, robot #2 does not meet robot #1 along its path to the ball, then robot #2 is able to assume role #1. When robot #1 meets an opponent, while keeping the ball, often it makes a back-step, to avoid collision, while robot #2, its supporter, succeeds to move to a better approaching position to the ball. Thus, robot #1 makes room to its supporter robot #2, that may take the ball, and swap its role.

Fig. 9

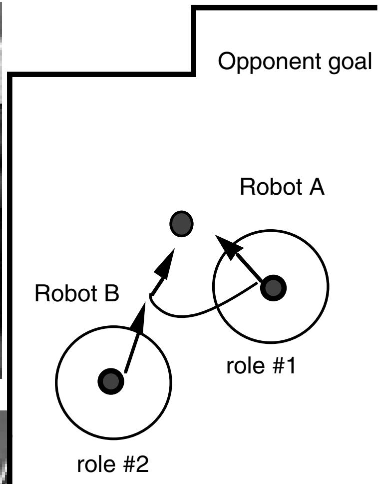

Fig. 10

In Fig 9 and 10, robot #1 keeps the ball, but robot #2 is in a better scoring position, although far from the ball, the value of Q computed by robot #1 becomes lower than the one computed by robot #2. Thus, the two robots swap their roles, and they succeed to *exchange the ball*, as an emergent behavior. This configuration really happened several times when Bart and Homer had the opportunity to play together with ART team. We verified it *(and video recorded in www.dei.unipd.it/~robocup)* several times in Stockholm during the quarter-finals and semi-finals against the Universities of Ulm and Friburg .

4. Conclusions

We illustrated our approach based on the emergent behaviors for controlling Bart and Homer that played together successfully at RoboCup'99 competition with ART team. To easily control the ball, a special kicker was designed for Bart and Homer, which allows to kick frontally or laterally. A set of basic skills, like carry_ball, and others, were implemented. We showed how to achieve an emergent cooperative ability, and to realize a ball exchange, through the use of efficient collision avoidance and robot role swapping.

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