A Flexible Conveying System using Hybrid Control under Distributed Network

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Abstract: In this research, we propose a flexible conveying system (FCS) which consists of multiple arrays of cells. Each cell is a wheel driven by a two degree-of-freedom mechanism. The direction and velocity of cell are controlled based on the concept of hybrid control under a distributed network. Each cell has its own controller under a subsumption architecture for low-level control. A cell communicates with its four neighboring cells to manipulate a targeted object towards its desired position. The high-level control assigns a desired position and direction of the object to each cell. The path of each object is generated by many supporting cells. Moreover, the FCS can handle multiple objects simultaneously.

To study the flexible conveying system, a GUI-based simulator of flexible conveying system is constructed. The simulated results show that the system can handle multiple objects independently and simultaneously under the proposed hybrid control architecture.

1. Introduction

In the flexible manufacturing systems (FMS), many parts with different production plans are required to share the same production line. The parts convey between several machines in arbitrary order. The conveyor that can handle multiple parts independently and simultaneously is needed in the production line. Traditionally, every object is moved by its own transportation system e.g., a pick-and-place robot. With an increasing number of objects to be moved simultaneously, this solution eventually becomes unfavorable due to end effector's conflict and high cost.

Recently, several attempts have been made to realize the new conveyors that allow a controlled motion of multiple objects on individual trajectories. S. Konishi and H. Fujita proposed small parts conveying system using fluidic micro actuators without feedback sensor [1]. A positioning method allows every actuator to exert forces to desirable directions. K. Bohringer, Donald and MacDonald have applied the array of actuators into the microscopic scale [2]. Their actuators consist of asymmetric torsional resonators that can lift objects lying on top of the actuator while applying horizontal forces to create motion. Luntz, Messner and Choset have built arrays of cell for moving parcels with three degree-of-freedom i.e., two translations and one rotation [3]. Their mechanical configuration consists of actuator cells having a pair of orthogonally oriented roller wheel. Those cells are capable of producing a force perpendicular to the wheel axis while allowing free motion in parallel to the wheel axis. Each of cells also contains a sensor that can detect the presence of parcel. P.U. Frei, M. Wiesendanger, R. Buchi, and L. Ruf proposed a vibratory conveyor that is normally used to move things like powder or gravel [4]. They used a combination of horizontal and vertical oscillations to produce a non-zero resulting friction force. The objects can be moved along any horizontal direction with this friction force. T. Fukuda, K. Sekiyama, I. Takagawa, S. Shibata, and H. Yamamoto proposed a flexible transfer system which composed of autonomous robotics modules [5]. Normally, this system is used to transfer a palette carrying object parts. They also used a hybridization method between the distributed and centralized approaches to control this system.

In this research, we propose a Flexible Conveying System (FCS) which consists of multiple arrays of cells. Each cell is a wheel driven by a two degree-of-freedom mechanism i.e., spinning and steering. The FCS has several advantages over conveyor belts and conventional robot manipulators. It provides simultaneous transportation of multiple objects on individual trajectory. These include feeding, orientating, sorting, separating, and arranging objects.

2. Flexible Conveying System (FCS)

The FCS consists of multiple arrays of cells as depicted in Figure 1. The FCS can handle multiple objects independently and simultaneously.

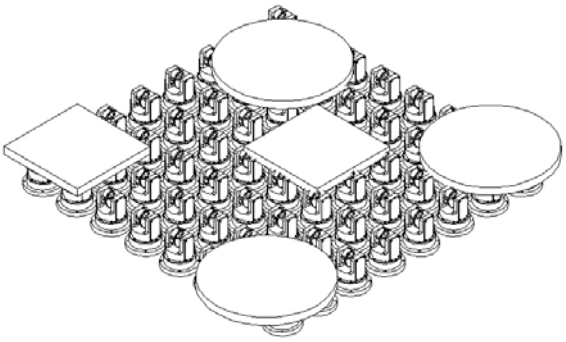

Figure 1. Flexible Conveying System (FCS)

2.1 Mechanical Configuration

Each cell of FCS is a roller wheel driven by a two degree-of-freedom mechanism i.e., spinning and steering. Figure 2 shows the configuration of a FCS cell. The roller wheel provides the powered motion perpendicularly to its axis of rotation while allowing free motion in parallel to its axis of rotation. The motion of the roller wheel is fully holonomic. The spinning motor drives the roller wheel through a single reduced bevel gear and two spur gears. The steering motor dictates the roller wheel direction through a single reduced spur gear.

