UTTORI United: Cooperative Team Play Based on Communication

K. Yokota[1], K. Ozaki[1], N. Watanabe[1],
A. Matsumoto[2], D. Koyama[2], T. Ishikawa[2],
K. Kawabata[3], H. Kaetsu[3] and H. Asama[3]

[1] Utsunomiya University,
7–1–2 Yoto, Utsunomiya–shi, Tochigi 321–8585, JAPAN.
[2] Toyo University,
2100 Kujirai, Kawagoe–shi, Saitama 350–8585, JAPAN.
[3] The Institute of Physical and Chemical Research (RIKEN),
2–1 Hirosawa, Wako–shi, Saitama 351–01, JAPAN.

Abstract. In order for multiple robots to accomplish a required mission together, they need to organize themselves, cooperate and share information. We regard such actions as "team play" and believe communication is the essential tool for team plays. This paper discusses communication in the distributed autonomous robotic system and development of cooperative actions for football playing robots. The discussed communication framework and cooperation are implemented in our omni-directional mobile robots which has vision for sensing and a wireless device for communication.

1 Introduction

The distributed autonomous robotic system (DARS) is a flexible and robust robotic system in which multiple robots and other agents act in a cooperative and coordinated manner to achieve tasks which are not easy for a single robot [1]. We believe communication is essential tool for cooperative actions of autonomous robots and have been developing communication technology and demonstrating cooperation based on communication [2, 3].

We regard the football game as a collection of cooperative actions of autonomous robots. In order for a team to score a goal, its players must cooperate in bringing the ball forward, maneuvering between fore players. We assembled a team of omni-directional, autonomous robots which are capable of communicating and sharing information between them[4, 5].

2 Communication-Based Cooperation

We regard explicit communication is the essential tool to realize team plays in the multi agent robotic system [2]. It is sometimes argued that explicit communication is too complicated to implement and implicit communication performs better in the environment where agents must act in real-time [6, 7]. However,

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explicit communication is more direct means to pass information and intention of a robot to other robots. The explicit communication is also expected to be reliable in that ambiguity can be avoided. The implicit communication, or communication based on observation, always is susceptible to errors arising from misunderstanding and misinterpretation of the situation.

3 Communication among Robots

We classify communication patterns as shown in Fig. 1. Of these patterns, "announcement", "order", "synchronization" are the communication which does not expect answers. Answers and interaction are expected in the other communication patterns.

Announcement This is broadcast communication. It is used to pass piece of information to the other agents.

Order When an agent asks the others to take certain action, this communication is used. Unlike "request" and "contract" described below, this communication is of broadcast type and does not expect answer, it is not guaranteed that the recipient agent will take requested action.

Request This is point-to-point communication and is used to retrieve particular information from a particular agent.

Contract When an agent wants to request action or service from one or more agents, this protocol is followed. It is based on the Contract Net Protocol [8]. Both parties of the contract are fully in agreement as to what is going to be done.

Collective Decision This communication provide "voting" mechanism. A robot initiates the voting procedure, and the other robots will give their votes. Result is summed up by the first robot and transmitted to the rest.

Synchronization This communication is used when synchronized action is required by more than one robot. All robots start intended action upon receiving this message.

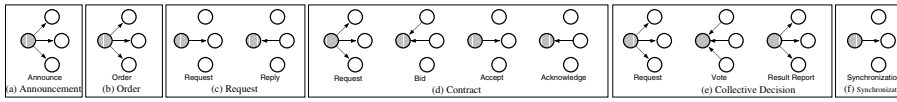

Fig. 1. Communication for "team play"

4 Autonomous Robots for Team Play

Fig. 2 and fig. 3 show our football playing robot and its system diagram. The robot is based on the omni-directional mobile robot. All the robots share the

same basic design, yet their control system, sensors and kicking mechanisms differ.

"ZEN" has an omni-directional driving mechanism which is driven by three actuators [9]. The primary sensing device of the robot is vision; a CCD camera is connected to a frame buffer whose resolution is 512 dots by 512 dots. A simple kicking mechanism (fan or repulsing plate) and tactile sensors are connected via parallel I/O.

