Chapter 2
Macroscopic Group Robots Inspired By "Brownian Motion"

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ABSTRACT

The sections contained in this chapter, Macroscopic Group robots inspired by "Brownian motion", examine the basic concepts and the methods to develop systems of new type of group robots. We take robots especially with neither external sensors nor apparatuses for mutual communication. In microscopic physics we have a phenomena of Brownian motion. We note that in Brownian motion pollen particles can be motivated by collision with surrounding molecules although each molecule has neither sensor nor mutual communication. By setting temperature gradient surrounding the pollen particle, controlling its motion is possible. So when we note correspondence between molecules and robots, we will obtain a transportation system of macroscopic objects that correspond to pollen particles in Brownian motion. We use a potential force signal that corresponds to temperature in Brownian motion. To perform the tasks, we show and solve various challenging problems in fundamental formulae, simulation scheme, and control method in these areas.

INTRODUCTION

A new type of group robots in macroscopic world is proposed in the chapter. Our objective is controlling a motion of an object by many robots that repetitively collide to the object. In our final goal we equip our robots with neither external sensor nor apparatuses for mutual communication. The way in which Brownian motion works in microscopic physics makes the group robots act to transport an object. To carry out our objectives, we need an appropriate control scheme that requires mathematical model of the systems. A word "macroscopic" means that our systems are subject to classical Newton mechanics. We take robots especially with neither external sensors nor apparatuses for mutual communication. In conventional systems of group robots we need various external sensors mainly for collision free goal. Apparatuses for mutual communication are also necessary to achieve cooperative motion. The equipment and increase of communication paths make systems complex and result in high cost. The mechanism

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of Brownian motion helps us to develop the systems of group robots that cannot see, hear, smell their external world. In microscopic physics we have the phenomena of Brownian motion. Pollen particles floating on liquids fluctuate by collision with liquid molecules. We note that in Brownian motion the pollen particles can be motivated by collision with the surrounding molecules although each molecule has neither external sensor nor mutual communication. Among the molecules around the pollen particle energy proportional to temperature value is distributed. By setting a temperature gradient surrounding the pollen particle, controlling its motion is possible. When we note correspondence between the molecules and the robots, we will obtain a transportation system of macroscopic objects that correspond to the pollen particles in Brownian motion. But we have serious problems that our systems certainly differ from Brownian motion. Firstly, the temperature gradient is too small to work as force of transportation. Also the established stochastic Langevin's equation for Brownian motion is not appropriate to our systems. In the chapter we make an external potential field play a role of the temperature gradient. Each robot moves as if it were a physical ball under the potential. Repetitive collisions of robots force the object follow some required transportation path. The tracking is controlled by a form of the potential function. Regarding a governing equation of the system, continuum mechanics is shown to efficiently describe classical Newton mechanics of the robots. After analysis of collision process of robots and an object, we show numerical simulation and tracking control in transportation systems. Validity is examined by comparing those with numerical simulation that are given by directly solving many-body Newton equations. The sections in this chapter show fundamental formulae, simulation results, and control method in these areas.

After we show new transportation systems inspired by Brownian motion, how to efficiently describe our systems is examined in detail. According to the analysis of collision process, we do simulation studies. Emphasis is on comparison of continuum mechanical calculation with those by direct simulation using Newton equations. We control macroscopic Brownian motion by group robots. To make an object track a required path, feedforward control input is found using our model of continuum mechanical description. In the final part of the chapter, an improvement of the continuum model and an experiment on control by potential force are given as future directions of research.

BACKGROUND

In cooperatively acting robots, we expect an intelligence that an individual robot will never achieve. We now have technology branch called swarm robotics or swarm intelligence (Pfeifer & Bongard, 2006; Abraham, Grosan, & Ramos, 2006). We have various studies on group robotics (Liu & Wu, 2001; Chen & Li, 2006; Li & Chen, 2006; Badano, 2008). They have been thoroughly investigated in a framework of multi-agent (Ota, 2006). In swarm intelligence scheme, sensors are inevitably equipped for each robot (Ohkura, Yasuda, & Matsumura, 2011). In Reynolds (1987) a centralization of control strategies has been fucused. Meanwhile local information without sensor fusion has been applied to target capturing task (Kobayashi, Ohtsubo, & Hosoe, 2007). In addition in Shimizu, Kawakatsu, & Ishiguro (2005), whether each robot can obtain global information or not have been argued. No global control is emphasized. There is a trade-off relation between equipping apparatuses for sensing and mutual communication among robots and assumption of global imformation. Local interaction can lead global order. In fact in physical phenomena we have "phase transition" due only to local interaction of physical agents (molecules, atoms). In many cases, we need to provide robots with specific devices to see, hear or smell to organize

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