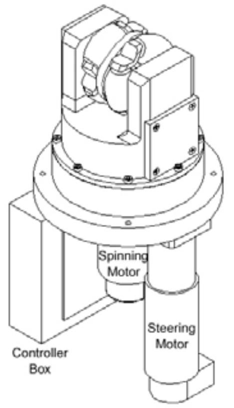

Figure 2. A Cell of FCS

The arrays of cell are designed to be easily snapped together. The arrays can be reconfigured to meet demand in a flexible manufacturing environment. The array's redundancy also allows for good fault tolerance because objects can be redirected around or passed over broken cells.

2.2 Electronic Configuration

In the FCS, a distributed control is applied. Each cell has its own controller for low-level control as depicted in Figure 3. The tasks of this controller include computation, wheel-speed controlling, power and motor drives controlling, object sensing, communication with its host, and communication with its four neighboring cells.

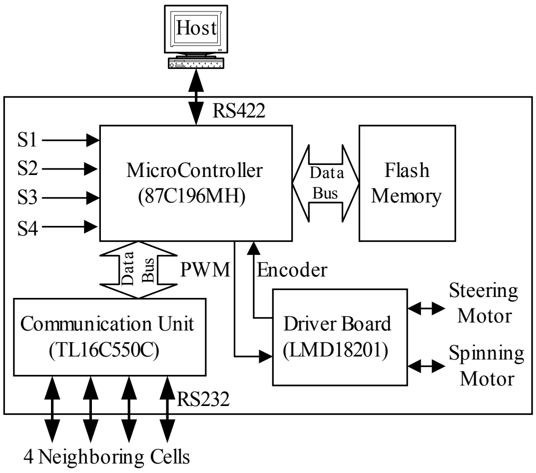

Figure 3. Structure of controller board

The computation is based on the Intel N87C196MH microcontroller. The controller board has two power sources which are 5V logic-level power and 24V motor power. To sense a position of an object above each cell, a photo-transistor detects the shadow of the object from the overhead lights. The communication between host PC and each cell is done through RS422 serial port. The communications between each cell and its four neighboring cells are done through the communication unit, which is based on the Asynchronous Communications Element with AutoFlow Control (ACE) TL16C550C.

2.3 Network Communication

The cells are arranged in a distributed network scheme where bilateral communication occurs between those cells and their four neighboring cells. Furthermore, there is also communication between those cells and host PC. Figure 4 shows a schematic diagram of the communication which allows the data to able to get through the broken cells to the other active cells.

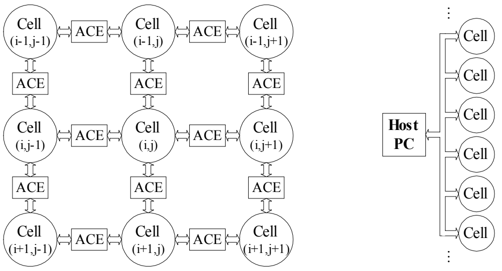

Figure 4. Distributed Network: Each cell has bilateral communication with its four neighboring cells (left) and host PC (right).

The data has the pattern defined as following: ID, data type, and data arrays. Once the ID is matched, the cell receives and stores the data into its buffer.

3. Hybrid Control

In order to function properly, the FCS needs precise cooperation from multiple arrays of cells. To overcome this control problem, a control strategy, which mimics the flying pattern of a flock of birds, is applied. The FCS also needs to handle multiple objects independently and simultaneously. The hybrid control seems to be a good candidate since it consists of both low-level control and high-level control. The low-level control with a subsumption architecture is implemented to control the object towards the desired position [6,7]. The high-level control is used to assign the desired position and direction of the object to each cell. Furthermore, it controls the object to be aligned with the desired orientation when the object approaches the desired position.

3.1 Subsumption Architecture for Low-Level Control

The overall subsumption architecture consists of four layers as depicted in Figure 5. Each layer works on individual behavior. The response of a lower layer can be suppressed or inhibited by a higher layer. The main properties of four layers are summarized as follows:

Layer 0: Move: This layer is a lowest layer. It always accelerates the spinning roller wheel when it is activated from its own sensors. This layer also dictates the steering roller wheel upon the object's starting and goal positions.

Layer 1: Avoid: This layer turns the steering roller wheel away from obstacles, depending upon the data obtained from the four neighboring cells's sensors. It also reduces the speed of the spinning roller wheel.

Layer 2: Target This layer is responsible for decelerating the spinning roller wheel when the object approaches the desired position.

Layer 3: Communication: This layer is a highest layer, which receives and sends data from/to its four neighboring cells, and sends signal to host PC when its own controller fails.

