

Design and Realization of Autonomous Decentralized Object Transfer System: Magic Carpet

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Abstract: The attempt to realize magic carpet driven by autonomous decentralized type control algorithm is proposed. The algorithm is evaluated mainly by computer simulation and trial manufacturing of experimental setup. Due to the recent development of micromachine technology, we can integrate a lot of very small decentralized modules, each of which consists of sensor, actuator and electronic circuit. However, control algorithm of such systems have not yet been developed enough. To avoid complicated wiring problem of communication network, it is assumed that the module should exchange information only with neighboring several modules. The proposed algorithm is divided into two steps. One is the macro rule based on the concept of "field" which controls the general behavior of the carpet. Another is the micro rule to control each module in a robust manner. Some basic simulations on macro control and experimental results on micro control are shown.

1 Introduction

Recent development of science and technology has realized a lot of things which have been drawn only in "SF" world. Micromachine is one of them. The submarine on the film "Fantastic Voyage" is often referred to as an example of future micromachine technology [1]. Micromachine is characterized by the following "3M" [2].

1. Miniaturization
2. Multiplicity
3. Microelectronics

Miniaturization means light and speedy action. Multiplicity means harmony of many micromachines. Microelectronics is important because semiconductor process technology is crucial in making micromachines. One micromachine module has actuator, sensor and electronic circuit like a microprocessor. As each micromachine module is very small and has poor ability, a lot of micromachine modules should be integrated to perform actual tasks [3] [4].

Micromachine technology has inherent problems as follows.

1. communication
To avoid large scale and complicated wiring problem of communication network, it should be assumed that the module can exchange information only with neighboring several modules.
2. structure
Semiconductor process technology is not good at making heterogeneous structure, but very suitable to make homogeneous structure.

As discussed above, micromachine modules must harmonize with each other. To realize this function, we propose the "combined control of central / autonomous decentralized algorithms" and apply the concept of "field" [5]

2 Problem setting

For consideration of autonomous decentralized control system, we set an explicit problem. The problem is to move a ball put on the magic carpet to the target position. Each module of the magic carpet shown in Fig.1 can move along only z -direction.

$$\begin{array}{l} \text{Move the Ball} \\ (x_{ini}, y_{ini}) \Rightarrow (x_c, y_c) \end{array}$$

where, (x_{ini}, y_{ini}) is the initial position of the ball and (x_c, y_c) is the target position.

We consider the micromachine array on the xy plane ($x_{\min} \leq x \leq x_{\max}, y_{\min} \leq y \leq y_{\max}$), which consists of m decentralized modules along x -direction and n along y -direction [6]. The function of each decentralized module is given as follows. The sensor detects whether anything exists on the module or not. The actuator drives the module along z -direction and keeps it at any position. The microprocessor can perform very simple calculation and communicate only with several neighboring modules.

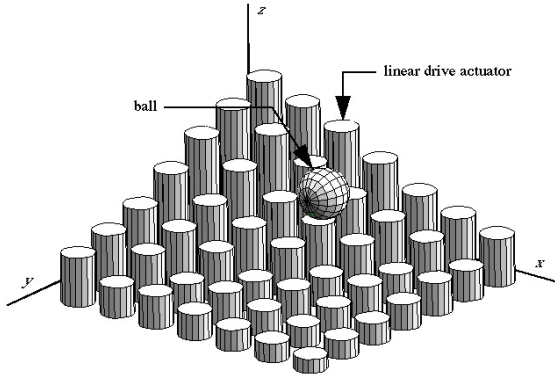


Fig.1: Conceptual configuration of magic carpet.

3 Control strategy

3.1 Concept of "field"

What is the concept of "field"? Generally speaking, autonomous decentralized system is a complex system composed of a lot of decentralized modules. However, its behavior can be divided into two steps. One is the micro-scale behavior of each module, and the other is the macro-scale behavior to rule many modules. For example, in our society, each human corresponds to a module and public opinion rules macro-scale behavior. Public opinion is a kind of "field". The micro behavior is relatively quick, and macro-scale behavior usually has a long time constant. Our proposal is to realize this "field" by central control.

