Paper:

Emergent Approach to Circle Formation by Multiple Autonomous Modular Robots

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[Received October 22, 2007; accepted March 26, 2008]

This paper deals with the problem of circle formation by multiple autonomous robots on emergent approach. The robots in question are simple, having fan-shaped local vision consisting of three areas to detect three states in each area – whether the number of robots in an area is zero, one, or more than one. We suggest heuristic action decision rule having robots form a circle stochastically. Using computer simulation, we make it clear that view angles of the local vision and the number of robots in the arena affect circle forming process, and that the certainty of circle formation is high enough if robots have certain view angles. We describe that view angles control the distance between robots using kinematic view. The keys to designing robots to form a circle are the front-view angle for making virtual attraction force toward one robot, and the side-view angle for making equilibrium of virtual force toward two robots.

Keywords: multi-autonomous-robot, micro-mechanism, local vision, circle formation, emergent approach

1. Introduction

1.1. Background

Design factor of a robot system consists of generally the following two:

– design of a task and environment and

– design of the robot's functional and informational mechanism for completing a task.

For a complicated task or environment, the robot's functions generally are expanded and the information dealt with increased, complicating the functions or control laws.

Distributed autonomous approach to problem solving is based on keeping robot's functions simple and having robots cooperate in completing a task against an approach to problem solving by extending robot's functions. Even this distributed autonomous approach, however, involves problems in improving robot's functions and control laws complexity. For study of group behavior [1, 2, 5] or pattern formation [3, 4], which is often dealt with by multi robot system, robot action is described based on rule or dynamics and an individual robot requires information on the locations of other robots, which implicitly implies that the locations of other robots can be known precisely. Advanced functions are needed for this purpose and the amount of information increases based on the degree of required precision. If robots must communicate, a complex protocol is required to exchange information. In short, system complexity and difficulty of implementation increases with the amount and quality of information and especially the number of robots. Shimizu et al. [6] proposed solving this problem using "emergent phenomena" derived by exploiting the interaction between control and mechanical dynamics. They use the interaction between neural oscillators to morphologically control a modular robot – a good example of how the improving of functions is not directly connected to complexity of control laws.

1.2. Minimalistic Robot System

In considering task difficulty and robot ability, a deterministic solution designs robot ability equal to or more than its minimum requirement (Design a, b) for a task (Task T) with a degree of difficulty (**Fig. 1**). Other solutions use an emergent approach that designs robot ability at less than its minimum requirement (Design c-e) and has robots in a group attempt to complete a task. Naturally, in such an emergent approach, an individual robot has minimum required ability and a task cannot be completed with equal to or less than a certain limit (Design e). Suzuki and Yamashita et al. [4] discuss autonomous and distributed algorithm in an alignment problem, but the premise is that a robot can acquire information needed to complete a task without any functional restriction. In short, no emergent element is included in the system and robot ability is equivalent to Design b in design logic.

We implement "minimalistic" robot design to simplify individual robot functions and control laws in so far as possible, targeting implementation of a robot system that solves the problem of increasingly improving of functions

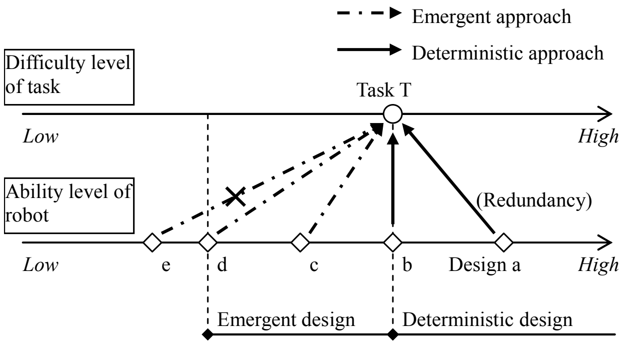

Fig. 1. Robot system design based on task difficulty and robot ability.

and control laws complexity. To do so, we take advantage of the interaction among robots and the goodness of design of a robot's function mutually related to individual robot control laws. This is useful in a multi robot system that uses simple functional robots given the effective use of a robot's finite functional resources. Also, it can be a helpful knowledge in designing an emergent system to clarify emergent phenomena and their mechanisms.

