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CONTROLLING A MANIPULATOR OF A SERVICE ROBOT BY FOLLOWING THE OPERATOR'S HAND MOVEMENTS IN SPACE

ŘÍZENÍ MANIPULÁTORU SERVISNÍHO ROBOTU KOPÍROVÁNÍM POHYBŮ RUKY OPERÁTORA V PROSTORU

Abstract

This paper describes a practical solution of the problem of controlling a manipulator arm of a mobile service robot by a human operator using the natural method of following the movements of the operator's hand in space. This system is a part of the complex control system of the mobile robot Hercules developed by the Department of robotics and is used to control its 3-degree-of-freedom manipulator with a gripper, but can be after some modifications applied to any similar arm with up to 6 degrees of freedom.

Abstrakt

Článek popisuje praktické řešení problematiky řízení manipulační nadstavby mobilního servisního robotu lidským operátorem pomocí přirozené metody kopírování pohybu operátorovy ruky v prostoru. Systém je součástí komplexního řídicího systému mobilního robotu Hercules navrženého katedrou robototechniky a je využíván pro řízení manipulátoru s 3 stupni volnosti a chapadlem, který je na tomto robotu umístěn. Po několika úpravách může být však použit pro řízení libovolného podobného ramene s až 6 stupni volnosti.

1 INTRODUCTION

Autonomous mobile robots able to perform complicated tasks without any intervention from a man are a popular and important field in robotics, but there are still a lot of situations where a mobile robot controlled remotely by a human operator is the best possible solution. This includes for example service robots used by pyrotechnics to disarm or transport explosions, or any similar complicated and non-repeating manipulating tasks in general.

There are few possible ways how to design a user interface translating human orders into movements of the manipulator, each having its advantages and disadvantages. Probably the most common interface consists of one or more analog joysticks operated in order to move either the individual joins of the robotic arm or to directly manipulate the effector in 3D space using the inverse kinematics.

More natural and easier-to-learn for the operator is a method using a special system tracking the movements of the operator's hand in space and reproducing this commands on the manipulator.

2 INVERSE KINEMATICS

The manipulator of the robot Hercules is a simple arm with 3 rotation joins. With 3 degrees of freedom, the operator is able to set 3 coordinates, in this case the 3D vector of position of the reference point of the effector (gripper) located on the last link of the arm. As already mentioned above, the operator is setting this vector directly by positioning his hand in space.

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Fig. 1 Mobile robot Hercules

Each of the three joins of the arm contains a DC motor with encoder. To get the desired control values for these motors (angle of rotation), it is necessary to perform inverse kinematics. The chosen algorithm for inverse kinematics is very easy to program for real-time control systems as it does not require multiple iterations and consists just of basic trigonometric operations.

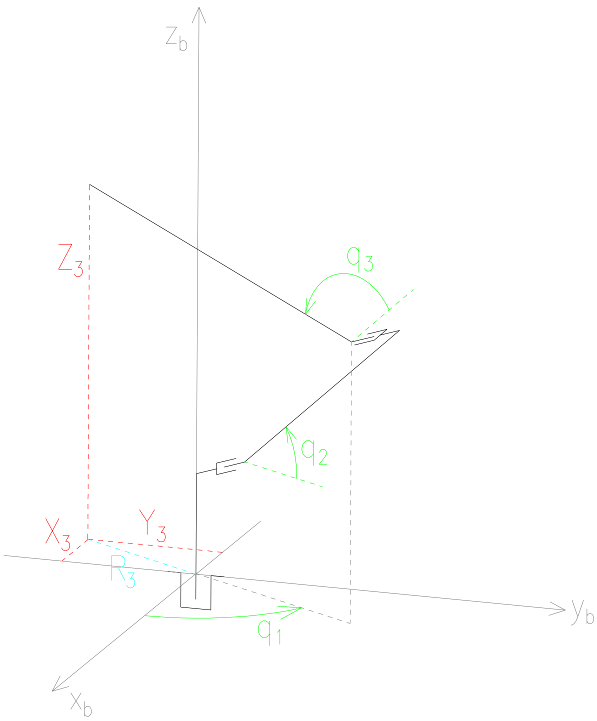

Fig. 2 Kinematic structure of the manipulator

Fig. 2 shows the input parameters of the algorithm – coordinates [X_3, Y_3, Z_3], and the output parameters – angles of rotation of the joints (q_1, q_2, q_3). The coordinate q_1 can be computed directly as:

$$q_1 = -\operatorname{atan2}(Y_3, -X_3) \tag{1}$$

The mechanism is planar; the plane is defined by the z_b axis and the angle q_1 (axis r), as shown on Fig. 2 and Fig. 3.

