Cooperative Conveyance by Two Robots with Tethers in Super-Mechano Colony

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Abstract-- This paper deals with the Super-Mechano Colony (SMC) which consists of a mother robot and child robots. Cooperative conveyance by two child robots with tethers was discussed. Three types of methods to tug an object avoiding obstacles were examined by computer simulation. The third method that keeps control points showed the best performance. The mechanical experiments demonstrated the validity of the algorithm so that two robots cooperatively avoided an obstacle tugging an object.

Key words: Cooperative conveyance, Group robots, Super-Mechano Colony, Tether, Marching of robots

1. INTRODUCTION

SMC (Super-Mechano Colony) consists of a mother robot and child robots. The mission of the child robots is that they find objects in a field and convey them to the mother robot. There are many studies on cooperative mobile robotics [1]. Most of them are computer simulations to examine new algorithms on path planning, formation and marching of the robots. Several studies experimentally examined cooperative conveyance [2, 3]. However, there are few studies that robots used tools such as bars or tethers for effective conveyance of objects although usefulness of tools was pointed out [4].

Our study focused on cooperative conveyance of two child robots with tethers. Cooperative motion with tethers enables the child robots to convey a heavy object that one robot cannot move. Tethers can handle various shapes of objects. They are also compact in storage and easy to carry them. It is therefore useful for collecting objects in exploration field.

This study assumed a subject that two robots pull an object with tethers, and convey it to the mother robot avoiding obstacles on the way of conveyance. The basic algorithm to avoid an obstacle is introduced in the next chapter.

2. ALGORITHM TO AVOID AN OBSTACLE

Basic algorithm to avoid an obstacle is the following two steps. As step 1, robot B is supposed to be approaching an obstacle as shown in Fig. 1. Robot B detects the edge of the obstacle. Then robot B has priority for decision to determine the direction of ongoing.

As step 2, robot B determines the direction as follows. First of all, an evaluation function expressed by equation (1) is introduced for avoiding the obstacle. $\boldsymbol{d_B}$ is distance between CCD camera of robot B and the edge of the obstacle. It is a function of $\boldsymbol{q}$. The direction of robots is geometrically determined by obtaining $\boldsymbol{q_d}$ which minimizes $\boldsymbol{I}(\boldsymbol{q})$.

$$\boldsymbol{I}(\boldsymbol{q}) = \frac{1}{\boldsymbol{d_B}(\boldsymbol{q})} \tag{1}$$

Using $\boldsymbol{q_d}$, robot B gives a command the deflection to robot A. Simultaneous actions changing the direction expect a cooperative formation of tugging the object. However, only $\boldsymbol{q_d}$ is not enough to evaluate motion of a robot system that consists of robots and an object because tension of tethers is not considered. In the next chapter, we examined behavior of the robot system by computer simulation.

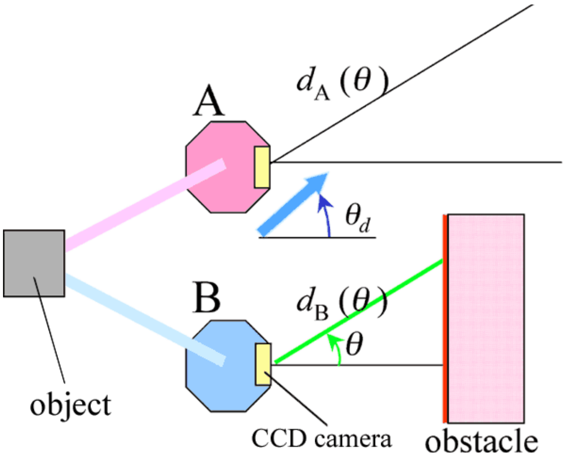


Fig. 1 Basic algorithm for avoiding an obstacle.

3. SIMULATION METHOD

This chapter first explains the simulation method, second describes the computational model and third reports the simulation results by three types of methods.

3.1 Procedure of simulation

Validity of the proposed algorithm was examined by computer simulation. The procedures of the simulation was the following steps as shown in Fig. 2.

