Study for Emergence of Implicit Control Law in Swiss Robot Phenomena

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Abstract: Living things exhibit adaptive and supple locomotion under the real world characterized by rapid changes, high uncertainty, and limited availability of information. We propose that Implicit Control Law is a key concept to understand the adaptive locomotion of the living things. In this paper, the Swiss Robot is picked up. The experimental results show this robot utilizes the Implicit Control Law for the realization of its interesting behavior. Then, this element is investigated using the molecular dynamics.

Keywords: Swiss Robot, Implicit Control Law, embodiment

1. INTRODUCTION

Living things can move adaptively even if they are placed in an unknown environment. To understand these adaptive locomotion, we focus on the element that appears by interaction among the brain (*e.g.* control law), the body (*e.g.* plant), and the environment. This element is recognized as an another control law called Implicit Control Law (Implicit C.L.). The remainder element is the element which stayed after substract the Implicit Control Law from the control law as the Explicit Control Law (Explicit C.L.) [1].

In this study, we focused on a Swiss Robot that shows interesting behavior even if the Exlicit C.L. is very simple [2]. Our experimental result verified that the Swiss Robot can cluster the cubes using the Implicit C.L.. In this paper, we proposed how to formulte the collecting mechanism and show the way to collect more cubes.

2. SWISS ROBOT

2.1 Experiment

Fig. 1 shows an overview of the Swiss Robot. The Swiss Robot is equipped with two motors and two infrared sensors, mounted symmetrically on its right and left sides. This robot is programmed with the following algorithm that provides a simple Explicit C.L..

if Left sensor stimulation **then**
(left motor, right motor)=(forward, inverse)
else if Right sensor stimulation **then**
(left motor, right motor)=(inverse, forward)
else
(left motor, right motor)=(forward, forward)
end if

We set one Swiss Robot and 15 cubes in a closed area (Fig. 2(a)). The length of one side of the cubes is 0.09 [m] and that of the field is 1.8 [m]. We set the sensor reference distance (l) at 0.15[m] and the sensor angle (ϕ) at 30° and the distance between two sensors (d) at 0.12[m]. Fig. 2 shows the experiment result. Fig. 2 indicates that the Swiss Robot can cluster the cubes even if the Explicit C.L. is very simple. This implies that the robot clusters them using Implicit C.L. that appears by the interaction between itself and its environment.

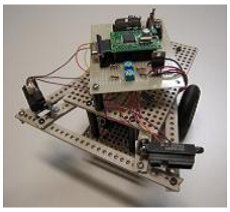


Fig. 1 Swiss Robot

(a) Initial State

(b) Final State

Fig. 2 The Experiment Result

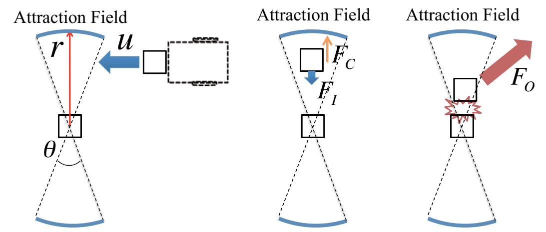
2.2 Formulation of this robot phenomena

In this section, we do not focus on the movement of the robot but that of the cubes and formulate as the state equation by using the kinetic theory of the molecules. In this process, we consider the attraction field as follows.

(a) When one cube is out of the attraction field (the attraction field is a part of a circle in a vertical direction to the cube movement), this cube moves with the velocity $\boldsymbol{u}$ caused by the random force $\boldsymbol{F}$ from the Swiss Robot (Fig. 3(a)).

