Development of the omni-directional, power-assisted cart

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1. INTRODUCTION

We developed an easy-to-operate, heavy duty cart comprising a power assist technology available for both longitudinal and rotational motions of the cart. The omni-directional, motor-assisted traveling mechanism uses universal wheels that provide smooth operation of the cart. This article describes the system configuration and power assist technology that we have applied, and one of the challenges that we addressed during the development of this new power-assisted cart.

2. CONFIGURATION OF THE OMNI-DIRECTIONAL POWER ASSIST SYSTEM

Figure 1 shows a rough sketch of the omni-directional, power-assisted cart. The control system, shown in Fig. 2, consists of a force detecting unit, CPU and driving unit. The force detecting unit detects the operating force and communicates with the CPU to inform it of the force detected. The CPU calculates the translational (longitudinal and lateral) and rotational speed of the cart based on the force detected, and rotational speed of the driving wheels accordingly. The driving unit receives the speed information from the CPU, and drives the wheels.

Figure 3 shows a diagrammatic explanation of the power assist system.

The final goal to be achieved by the system is to obtain a smooth control of the traveling speed ($[V_{ax}, V_{ay}, V_{a\psi}]^T$ measured with respect to the center-of-control) of

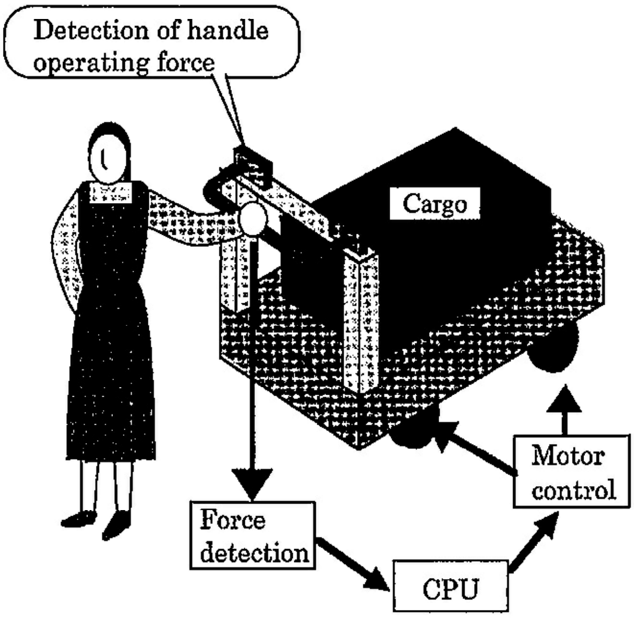

Figure 1. Outline.

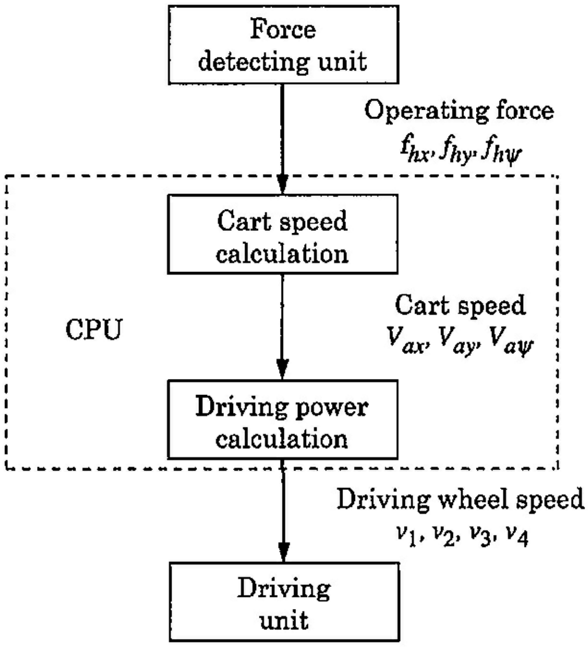

Figure 2. Control system.