3.2 Combined control of central / autonomous decentralized algorithms

We apply the proposed "combined control of central / autonomous decentralized algorithms" to the magic carpet. Fig.2 shows its conceptual configuration. The central controller is allocated around decentralized modules. The modules have lattice structure. The operator commands only to the central controller. The central controller sends commands to the several neighboring modules close to the boundary. Each module is activated by communicating with neighboring modules.

Here, it is clear that the central controller is in charge of macro-scale control, and each module is of micro control.

3.3 Control of macro-scale behavior

To convey a ball to the target position, the carpet makes a hollow. To do this, "each" module should know the target position and its own position. How does each module get these important information? It is discussed in this section.

It is easily known from the configuration of the system, the central controller gives the boundary condition.

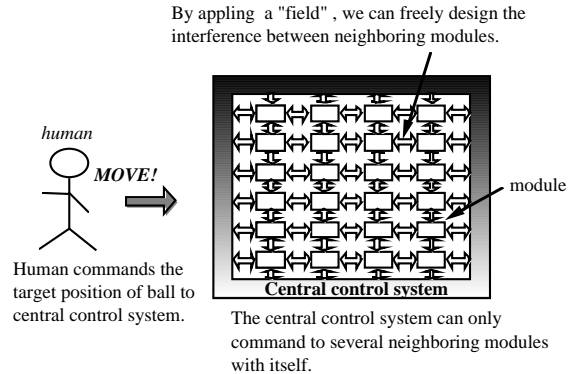


Fig.2: Combined control of central / autonomous decentralized algorithms.

At first, we design the field to tell each module of its own position. If u^{xcd} , the field value, has the solution given by (1), each module can know its own position as follows.

$$u^{xcd} = \frac{x_{\max} - x_{\min}}{x_{\max}} x + x_{\min} \quad (1)$$

$$(x_{\min} \leq x \leq x_{\max}, y_{\min} \leq y \leq y_{\max})$$

(2) is the field equation to give the solution (1). The field (2) can be realized only by local communication between modules.

$$\frac{\partial^2 u^{xcd}}{\partial x^2} + \frac{\partial^2 u^{xcd}}{\partial y^2} = 0 \quad (2)$$

To the central controller, (3) is given as the boundary condition.

$$\begin{aligned} u^{xcd}(x_{\min}, y) &= x_{\min}, u^{xcd}(x_{\max}, y) = x_{\max}, \\ u^{xcd}(x, y_{\min}) &= u^{xcd}(x, y_{\max}) = x \end{aligned} \quad (3)$$

Next, the field to tell each module of the target position of the ball is designed. If u^{xc} , the field value, has the solution of (4), each module can know the target position.

$$u^{xc} = x_c \quad (4)$$

$$(x_{\min} \leq x \leq x_{\max}, y_{\min} \leq y \leq y_{\max})$$

The field (5) gives the solution (4). Here, (5) can be realized only by local communication, too.

$$\frac{\partial^2 u^{xc}}{\partial x^2} + \frac{\partial^2 u^{xc}}{\partial y^2} = 0 \quad (5)$$

In this case, (6) is given to the central controller as the boundary condition.

$$\begin{aligned} u^{xc}(x_{\min}, y) &= u^{xc}(x_{\max}, y) = u^{xc}(x, y_{\min}) \\ &= u^{xc}(x, y_{\max}) = x_c \end{aligned} \quad (6)$$

(7) is the function to make a hollow at the target position (x_c, y_c) . (u^{xcd}, u^{ycd}) shows the module position.



Fig.3: The real world actuator module consists of solenoid plunger.