First, positions of robots A and B at the next step are calculated by velocity of the two robots. Then the new positions are replaced as new formation of robots. Tension of tethers is obtained as described below. Then, acceleration of the object is calculated and position of the object at the next step is estimated. These iterative calculations are executed by a discrete time step.

3.2 Tension of tethers in tugging

In the above mentioned procedures, extension of tethers is an important physical value for calculating the motion of the object. The value was determined by the following way. First, acceleration of the object was calculated by considering balance of tension of tethers. Fig. 3 shows force balance of two tethers exerted on the object.

In this situation, we assumed that a tether is elastic and produces a constant force for expansion of the tether as shown in Fig. 4. Such mechanical property can be realized by use of a constant force spring mechanism.

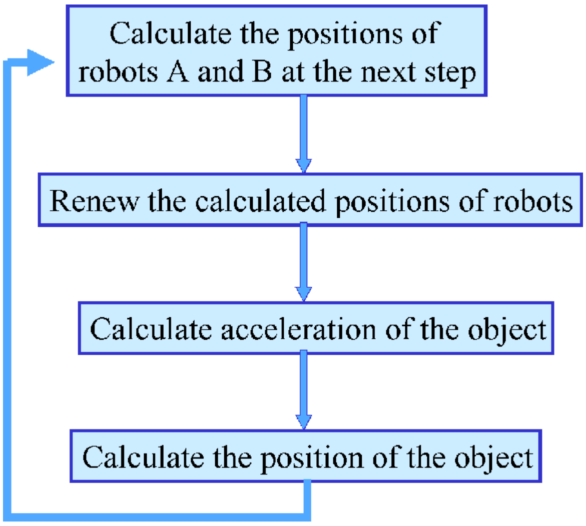
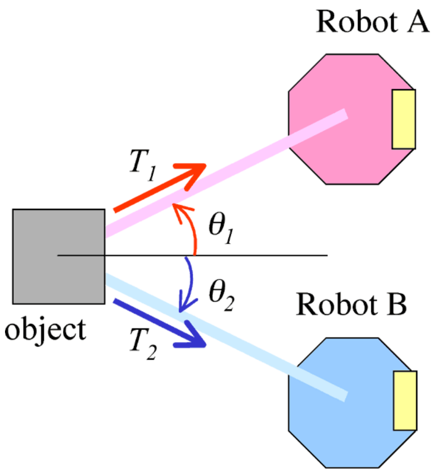


Fig. 2 Procedures of computer simulation



$\boldsymbol{T}$: tension of tether
$\boldsymbol{L}$: length of tether
$\boldsymbol{L}_0$: initial length of tether
$\boldsymbol{M}$: mass of object
m_s: coefficient of static friction
m_k: coefficient of kinetic friction

Fig. 3 Force balance exerted on the object.

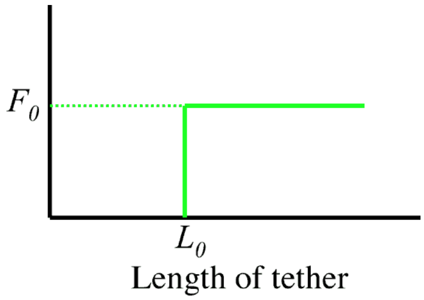


Fig. 4 Produced tether's force by extension

If the tethers are rigid and they are not stretched by any force, it is difficult to control the tensions of tethers because they quickly change during even small movements of robots or an object. It will need force control with high speed rate, which requires a high performance computational system. Moreover, weight for the computer system mounted on a child robot is limited.

In our situation, the tethers produce constant force by any tension. It does not need force sensors of tethers for control of the robot system. This means the control method of tethers become remarkably easy.

From the elastic property of tethers as in Fig. 4, $\boldsymbol{T}_1$ and $\boldsymbol{T}_2$ are calculated by the next equation.

If $\boldsymbol{L}<\boldsymbol{L}_0$ then $\boldsymbol{T}=0$ otherwise $\boldsymbol{T}=\boldsymbol{F}_0$ (2)

Then, exerted force $\boldsymbol{F}$ to the object is calculated by the following equation.