A single microcomputer (i486/DX4 100MHz or Pentium MMX 200MHz) controls all actuators, manages sensory inputs, and processes image input from the CCD camera. A wireless LAN adapter is provided so that the robot program can exchange data with the other robots. The current communication program module uses UDP/IP as communication protocol and implement message exchange protocol on top of it.

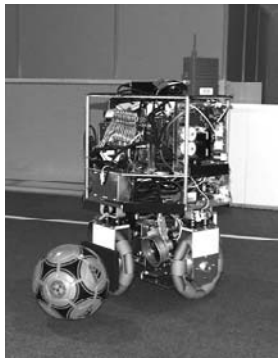

Fig. 2. Omni-directional mobile robot "Zen"

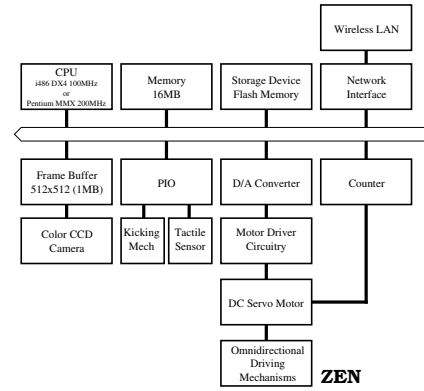

Fig. 3. System diagram of the football playing robot

5 Cooperative Team Play

Fig. 4 lists the cooperative actions implemented by the football playing robot.

Coordinated Offense When a robot thinks that it is in control of the ball, it will let the other robots know that the ball is owned by the first robot. The other robots will not approach the ball and will prepare for the next attacking action. These actions are coordinated by the broadcast communication "announcement" and will give the team the ability to infiltrate into the enemy half of the field quickly towards the goal.

Defense When the goal keeper finds the ball near the goal, it will assume that the opponent is attacking the goal and will order the other robots to backup and defend the goal. This is implemented by the broadcast communication "order".

Pass Explicit agreement between the two robot is sought before the ball is passed. The action must be negotiated by the robots as described in Section 3.

Distributed Sensing It so often happens that a robot may loose sight of the ball. Another robot may be able to find the ball and will tell the others of the location of the ball, if possible. This is a form of distributed sensing. The robot which finds the ball will use the broadcast communication "announcement" to tell the robots of the location of the ball.

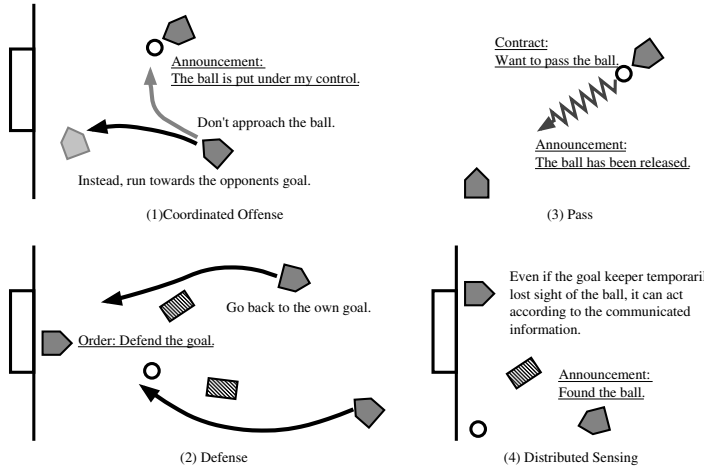

Fig. 4. Cooperation among robots

6 Performance of UTTORI United at RoboCup-98 Paris

The team UTTORI United brought three robots to Paris: two forward robots and a goal keeper. A laptop computer was used to instruct the robots to start and end playing the game. However, the computer was not used in any way to tell the robots what to do during the game. There is no centralized control in the team. The entire system is fully autonomous and distributed; the robots acts, based only on sensory information and communication from the other robots.