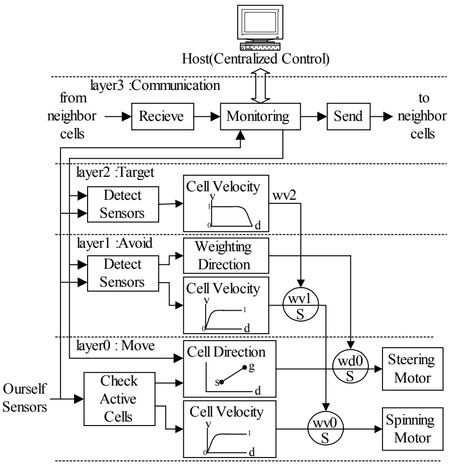

Figure 5. Four-layer control of subsumption architecture

Velocity Response Function

The spinning roller wheel's velocity can be easily determined from Equation (1) and Equation (2). First, the velocity weight of each layer, Wv_i, can be obtained as follows

$$Wv_i = 1 - e^{-\alpha_i I_i} \quad i = 0,1,2 \tag{1}$$

where α_i is a coefficient that adjusts the abruptness function of each layer, I_0 is a distance between cell location and the object's starting location, I_1 is the shortest distance between cell location and the approximated locations of the other objects, and I_2 is a distance between cell location and the object's goal location. Figure 6 shows plot of velocity weights versus distances I with α ranging from 0.01 to 0.2.

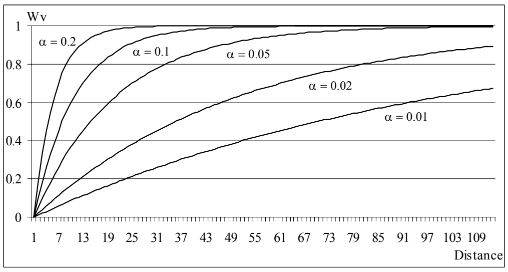

Figure 6. The velocity weights are varied with α

Secondly, the velocity response of each layer can be determined from Equation (2).

$$V_i = Wv_i \cdot Vm_i \qquad i = 0,1,2 \tag{2}$$

where Vm_i is a maximum velocity of each layer.

Suppressor Function

The response of a lower layer can be suppressed or inhibited by a higher layer as follows:

$$V_i = \begin{cases} Wv_{i+1} \cdot Vm_{i+1} & \text{if } Wv_{i+1} \le S_i \\ Wv_i \cdot Vm_i & \text{if } Wv_{i+1} > S_i \end{cases} \tag{3}$$

where S_i is a threshold of an active layer.

3.2 Inverse Kinematics for High-Level Control

When an object approaches the desired position, its velocity is decreased. From this point, the inverse kinematics can be used to control the object towards the destination. Figure 7 illustrates the physical relationship between translational and rotational velocity of an object (V_p, ω_p) and velocities of supporting cells.

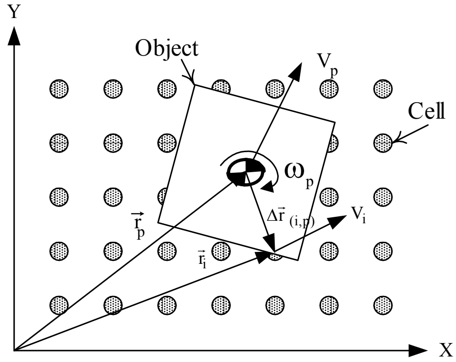

Figure 7. Motion of an object on a multiple arrays of cells

The velocities of supporting cells (V_i) can be determined as follows:

$$\vec{V}_i = \vec{V}_p + \vec{\omega}_p \times \Delta\vec{r}_{(i,p)} \tag{4}$$

where $\Delta r_{(i,p)}$ is a distance from the center of an object to the location of supporting cell. To control the velocity of spinning wheel ($\dot{\theta}_{ix}$) and the direction of steering roller wheel (θ_{iz}), the world coordinate system is assigned as shown in Figure 8.