If $(\boldsymbol{T}_1\cos\boldsymbol{\theta}_1+\boldsymbol{T}_2\cos\boldsymbol{\theta}_2) > \mu_s \boldsymbol{Mg}$
then $\boldsymbol{F} = (\boldsymbol{T}_1\cos\boldsymbol{\theta}_1+\boldsymbol{T}_2\cos\boldsymbol{\theta}_2 - \mu_k \boldsymbol{Mg})$ otherwise $\boldsymbol{F}=0$ (3)

Using the exerted force $\boldsymbol{F}$, the acceleration of the object is calculated by the Newton equation of motion.

3.3 Visual function of child robot

Visual functions of a child robot were determined as in Fig. 5 taking into consideration of an experimental model. Visual distance of CCD camera was set as 1500 mm and the visual angle of sight was 120 degrees.

To avoid obstacles, two robots take visual images for each 250 mm movement and check existence of an obstacle detecting edge of the shape and tug the object with tethers.

For safe avoidance, virtual imaging technique was used as shown in Fig. 6. The blue robot views the dark blue area and calculates a moving direction denoted with the blue dotted arrow. However, the direction has danger of collision with the obstacle because scale of the child robot is not considered.

To solve the problem, a virtual image was adopted. The virtual image was generated by shifting the real image to the right side by scale of the child robot. The blue solid arrow is obtained as a safe direction from the virtual image. This method directly output a safe direction without considering scale of child robot during the image processing.

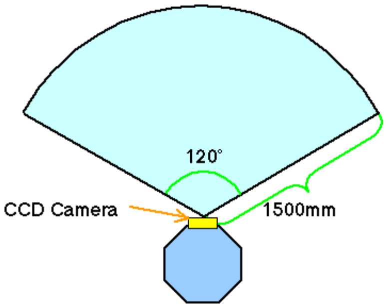


Fig. 5 Visual scope of a cellular robot

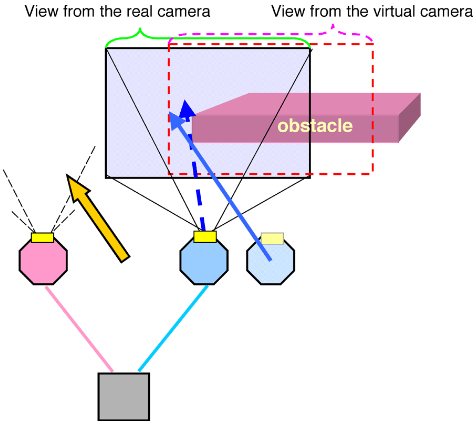


Fig. 6 View from a virtual camera

4 SIMULATION TESTS

We proposed three types of method for marching of two robots and examined them by computer simulation step by step. For the computer simulation, we provided the following conditions. The simulation field is 200 cm by 400 cm and has two rectangular obstacles in it. The two robots are placed on the left side as the first position. The mission of the robots is to move to the right direction and to reach the final goal at right side of the field avoiding the two obstacles tugging an object with tethers. The following parameters were set up for the computer simulation.

$\boldsymbol{L}_0$: 500mm, $\boldsymbol{M}$: 2.5 kg, $\boldsymbol{m}_s$: 0.15, $\boldsymbol{m}_k$: 0.1, $\boldsymbol{F}_0$: 20 N.

4.1 Simulation by method 1

The first method is the easiest way, which keeps the conveyance form of the two robots with same direction and velocity while ongoing. The two robots take a regular alignment in movement as shown in Fig. 7(a).

Fig. 7(b) shows the simulation result. The red line corresponds to the motion of the red robot, the blue line is for the blue robot and the dark green line is the orbital course of the object. The produced courses of the robots seem to be good as they show smooth lines. The course of the object is however not placed in the center of the robots. It means that either tether is too extended. This causes irregular motions of the object.

4.2 Simulation by method 2

To improve the improper tugging by the first method, second method was proposed. The method is to keep conveyance form between robots and object an shown in Fig. 8(a). The robots rotate to adjust direction before going forward so that the object is almost always placed in the center position of two robots.

Fig. 8 (b) shows the simulation result. As the generated course of object is almost in the center of the robots, the result tells us that two tethers maintained almost same length. However, the motions of the two robots showed complex. It means that the two robots wasted energy in conveyance.