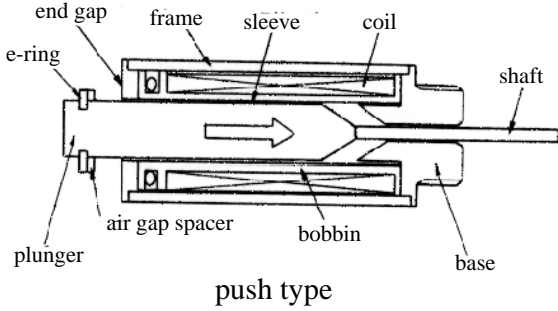


Fig.4: Configuration of the solenoid plunger.

$$z(x, y) = f(\mathbf{u}) = f(u^{xc}, u^{xcd}, u^{yc}, u^{ycd}) \\ = \frac{\alpha \{(u^{xcd} - u^{xc})^2 + (u^{ycd} - u^{yc})^2\}}{\alpha \{(u^{xcd} - u^{xc})^2 + (u^{ycd} - u^{yc})^2\} + 1} \quad (7)$$

3.4 Control of micro-scale behavior

The micro-scale control is the position (or force) control in each module. Our final goal is the realization of magic carpet based on micromachine technology, but here we realize it by a "real world actuators". Fig.3 shows a solenoid plunger, which we selected as "modules" in trial manufacturing. The structure of this solenoid plunger is shown in Fig.4. Linear position sensor is seen. Electromagnetic force is calculated using the simple model in Fig.5 as electromagnetic model. The force of the solenoid plunger takes the form of (8) using Ampere's integration law. It is inversely proportional to the square of position z and proportional to the square of current i .

$$f_e = -\frac{2\mu_0 N^2 \pi R^2}{(2dz + gR)^2} i^2 \quad (8)$$

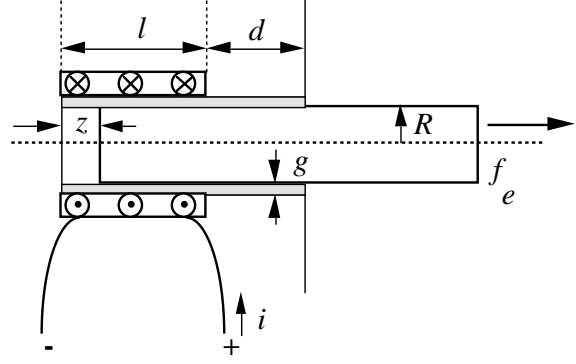


Fig.5: Electromagnetic model of the solenoid plunger.

where, μ_0 , N , R , g , π and i are vacuum permeability, turn number per meter, radius of plunger, gap length, the circle constant and solenoid current, respectively.

$$f_e = f_e(z^{-2}, i^2) \quad (9)$$

Because of high nonlinearity in force generation, position control of the solenoid is not so easy. We applied several robust control methods, and as the result, we selected variable structure control. Fig.6 and Fig.7 are its block diagram and analog diagram respectively. The comparator represents variable structure and high pass filter suppresses chattering of position z near desired position z^* in Fig.6.

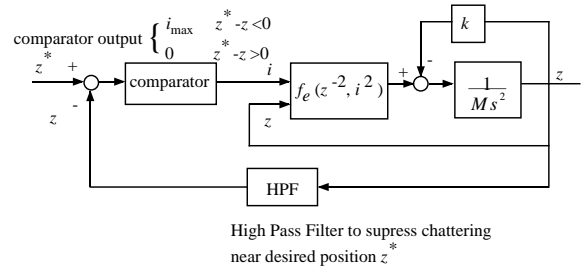


Fig.6: Block diagram.

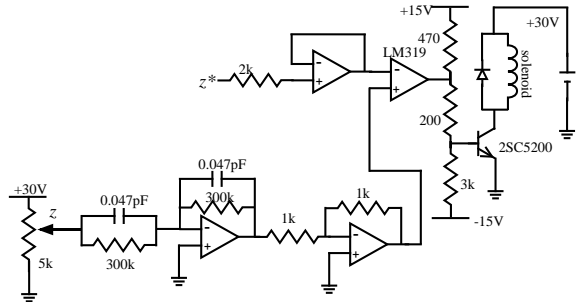


Fig.7: Variable structure controller actually used in the experiment.