1.3. Task and Minimalistic Robot Design

We propose circle formation on emergent approach involving a robot designed based on the above premises. Circle is a simple geometric pattern that uniquely represents boundary conditions – robot placement – of individual robot forming the circle.

A minimalistic robot consists of a function part and an information processing part. The function part has movement and local vision functions. Movement assumes the ability to move forward and turn left or right, controlled by whether two wheels are active or inactive. Local vision consists of three visual fan-shaped areas – front, left, and right – for detecting another robot's being. The number of robots detected in each area is one of three states – zero, one, or more than one. Information processing in circle formation uses a reflex action decision rule that makes input information from local vision correspond directly to robot movement.

1.4. Overview

We show how to form a circle using emergent approach and a mechanism to bring it in using computer simulation. Section 2 details the minimalistic robot model used in simulation, and Section 3 details the action decision rule of a robot. Section 4 gives an example of the task environment, setup, and formation process of a circle in simulation to explain circle formation (task completion) and how to evaluate the characteristics of this formation process. Section 5 shows the characteristics of circle obtained in simulation and shows that the view angles setup of local vision is a design point in circle formation. Section 6 analyzes robot movement using kinematic view because this movement is observed based on something like

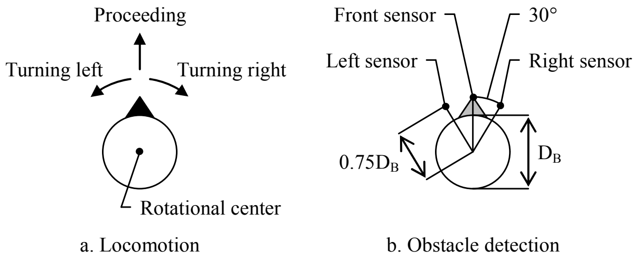

Fig. 2. Movement and sensing for obstacle detection.

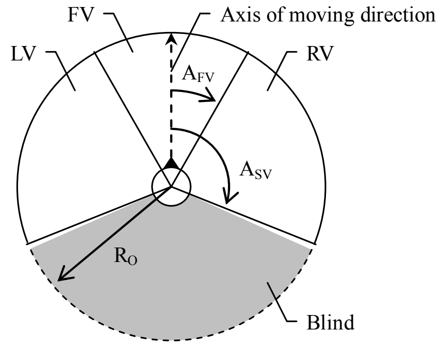

Fig. 3. Model of local vision function for robot detection.

forces due to the action decision rule and local vision interrelated. The virtual force is defined by the number of robots detected through the local vision and view angles setup. We consider the emergent mechanism of circle formation. Section 7 summarizes conclusions.

2. Minimalistic Robot Model

The robot model is round, has a diameter of D_B, can move, senses obstacles for avoidance during movement, and uses local vision function to detect other robots.

2.1. Movement and Touch Sensor

The robot's movement function lets it move forward and turn left or right (**Fig. 2a**). The robot's movement during simulation represents the sum of moving and turning per discrete unit time as a change in its position and direction of movement.

When a physical collision between robots is dealt with by computer simulation, a touch sensor (**Fig. 2b**) serves as the sensing function, detailed in Appendix A.

2.2. Local Vision Function for Robot Detection

The local vision model (**Fig. 3**) set as the vision function detects another robot within finite distance R_O in polar coordinates with the center of the robot assumed to be the origin and the direction of movement the reference angle (0°). Local vision is symmetrical to the reference angle and consists of three fan-shaped areas – forward (FV) and its left and right sides (LV, RV). Front-view angle A_{FV} and side-view angle A_{SV} are defined as an index that represents the angular orientation size of the vision area. The backward area (Blind) after the side-view angle is that not