the cart according to the operating force ($[f_{hx}, f_{hy}, f_{h\psi}]^T$). First, the force acting on the center-of-control ($[f_{hx}, f_{hy}, f_{h\psi} + L_h \cdot f_{hy}]^T$) is calculated from the operating force ($[f_{hx}, f_{hy}, f_{h\psi}]^T$). The product of the force acting on the center-of-control and 'assist gain' (K_x, K_y, K_ψ) is the traveling speed of the cart ($[V_{ax}, V_{ay}, V_{a\psi}]^T$):

$$\left.\begin{aligned} V_{ax} &= K_x \cdot f_{hx} \\ V_{ay} &= K_y \cdot f_{hy} \\ V_{a\psi} &= K_\psi \cdot (f_{h\psi} + L_h \cdot f_{hy}) \end{aligned}\right\}, \qquad (1)$$

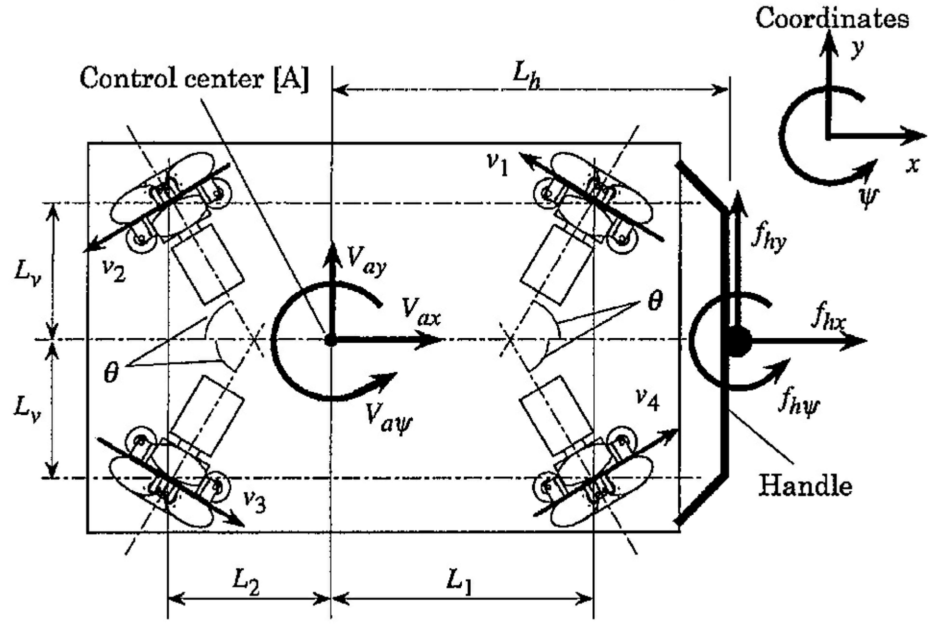

Figure 3. Power assist system.

where, the subscript x denotes the longitudinal direction, y denotes the lateral direction and ψ denotes the counterclockwise rotation. L_{h} shows the distance between the handle and center-of-control.

Next, the revolution of each driving wheel is calculated based on the cart speed given by equation (1). The driving wheels are motor-driven universal wheels located at the four corners of the cart.

The calculation of the wheel r.p.m. ($[v_1, v_2, v_3, v_4]^T$) based on the cart speed ($[V_{\mathrm{ax}}, V_{\mathrm{ay}}, V_{\mathrm{a}\psi}]^T$) uses the following equations:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} -\sin\theta & \cos\theta & (L_1 \cdot \cos\theta + L_v \cdot \sin\theta) \\ -\sin\theta & -\cos\theta & (L_2 \cdot \cos\theta + L_v \cdot \sin\theta) \\ \sin\theta & -\cos\theta & (L_2 \cdot \cos\theta + L_v \cdot \sin\theta) \\ \sin\theta & -\cos\theta & (L_1 \cdot \cos\theta + L_v \cdot \sin\theta) \end{bmatrix} \begin{bmatrix} V_{\mathrm{ax}} \\ V_{\mathrm{ay}} \\ V_{\mathrm{a}\psi} \end{bmatrix}. \quad (2)$$

Equations (1) and (2) are the essence of the omni-directional power assist control that provides a smooth operation in every direction according to the operating force given to the cart.