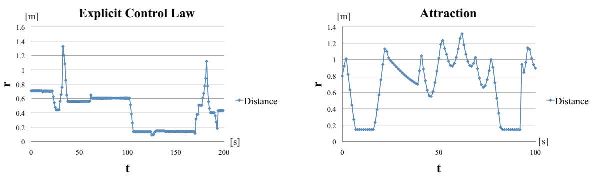
(b) When one cube is inside the attraction field, the attraction force $\boldsymbol{F}_I$ and viscous force $\boldsymbol{F}_C$ is applied to this cube (Fig. 3(b)). This attraction potential can be decided by using Lennard-Jones potential $\phi(r)$ written by the equation [4].

$$\phi(r) = \epsilon_0\{(\frac{r_0}{r})^{12} - 2(\frac{r_0}{r})^6\}$$



(a) Out of the attracton field (b) Inside the attraction field (c) Influence of the repulsive force

Fig. 3 Formulation with the attraction field



(a) Swiss Robot (b) Attraction Field

Fig. 4 Comparision with the Swiss Robot model and attracion field model

Where ϵ_0 is the potential coefficient, r is the distance between the cubes and r_0 is the distance which cut off the force. Moreover the viscous force $\boldsymbol{F}_C$ is stronger than the attraction force $\boldsymbol{F}_I$. That is, the cube inside the attraction field do not move so much.

(c) The cube existed in the attraction field, the random repulsive force $\boldsymbol{F}_O$ is applied to this cube under the small probability (Fig. 3(c)).

Moreove, the radius of the circle r is approximately equal to the sensor reference distance l of the Swiss Robot. And the angle θ is decided by the sensor angle ϕ.

From the above consideration, the Swiss Robot phenomena is written by the equation.

$$\xi \frac{d\boldsymbol{x}}{dt} = \boldsymbol{F}_a \tag{1}$$

$$m\frac{d^2\boldsymbol{x}}{dt^2} = \nabla\phi(r) - c\frac{d\boldsymbol{x}}{dt} \tag{2}$$

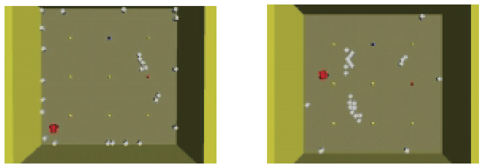
$$m\frac{d^2\boldsymbol{x}}{dt^2} = \boldsymbol{F}_c \tag{3}$$

Where ξ is the resistance coefficient, m is the mass of the cubes, $\boldsymbol{F}_a$ is the random force, r is the distance between cubes, c is the viscosity coefficient and $\boldsymbol{F}_c$ is the random repulsive force.

Then, we set the simulation environment as follows:

1. We use two cubes and five robots to simplify the cubes phenomena.
2. We set the field as equal probability condition $-1 \leq x \leq 1, -1 \leq y \leq 1$.

Fig. 4(a) shows the result of the above Swiss Robot model and the Fig. 4(b) shows that of the above the model with the equation (1)-(3). From Fig. 4, we consider that attraction force $\boldsymbol{F}_I$ express the clustering and repulsive force $\boldsymbol{F}_O$ also express the cubes are devided by Swiss Robot accidentally. That is, the Swiss Robot phenomena can be



(a) l=0.10m (b) l=0.25m

Fig. 5 The influence of the short and long sensor reference distance

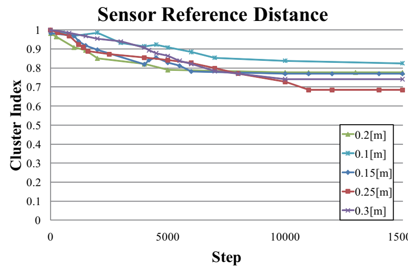


Fig. 6 The influence of the sensor reference distance

expressed as the another simulation model which consists of the attraction and repulsive force that will be expected to be equivalent to the Implicit Control Law.

2.3 Influence of the radius of the attraction field

In the real Swiss Robot model, we have to consider the influence from the walls. If the cubes is pushed near the walls at once, the cubes near the walls should not move. From the reason in order to collect more cubes, the size of the attraction field will be important.

Then, the simulation is carried out with the sensor reference distance $l = 0.10, 0.15, 0.20, 0.25, 0.30[m]$. Moreover, using the statistical approach, the Cluster Index that is able to examine the collecting ability is introduced. Fig. 5 shows the worst and best collected results and the change of the Cluster Index is shown in Fig. 6. From Fig. 6, we verified that the cubes is more collected when the sensor reference distance is large.

3. CONCLUSION

In this paper, we formulated the Swiss Robot model using the kinetic theory if the molecules and shows the attraction force and viscous force is equivalent to the Implicit C.L. element.

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