Our system worked very well throughout the competition. Table 1 (a) shows communication log in one of the games. Soon after kick off, the two forward robots *stmr2* and *omni4* dashed towards the ball. The robot *omni4* reached the ball first and declared that it was in control of the ball by sending the message "CONTROLLED" to the other robots (it continued to transmit the same message while it is moving the ball). The robot *stmr2* then stopped approaching the ball and turned towards the goal. The two robots moved together, side by side, to the goal. This is one instance of the most powerful performance of UTTORI United; two robot showed coordinated offense action. This is not achieved by the

centralized control or planning; it is realized by cooperation by the two robots based on communication.

Table 1 (b) shows negotiation process (Fig. 1 (d)) of the two forward robots. The robot *stmr2* wants to pass the ball to another robot. The argument "5" for the message "PASS" indicates that the robot *stmr2* wanted to kick the ball towards the very front of the goal. The negotiation succeeded and the robot *stmr2* kicked the ball. However, the ball did not successfully reached the robot *omni4* in this particular case.

Table 1. Communication log

(a) Coordinated offense

Time	From	To	Message	Notes
0000				stmr2 and omni4 dashes to the ball
0017	omni4	all	CONTROLLED	omni4 declares it has the ball
0017	omni4	all	CONTROLLED	two robots run side by side
0017	omni4	all	CONTROLLED	
0018	omni4	all	CONTROLLED	

(b) Pass

Time	From	To	Message	Notes
3184	stmr2	all	CONTROLLED	stmr2 is in control of the ball
3184	stmr2	all	CONTROLLED	stmr2 is in control of the ball
3185	stmr2	all	PASS 5	stmr2 wants to pass the ball
3185	omni4	stmr2	RECEIVE 5	omni4 offers to receive the ball
3185	stmr2	omni4	PASS_OK 5	stmr2 accepts the offer
3185	stmr2	all	CONTROLLED	stmr2 is still in control of the ball
3185	omni4	stmr2	PASS_ACK 5	omni4 acknowledges
3185	stmr2	all	CONTROLLED	stmr2 is about to kick the ball
3193	stmr2	all	RELEASED	stmr2 has kicked the ball
3193	stmr2	all	RELEASED	

Other communication patterns, defense and distributed sensing, also appeared during the games. Communication-based cooperation made UTTORI United one of the most powerful teams during preliminary games; the team scored 8 goals in three games, although it has only three robots and they are slower than most robots from other teams.

However, when wireless communication does not work due to various disturbances, performance of the team suffers. For some reasons, wireless communication in our team was disappointingly inferior during the final tournament and the team failed to score any goals.

Fig. 5 shows the proportion of cooperative actions and autonomous actions by robots in terms of time. Figures are derived by examining communication logs and adding duration of valid messages. The figure clearly indicates that the performance of the team is better when the robots cooperate than when they behave independently. These results proves that cooperation based on communication significantly amplified the performance of the team.

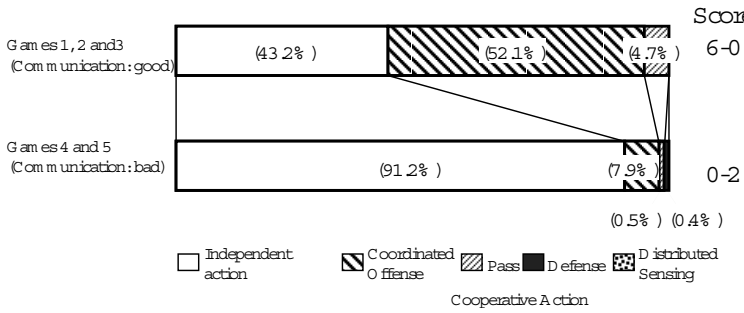

Fig. 5. Cooperative actions and independent actions

7 Conclusion

We believe communication is the essential tool for team plays. The paper discussed communication among autonomous robots and development of cooperative actions by them. The discussed communication framework and cooperation are implemented in our omni-directional mobile robots which has vision for sensing and a wireless device for communication. The games in Paris demonstrated the validity of our approach.

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