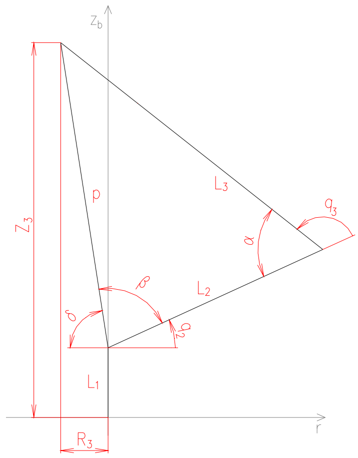

Fig. 3 Schema of the inverse kinematics calculations

The scheme on Fig. 3 can be used to deduce the following equations:

$$R_3 = \sqrt{{X_3}^2 + {Y_3}^2} \tag{2}$$

$$p = \sqrt{{R_3}^2 + (Z_3 - L_1)^2} \tag{3}$$

The value of p must now be checked to be not bigger than $L_2 + L_3$. If it is bigger, the desired point is out of reach for the manipulator. Otherwise, the calculation continues as follows:

$$\delta = atan2(Z_3 - L_1, R_3) \tag{4}$$

$$\beta = acos\left(\frac{-{L_3}^2 + {L_2}^2 + p^2}{2L_2 p}\right) \tag{5}$$

$$\alpha = acos\left(\frac{-p^2 + {L_2}^2 + {L_3}^2}{2L_2 L_3}\right) \tag{6}$$

$$q_2 = \delta - \beta \tag{7}$$

$$q_3 = \pi - \alpha \tag{8}$$

3 MOTION TRACKING

The movements of the operator's hand are tracked by the 6-DOF sensor Polhemus PATRIOT. The system consists of a source of a magnetic field, a sensor and a central unit, which is connected to a PC by the USB or serial (COM) port.

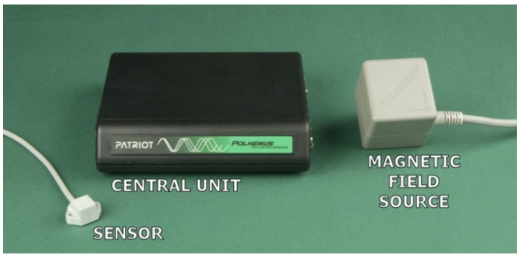

Fig. 4 The 6-DOF sensor PATRIOT

The operator has the sensor fixed to his hand; the magnetic field source is stationary. PATRIOT measures the distances and rotations between the sensor and the source and sends these data periodically to the control system in the form shown on Fig. 5.

8 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes
header	cartesian coordinate X	cartesian coordinate Y	cartesian coordinate Z	Euler angle *(Azimuth)*	Euler angle *(Elevation)*	Euler angle *(Roll)*

Fig. 5 The form and content of the PATRIOT data packet

The control system of Hercules allows the operator to change the scale even during operation, which means that the hand movement of for example 10 cm can be reproduced as a 10 cm movement of the effector one time, and as 2 cm or 50 cm other times. Because of this scaling, it is possible to both cover easily the whole working space of the manipulator and maintain required accuracy for fine movements.

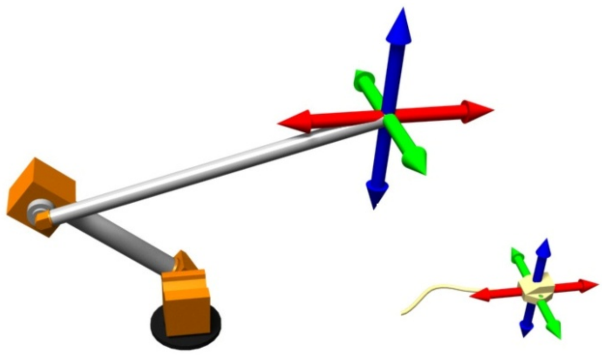

Fig. 6 Principle of operation

The sensor provides all 6 coordinates in space (3 for position and 3 for rotation, see Fig. 5). For the Hercules manipulator, only the position is needed. The rotations are, however, used for other functions, for example to enable or disable tracking – when the operator rotates the palm of his hand upwards, the tracking is paused and the operator can safely reposition his hand without affecting the robot. In this paused state, the operator can use the sensor to draw gestures to control additional features of the robot, like turning off and on the laser proximity sensor located on the arm.

In every step of the discrete control system, the required vector of position is acquired from the PATRIOT sensor, and the actual position vector of the effector is computed by forward kinematics using the values from motor encoders. Both these vectors are converted into joint rotations using the inverse kinematics. DC motors of the arm are controlled in velocity mode – the velocities are calculated from the differences of angles and time between two steps:

$$\omega_1 = \frac{q_1^i - q_1^{i-1}}{t_i - t_{i-1}}, \quad \omega_2 = \frac{q_2^i - q_2^{i-1}}{t_i - t_{i-1}}, \quad \omega_3 = \frac{q_3^i - q_3^{i-1}}{t_i - t_{i-1}} \qquad (9)$$

4 CONCLUSIONS

The method described in this article has already been tested in practice on the real robot Hercules. It was discovered that for a really natural feeling of motion tracking and following, the arm must be equipped with drives fast enough to allow the manipulator to actually follow the operator's hand. This is not entirely the case of the Hercules robot and the operator is unwittingly forced to slow his movements and wait for the manipulator. Another drawback of this method is the fact that it can become wearing for the operator to hold his hand steadily for few minutes.

However, the advantages are appreciable even more. The operator can perform really complicated movements with ease and does not have to worry about performing a wrong move because of the common but unnatural joystick controls.

The tested sensor PATRIOT measures all the possible 6 coordinates of an object in 3D space. The system can be thus adapted also to more complicated robotic arms with up to 6 degrees of freedom. In this case, not just the position of the operator's hand is considered, but also the orientation of the hand or the whole arm, which is then represented by corresponding rotation of the robot's effector around the reference point.

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