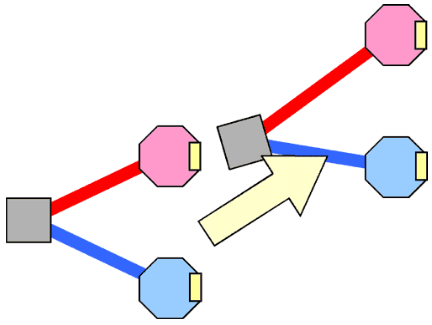


Fig. 7 (a) Method 1: keeping the arrangement of robots
Two robots keep a same posture so that they face an obstacle in the same direction during tugging an object.

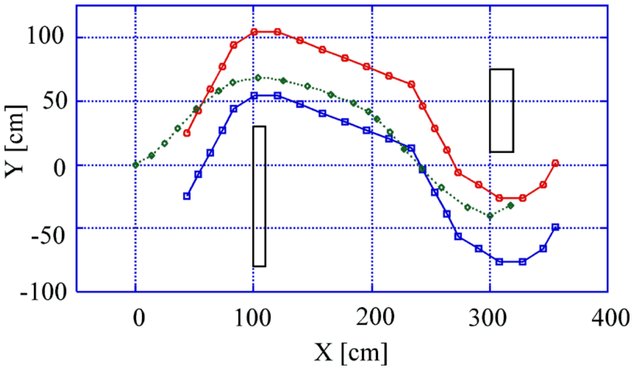


Fig. 7 (b) Simulation result by method 1

4.3 Simulation by method 3

To decrease the wasteful motions of child robots by method 2, the third method was proposed. The method is to keep configuration of robots using a control point as shown in Fig. 9 (a). The control point at the next step is determined by the direction $\boldsymbol{q}$. Then the configuration of robots at the next step are determined based on the control point.

Fig. 9 (b) shows the simulation result. Courses of the two robots and the object are almost smooth and the object was almost in the center of robots. This means that the object was equally pulled. The third method is evaluated to be the best among the three methods.

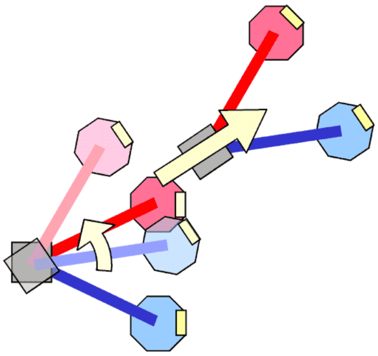


Fig. 8 (a) Method 2: keeping conveyance form
Two robots rotate before ongoing and march straight.

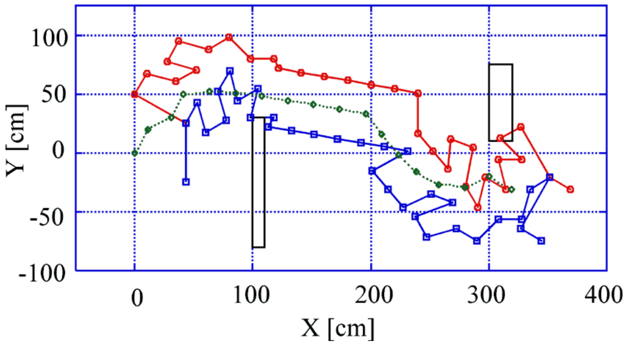


Fig. 8 (b) Simulation result by method 2

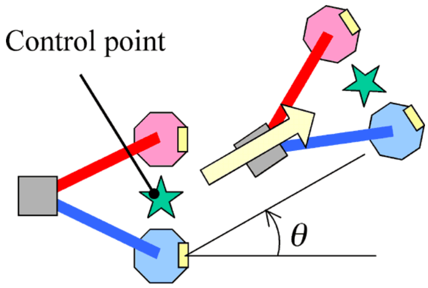


Fig. 9 (a) Method 3: keeping the control points
The green stars denote control points. Position of the control point at the next step is calculated referring the direction $\boldsymbol{q}$ which is determined by equation (1).

