Strategy of Cooperative Behaviors for Distributed Autonomous Robotic Systems

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Abstract

In this paper, we present the strategy of distributed autonomous robotic systems (DARS) for cooperative behaviors. The DARS are the systems which consist of multiple autonomous robotic agents into which required function is distributed. For building of DARS, the agents can recognize the environment where they are located, communicate each other, and generate some rules to act by themselves. In the paper, we introduce our DARS robot to perform cooperative behavior which is the task of our research – the pursuit competition with one-fugitive robot versus multi-detective robot. The paper also presents the area-based decision making algorithm to determine the direction of the robot maneuver.

Keywords: DARS, camera vision, sensor, motor, bluetooth communication, main MCU, area-based decision making algorithm, fugitive and detective robot

1. Introduction

Nowadays, the robots replace the human working in the fields of rescue a life at highly destroyed building by fire or gas contaminated place, getting some information in the deep sea or the space, and watching the weather condition at the extremely cold area like the Antarctica. Especially, we need to penetrate multiple robots to get more trustful and robust information data from hardly accessible area, such an ant's nest under the ground. In this case multiple robots send the data by cooperation and communication each other and make a decision to act by themselves.

Distributed autonomous robotic systems (DARS) have been focused by many researchers as a new way to control the multi-agents more flexibly and robustly. The DARS are the systems being organized by multiple autonomous robotic agents into which required function is distributed. The most unique and important feature of DARS is that each system is a distributed system composed of multiple agents (robots) [1]. According to this feature, the subject of DARS can be various widely. DARS are now applied to multi-robot behavior, distributed control, coordinated control, and cooperative operation, etc.

Typical mobile robot systems consist of robot body (frame), vision system, sensor system, drive (motor) system, communication system, and main controllers. There are many ways, which depends on the main task of robot and which part of robot will be specially intellectualized, to apply these systems efficiently [2]. For cooperative works, the Khepera can be the role model of design. It consists of a main processor (Motorola 68331), driven by two d.c. motors, and has eight infra-red proximity sensors around its body (55mm diameter, and 30mm height) [3]. This robot still being used for in many fields like fuzzy control, wall following, obstacle avoidance. We take similar appearance with Khepera or RoboSot (one model of the soccer robots) for our robot.

In this paper, we organize DARS to perform the pursuit competition with one-fugitive robot versus multi-detective robot. The paper introduce about our robot system and its functional block component in chapter 2. We present the task of our DARS, the area-based decision making algorithm, and experimental results in chapter 3. The paper concludes the subject and issues future works in chapter4.

2. The Autonomous Robot for DARS

Our robot system consists of four sub-parts and a main micro-controller part. The sub-parts are camera vision, sensor, motor, and bluetooth communication, respectively. Each sub-part has its own controller to perform a unique function more efficiently. The main micro-controller part controls four sub-parts to avoid process collision and performs decision making by the data of its sub-parts.

2.1. Camera vision

The camera, which we use for the robot, is Movicam II made by Kyosera. The Movicam II is the CCD camera being used for SKY cellular phone. Its size is 30×47×29 mm (width × height × thick) and weight is 12g approximately. A frame consists of header, image data, and end maker. Fig. 1 shows camera appearance and the data components of a frame in detail.

When clock is applied to the clock-port (port #2), it starts to send the data at rising clock from the header to the end maker bit by bit. The data-out port (port #1) of camera is attached to DSP (Digital Signal Processor) TMS320LF-2407A which is programmed to perform signal processing. The size of image data is rather bigger to wait the end of pro-

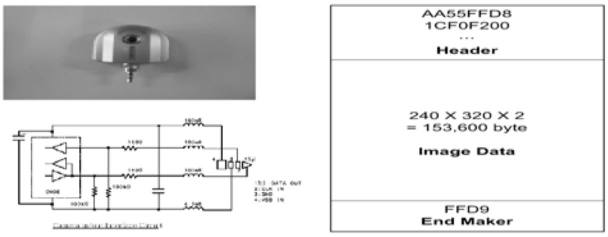

Figure 1. Camera and the data component of a frame

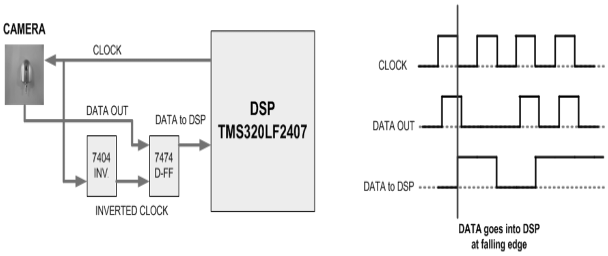

Figure 2. The connection between camera and DSP (left), the data transfer timing (right).