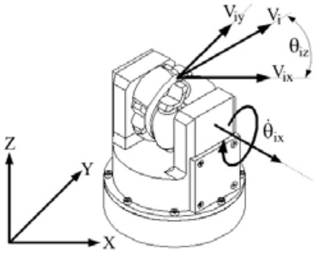

Figure 8. The spinning and steering roller wheel's coordinate with respect to the world coordinate system

In addition, the velocities of supporting cells in the x-y coordinate can be written as follows.

$$\begin{bmatrix} V_{ix} \\ V_{iy} \end{bmatrix} = r \begin{bmatrix} \cos\theta_{iz} & 1 \\ \sin\theta_{iz} & 1 \end{bmatrix} \begin{bmatrix} \dot{\theta}_{ix} \\ 0 \end{bmatrix} \tag{5}$$

where r is a radius of the roller wheel. Hence, the direction of steering roller wheels can be easily determined from Equation (6).

$$\theta_{iz} = A\tan 2\left[\left\{V_{px} - (y_i - y_p)\omega_p\right\}, \left\{V_{py} + (x_i - x_p)\omega_p\right\}\right] \tag{6}$$

The velocity of spinning roller wheel can be easily determined from Equation (7).

$$\dot{\theta}_{ix} = \frac{V_{px} - (y_i - y_p)\omega_p}{r(\mathrm{Cos}[\theta_{ix}])} = \frac{V_{py} + (x_i - x_p)\omega_p}{r(\mathrm{Sin}[\theta_{ix}])} \tag{7}$$

4. Simulation Results

Figure 9 illustrates a GUI-based simulator using the proposed concept, which can manipulate multiple objects simultaneously. This simulator is developed under the Windows-based operating system using the Microsoft Visual C++.

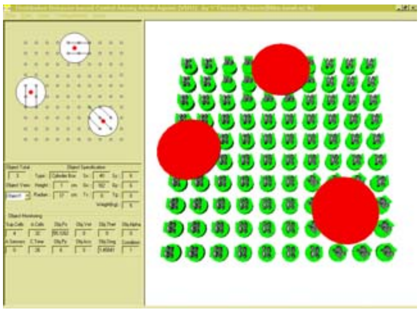

Figure 9. GUI-based simulator of FCS

The simulator was run using the parameters of $\alpha_0 = 0.1$, $\alpha_1 = 0.1$, $\alpha_2 = 0.02$, $S_0 = 0.7$, $S_1 = 0.7$, and the maximum velocity of each layer is 10 cm/sec.

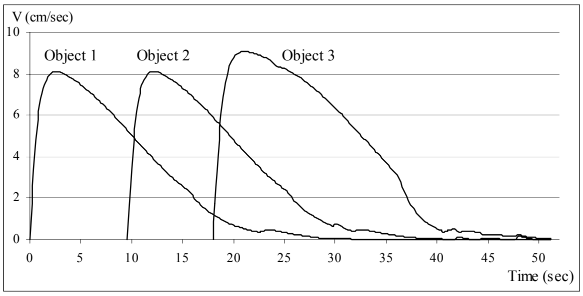

Figure 10. Velocities of three objects vs. time

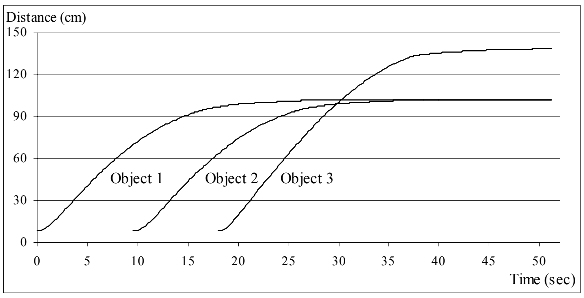

Figure 11. Positions of three objects vs. time

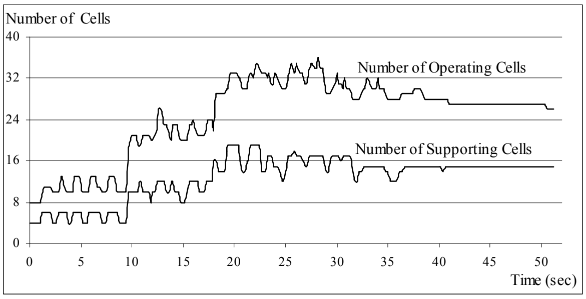

Figure 12. Number of operating cells and supporting cells under a subsumption architecture during operation

Figure 10 and Figure 11 illustrate that the velocity of each object is greatly increased after the object starts moving. Subsequently, its velocity is decreased when the object approaches the desired position. Figure 12 shows the number of operating cells, which are dynamically activated and deactivated to guide the object's direction, and the number of supporting cells, which control the object's velocity and direction to the desired location.

5. Conclusions

In this paper, the concept of hybrid control for FCS under a distributed network is presented. The high-level control is used to assign the desired position and direction of the object to each cell. In the low-level control, a subsumption architecture is implemented to control the multiple arrays of cells to manipulate the object towards the desired position.

Furthermore, a GUI-based simulator of FCS is constructed to illustrate that the system can handle multiple objects independently and simultaneously under the proposed hybrid control architecture.

Acknowledgement

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