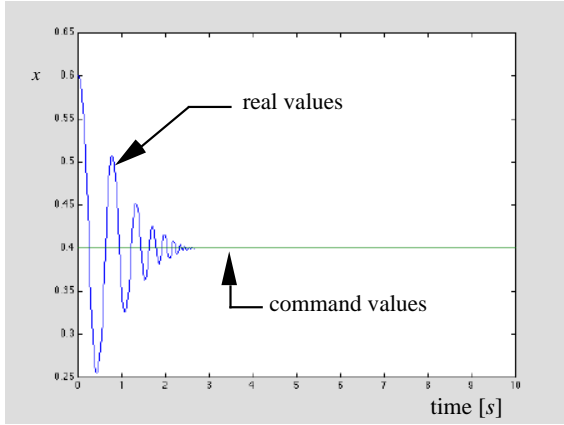


Fig.8: Simulated time response of the object transfer along x -direction.

4 Simulation and experimental results

4.1 Macro-scale behavior - simulation results -

Behavior of the ball put on the magic carpet is simulated and shown in Fig.8. Some parameters are given by Table.1. The ball position converges to the target position (0.4, 0.4) with vibration. Needed time is about 3 seconds in this simulation. Figs.9 and 10 show the surface curves of the magic carpet at 0.21[s] and 3.15[s], respectively. At 0.21[s], the object begins to move to the target position, and at 3.15[s] it arrives there.

Table 1: Parameters in macro scale control simulation.

module array number along x -direction	11
module array number along y -direction	11
(x_{\min}, y_{\min})	(0, 0)
(x_{\max}, y_{\max})	(1, 1)
(x_{ini}, y_{ini})	(0.6, 0.6)
(x_c, y_c)	(0.4, 0.4)
α	5

4.2 Micro-scale behavior - experimental results

In this section, the experiment results of micro-scale behavior is shown. Fig.11 is the position response driven by the analog circuit of Fig.7. We can see a good agreement between the command and actual position and recognize to overcome nonlinearity of the solenoid plunger by using robust variable structure controller.

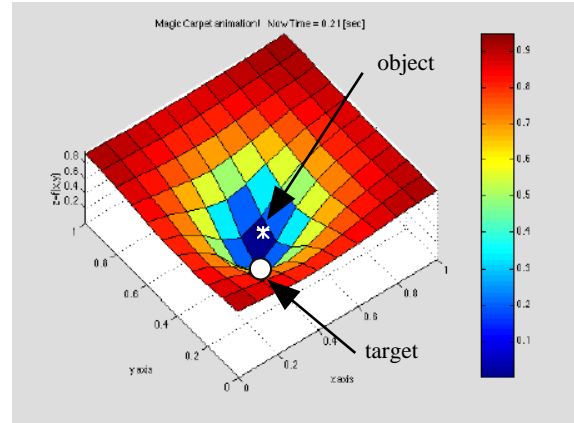


Fig.9: Surface curve at 0.21[s].

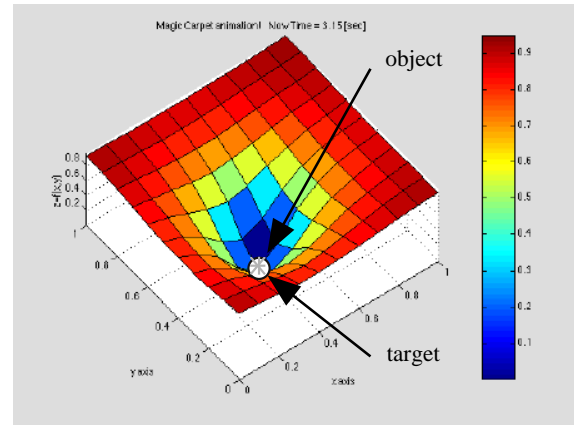


Fig.10: Surface curve at 3.15[s].