cess with whole image(153,600 byte). Accordingly, we optimize the program to cramp the image data within 25,000 byte. The connection between DSP and camera is showed in Fig. 2(left). The data transfer is presented in Fig. 2(right).

2.2. Sensor

The robot has six of infra-red (IR) sensor pairs (emitter/detector) to measure the distance around itself. The emitter is Kodenshi EL-1kl3, high-power GaAs IR mounted in durable, hermetically sealed TO-18 metal package. The detector is ST-1kla, high-sensitivity NPN silicon phototransistors mounted in durable, and the package is same with the emitter's. The six IR sensors are placed with 60 degree angle of each other, so they can cover whole 360 degree.

We chose the emitter, which has narrow beam angle (about 17°), to avoid interference. The detector, however, has almost 50° beam angle, therefore it can detect most of IR reflection by the object. The appearance is showed in Fig. 3 (left). The arrangement, the area where can be covered by the six of sensor pairs, and the block diagram are depicted in Fig. 3 (right).

2.3. Motor

As driving part, we use NMB PG25L-024 stepping motor. Its characteristics are drive voltage-12V, drive method 2-2 phase, and 0.495° step angle, etc. Fig. 4(left) shows torque-

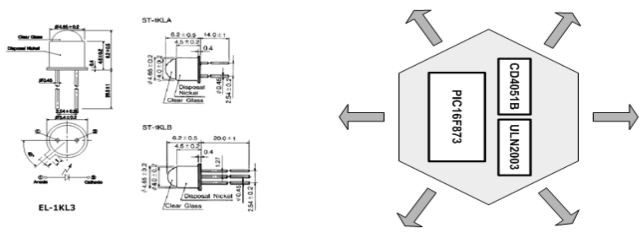

Figure 3. El-1ka3 and ST-1kla (left), sensor block diagram (right).

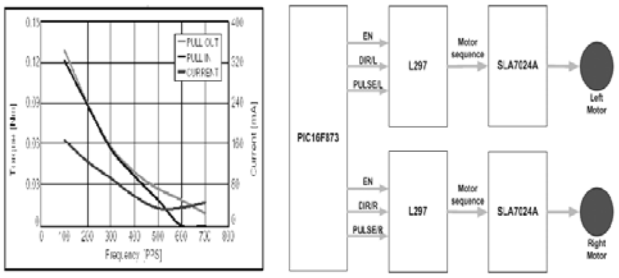

Figure 4. Torque characteristic (left), motor block diagram (right).

Table 1. The relationship of signals and actions.

Signals	Actions
0x00	Forward
0x01	Rotate 60° clockwise
0x02	Rotate 120° clockwise
0x03	Turn around (rotate 180°)
0x04	Rotate 60° counter clockwise
0x05	Rotate 120° counter clockwise

frequency-current characteristic curve. By the figure, the maximum self-operating frequency is 600 pps. We assemble the driver with L297 and SLA7024A combination to control two motors. Fig. 4(right) and Table 1 present the block diagram and the signals associated actions pair of robot by decision making.

2.4. Bluetooth communication

Blutooth communication was developed to use for mobile device, which includes battery source, with the motto 'low -cost,' 'low-power,' and 'compact.' For these characteristics, bluetooth regard as very suitable for wireless communication system [4].

Bluetooth fundamentally organizes its network with 1 master to 7 slave architecture. The PicoNet is the net which consists of one master and multiple slaves. The ScatterNet is the net organized by PicoNets. Fig. 5 depicts the concept of PicoNet and ScatterNet.

In DARS, there is no pre-defined classification like master and slave. All agent robots should be distributed individually. We'd like to apply, however, the concept of master/slave only for communication. The detective robots need to communicate each other only when they catch the fugitive robot in their vision. Therefore it can be said that "We are still in the DARS."