3. CHALLENGES

Although the above-mentioned control can provide a omni-directional power assist to the cart, the operator may experience a difficulty in translating the cart in the lateral direction when it has a longer body.

Given that the operator holds the handle with his hands separated by a distance L_{s}, and operates the cart by giving it a couple-of-forces (see Fig. 4), the operating force acting on the handle, $f_{\mathrm{h}x}$ and $f_{\mathrm{h}\psi}$, is given as follows.

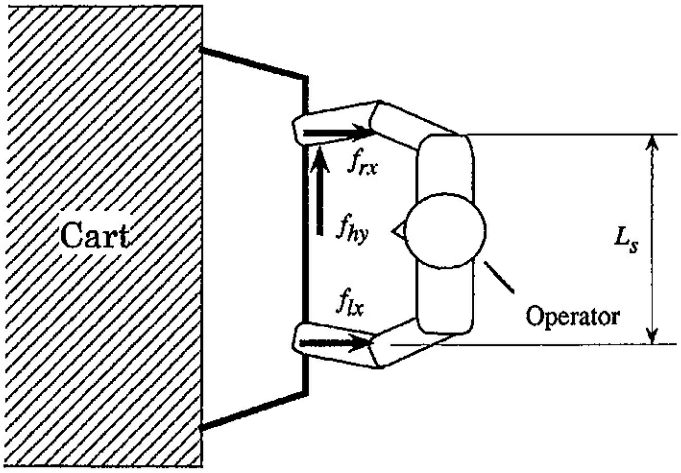

Figure 4. Operating force.

$$f_{hx} = f_{lx} + f_{rx},$$
$$f_{h\psi} = f_{lx} \cdot \frac{L_s}{2} - f_{rx} \cdot \frac{L_s}{2}.$$

Translation in the lateral direction means $V_{ax} = 0$ and $V_{a\psi} = 0$. From the equation (1):

$$f_{hx} = f_{lx} + f_{rx} = 0,$$

$$f_{h\psi} + L_h \cdot f_{hy} = f_{lx} \cdot \frac{L_s}{2} - f_{rx} \cdot \frac{L_s}{2} + L_h \cdot f_{hy} = 0.$$

Combining the above two equations,

$$f_{rx} = -f_{lx} = \frac{L_h}{L_s} \cdot f_{hy}.$$

The equation above indicates that lateral translation needs a longitudinal operating force L_h/L_s times as large as the lateral operating force. Carts having a slender body may thus not be operated easily.

4. COUNTERMEASURES

To solve this problem, another assist gain, $K_{y\psi}$, was added to the equation for calculating $V_{a\psi}$.

$$V_{a\psi} = K_\psi \cdot f_{h\psi} + K_{y\psi} \cdot L_h \cdot f_{hy}. \qquad (1')$$

The value of $K_{y\psi}$ can be determined in consideration of various factors including the cart geometry (L_h/L_s, etc.) and its center of rotation so that a variety of operating feels can be obtained.

5. EXPERIMENTS AND RESULTS

Using a cart about 2.3 m long, 0.8 m wide and 600 kg in weight, translational operation in the lateral direction was tested. This experiment used two different equations for calculating the rotation speed $V_{a\psi}$. One is the equation (1). The other one is the equation (1′) with $K_{y\psi} = 2.5K_{\psi}$. Figures 5 and 6 show the comparison of the operating force between the two cases. These two figures show a couple-of-forces, not the moment $f_{h\psi}$, to indicate the difference between the longitudinal and lateral components of the operating force.

As can be seen in Fig. 6, the additional assist gain $K_{y\psi}$ permits the operator to translate the cart in the lateral direction with a so small couple-of-forces as usual operating forces for moving it sideways. This means that the cart can be operated smoothly even in translation in the lateral direction.