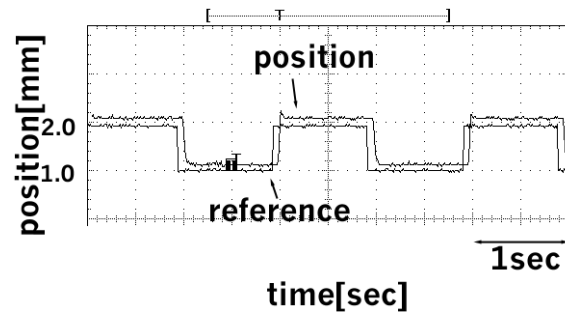


Fig.11: Position response with variable structure controller.

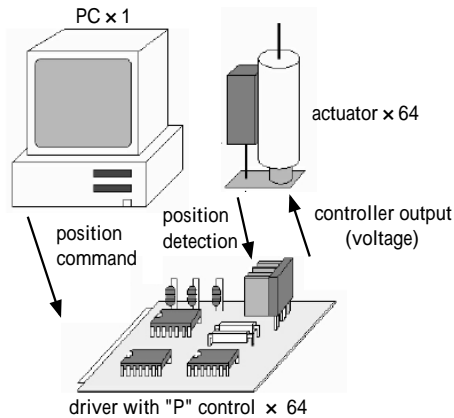


Fig.12: Experimental setup (1) under manufacturing.

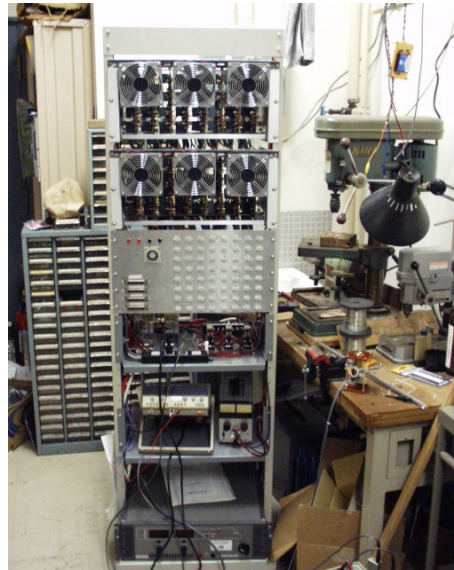


Fig.14: Experimental setup (3) under manufacturing.

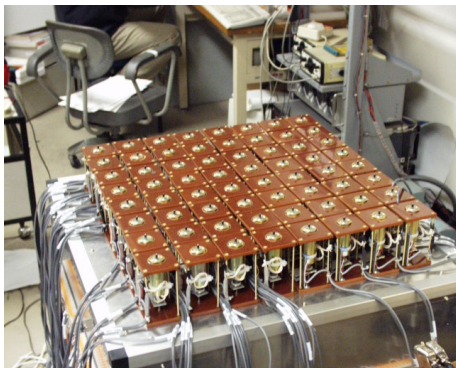


Fig.13: Experimental setup (2) under manufacturing.

5 Conclusion

We proposed the combined control of central / autonomous decentralized algorithms in the realization of magic carpet. The algorithm is divided into two steps: macro-scale and micro-scale behaviors. For control strategy of macro-scale behavior, we proposed the concept of "field". We have shown that the object can be conveyed to the target position by making a hollow in the "field", where each module estimates the target and its own positions only by communication with several neighboring modules. In micro-scale control, variable structure control of solenoid plunger position was applied successfully.

Fig.12 shows the rough sketch of the experimental setup consists of 64 decentralized modules. We will report on the experimental results in the workshop. Fig.13 and Fig.14 are actuators and controllers of magic carpet under manufacturing. We will report on the experimental results in the workshop.

6 Acknowledgement

We appreciate Ryo Marutani's cooperation. He spent his energy to manufacture the analog circuit Fig.7 of variable structure controller.

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