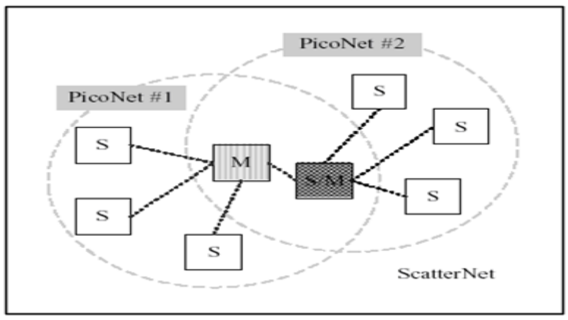

Figure 5. The PicoNet and the ScatterNet diagram.

2.5. Main Controller

We design the system as every sub-part has its own controller. Therefore, main controller has little overhead. The function of the main controller is control the UART Tx/Rx communication between main controller and sub-controller. It also generates the rules of next action, change moving direction or camera vision on/off or send the data to other robot, by the sub-parts' data. Fig. 6 is the block diagram of whole robot system connected with main controller and the appearance of our robot.

3. Cooperative Behavior Example of DARS

In DARS, the best role model for cooperative behavior is the ants' cooperation. When the ants find a food which is much bigger than an ant itself, they get around by the food and start to cooperation. Similarly, the robot cooperation means operating multiple robots cooperatively. Therefore, the communication between robots is essential.

In our system, the fugitive robot must run away from the pursuit of multiple detective robots. To perform their own task (i.e. escaping and tracking), both the fugitive and the detective robot recognize the surrounding by their sensors, and generate the rule by recognizing the situation. In this chapter we discuss with two issues – the distance measurement and the area-based decision making to generate rules and change direction, and show the experimental results.

3.1. Distance measurement

The robots must know its situation by measuring the distance around itself. In Fig. 7, dashed line presents the distance-A/D converting value curve. It is expected to have inversely proportional form rather than linear or hyperbola. The approximation of this fomula is

$$Distance = \frac{\alpha}{A/D\ conv.\ value} + offset \qquad (1)$$

We set the coefficient α = 580 and *offset* = 7 by experiential result. The solid line presents its approximated value curve in Fig. 7.

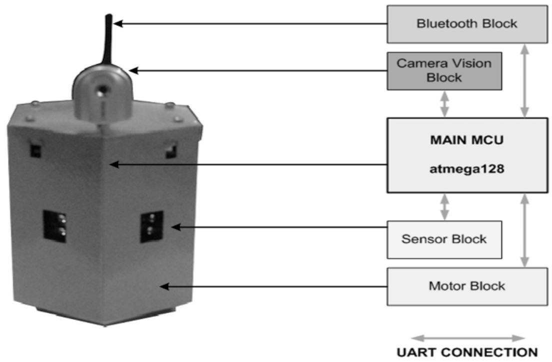

Figure 6. The robot and main MCU with 4 sub-parts connection.

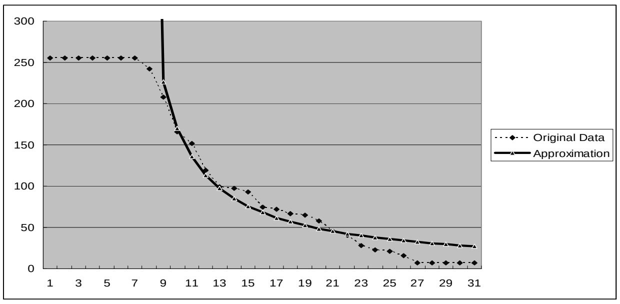

Figure 7. Distance to A/D conv. value curve by equation (1).

3.2. Area-based decision algorithm

To change the direction of running, we can consider two algorithms – the distance-based and the area-based algorithm.

In the distance-based decision algorithm, the fugitive robot considers the direction which a sensor returns the longest distance as the safest direction. Thus, the robot takes the following steps to determine the next direction.

- The robot gets 6 of A/D conv. value from detect sensor.
- The robot decides the direction which returns the longest distance as safe way without any obstacles.
- The robot changes the direction.