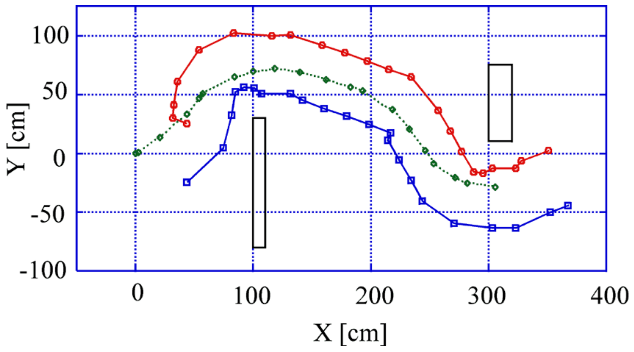


Fig. 9 (b) Simulation result by method 3.

5. EXPERIMENTS

Using third method, we demonstrated actual performance with SMC system. The child robots were designed by Professor Hirose and his group. The mechanical details were reported in the reference[4].

To realize cooperative conveyance, two robots must share information about obstacles and positions of each robot. Fig. 10 shows a flow chart to perform cooperative actions.

First, two robots measure the position of the obstacle by CCD camera. Robot B is preprogrammed to be a leader for information management. Robot A thereby sends obstacle information to robot B. Next, robot B determines the direction of movement taking account of both obstacle information, and sends the information of the movement to Robot A. Finally both robots move synchronously.

For the experimental study, about 400cm by 500cm flat field was provided. Two obstacles were place in the field. One is toll, other is low. Position of the final goal was given to the child robots before starting. Flexible strings with simple elasticity were used this time. For this reason, a light plastic box weighing about 100 gram was provided for an object.

Fig. 11 is a snapshot of the robot system. Two child robots successfully tugged the object with tethers avoiding an toll obstacle. After avoiding the toll obstacle, they change the direction to the final goal and marched. Then they encountered the low obstacle. This time, the robot lifted the object up by setting apart together and conveyed keeping the same interval. After passing it, they became the initial configuration coming near each other, and again went forward. These motions can be seen in the movie file attached to this paper.

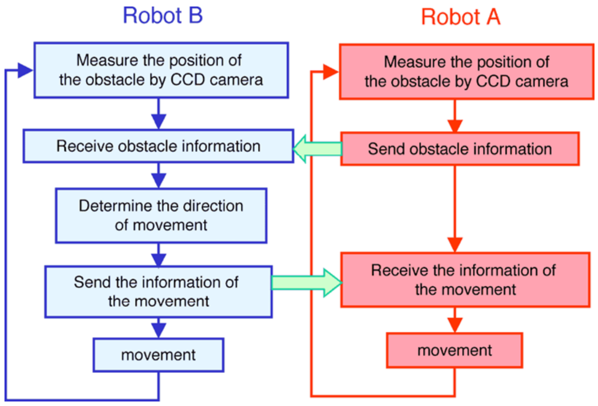


Fig. 10 Flow chart of cooperative conveyance

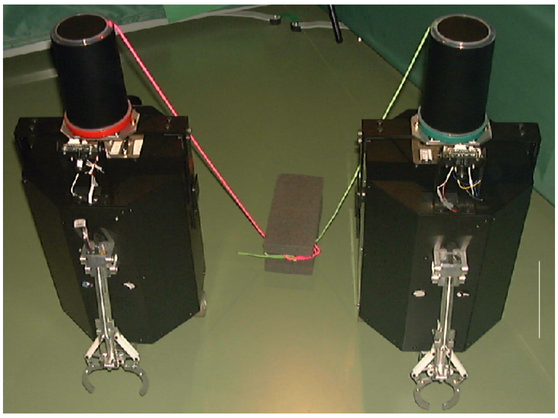


Fig. 11 Two robots tugging an object with tethers

6. CONCLUSIONS

Cooperative conveyance of two child robots with tethers was discussed. Three methods of cooperative conveyance were proposed and examined by computer simulations. Tethers were assumed to have constant force property which made robot control easy.

The simulation results showed that the method keeping a control point is the most reasonable among the three method. The experimental system successfully performed the conveyance of an object. However there are some subjects to improve the robot system.

In this experiments, two robots lifted an object by setting apart together. It will be an effective way to lift the object up by winding tethers. We therefore examine mechanism of a winder unit mounted on the robots. The unit has also constant force property and is mounted on each child robot.

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