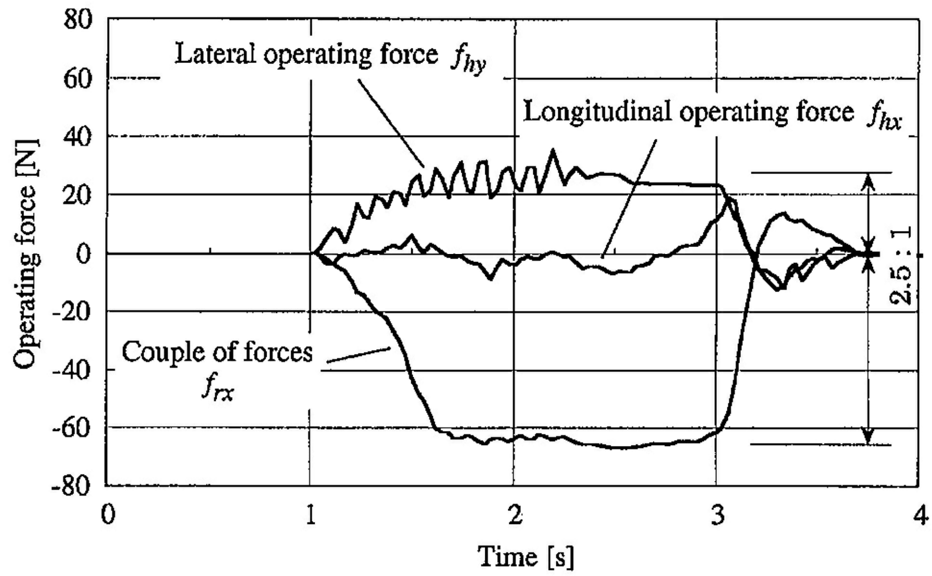

Figure 5. Experiment results: control by equation (1).

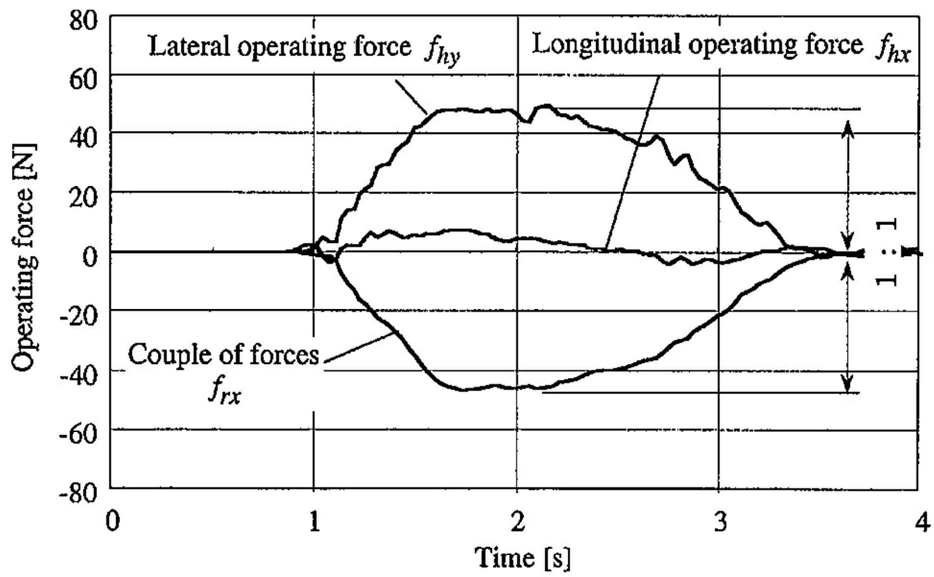

Figure 6. Experiment results: control by equation (1′).

6. CONCLUSION

We developed a motor-assisted cart that can detect the operating force in all of the longitudinal, lateral and rotational directions given by the operator, and provide an appropriate assisting power for any motion of the cart so that smooth and easier operation can be obtained. Our experiments demonstrated the expected performance of the cart.