In the area-base decision algorithm, however, the robot follows these steps,

- The robot gets 6 A/D conv. value from detect sensor.
- The robot calculates the 6 areas with each A/D conv. value from detect sensor.

  $Area = \frac{1}{2}\, \overrightarrow{s_1} \times \overrightarrow{s_2}\, \sin 60°$, where $\overrightarrow{s_1}, \overrightarrow{s_2}$ are the distance measured by sensor 1 and 2.
- The robot decides the direction which returns the widest area as safe way.
- The robot changes the direction.

In brief, we can generate the rule of fugitive robot's behavior with this simple concept,

"Change your direction to where you can guarantee more wide space."

The rule of the detective robots can be define easily by adding one more condition to above,

"If you get the fugitive in your camera, try to occupy more wide area in the fugitive's plane."

This is the basic concept of area-based decision making. The concept is similar with the behavior-based decision making but is different to change the direction by the area [5]. Fig. 8 shows the difference between the distance-based and the area-based decision making by example.

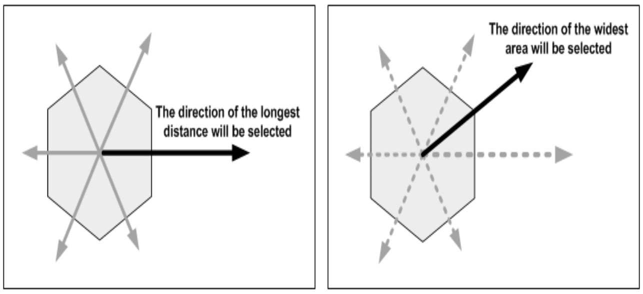

Figure 8. The different results, with the same sensor values, by the distance-based (left) and the area-based (right) decision making.

3.3. Experiments

We experiment two different situations with our robots. The results are shown in this chapter.

First, we release the robot on the hallway where no obstacle but walls. Fig. 9 shows the pictures of the robot on running. We tested the robot's running by 50 trials. The robot succeeded 43 times out of 50 trials, but 7 times failed. The reason of fails was the robot took the turnaround (turn 180°) decision continuously, even if both its front and back space are freely empty. To clear this problem, we modified area- calculating function by the multiplying of weight, $\boldsymbol{w}_{front}$ = 1.2, to the calculation of front area.

Second, we try for the robot to explore the hallway where three obstacles are located. Fig. 10 depicts the robot's running in the second situation. The result shows the robot found the next direction more easily when it is surrounded by other obstacles. At the 1st and the 3rd turns, however, the robot has many other choices to avoid the 1st and the 3rd obstacle. It is the main reason that the malfunction (i.e. back to the 1st obstacle when tries to avoid the 3rd) occurs several times. By the reason, the robot succeeded its task 31 times out of 50 trials.

Figure 9. The robot is running in the hallway.

Figure 10. The robot is running through the 3 obstacles.

4. Conclusions and Future Works

In this paper, we introduced the hardware specification of the robot and architecture of our DARS. We also proposed the area-based decision making algorithm and presented the two experimental results with the robots in the two different situations. The result shows us that the area-based decision making can be a new way for the obstacle avoidance.

The future works would be to complete the implement-tation of the detective robots and to find out appropriate and efficient way to pursue the fugitive robot more concretely in DARS.

Acknowledgement

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References

[1] H. Asama, T. Fukuda, T. Arai, et al, Distributed autonomous robotic systems, Springer-Verlag, 1994.

[2] J. H. Kim, H. S. Sim, S. H. Kim, et al, Robot soccer engineering, Dooyang, 2003.

[3] S. H. Lian, "Fuzzy logic control of an obstacle avoidance robot," *Proc. of the Fifth IEEE International Conference on Fuzzy Systems*, vol. 1, pp.26-30, 1996.

[4] S. H. Whang, K. B. Sim, I. C. Jeong, et al, "Design of efficient strategies for distributed multi-agent robot soccer system," *FIRA Robot Congress*, pp. 1-5, 2004.

[5] W. Ashley, S. Balch, and T. Balch, "Value-based observation with robot teams (VBORT) using probabilistic techniques," *Proc. of ICAR 2003*, vol. 1, pp. 1-8, 2003.