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CONTROL OF A CABLE ROBOT ON PSOC CYPRESS PLATFORM

PÁLMA KAPITÁNY[1]–JÓZSEF LÉNÁRT[2*]

[1] Robert Bosch Department of Mechatronics,
Faculty of Mechanical Engineering and Informatics
University of Miskolc, Egyetemváros, H-3515 Miskolc, Hungary,
e-mail: kapitanypalma@gmail.com
[2] Robert Bosch Department of Mechatronics,
Faculty of Mechanical Engineering and Informatics
University of Miskolc, Egyetemváros , H-3515 Miskolc, Hungary,
e-mail: lenart.jozsef@uni-miskolc.hu

Abstract: This paper deals with the control of a cable model robot. The continuous motion of the end effector is provided by velocity control of four DC motors. In each uniform time step the rotational speed of the motors are predicted based on the assumption of constant path velocity of the end effector in order to move it to prescribed position. In the next time step the rotational speed of the motors are calculated from the difference between the actual position and the target one. This way the discrepancy between the actual position and the prescribed one is corrected step-by-step. The control algorithm is implemented on Cypress Semiconductor CY8CKIT PSoC 5LP microcontroller.

Keywords: *Cable robot, Velocity control of DC motors, Microcontroller, Inverse kinematics*

1. INTRODUCTION

Cable robots are frequently used e.g. to move cameras in sport halls and stadiums and for logistics in high stores [1]. Big working space and fast positioning are the advantages of cable robots. There are two main groups of cable robots planar ([5], [6]), and spatial ones ([7], [8]).

The most important purpose of the plane movers is the precise positioning, it is utilized in cable drawing machines, in industrial applications they carry out logistical tasks, or external cleaning of office buildings. 3D cable robots are capable of not only positioning, but can also control the orientation of the end-effector being moved. Robots are popular in the airplane industry, because they can follow complicated spatial shape when welding wing elements, similarly to painting.

Nowadays it is also used for nonindustrial purposes, e.g., flight simulation, theatrical performances, solar panel assembly, and health rehabilitation exercises, etc. [1].

* Corresponding Author

In a previous article [2], the authors of this paper published a test bench that approximated a curve path by a polygon. Four DC motors were controlled with one master and four slave microcontrollers. The motion of the end-effector was non-continuous, because the master waited for the slaves to finish their tasks in each increment, i.e., to perform the motion along one polygon side.

This robot has been upgraded, with the complete replacement of the control unit by a single Cypress Semiconductor CY8CKIT PSoC 5LP microcontroller. As a result of the current research it has a continuous speed control. It is checking the predicted progress at each time step. When the length of the cables are lagging behind the calculated values the speed of the motors are increased, and vice versa.

The organization of this paper is as follows. In Section 2, the inverse kinematics of the robot is discussed. In Section 3, the control of the four motors are described. Finally, summary is given in Section 4.

2. Inverse kinematics

Figure 1 shows the picture of a planar cable robot. The end effector is suspended by four cables, which are winded on winches. The winches are driven by four DC motors identified by letters *a, b, c, d*. The displacement increment of the end effector is sketched in *Figure 2*. The end-effector of cable robot denoted by blue disc is moved in plane xy.

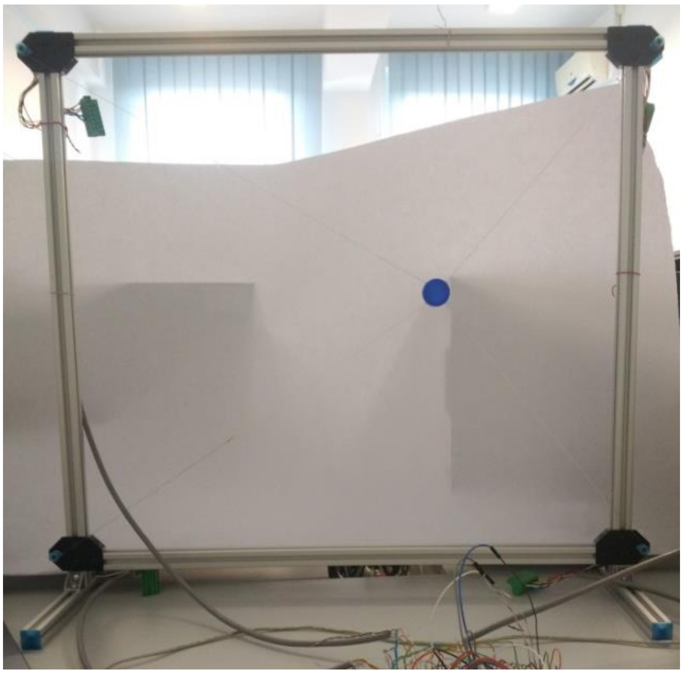

Figure 1. Planar cable robot

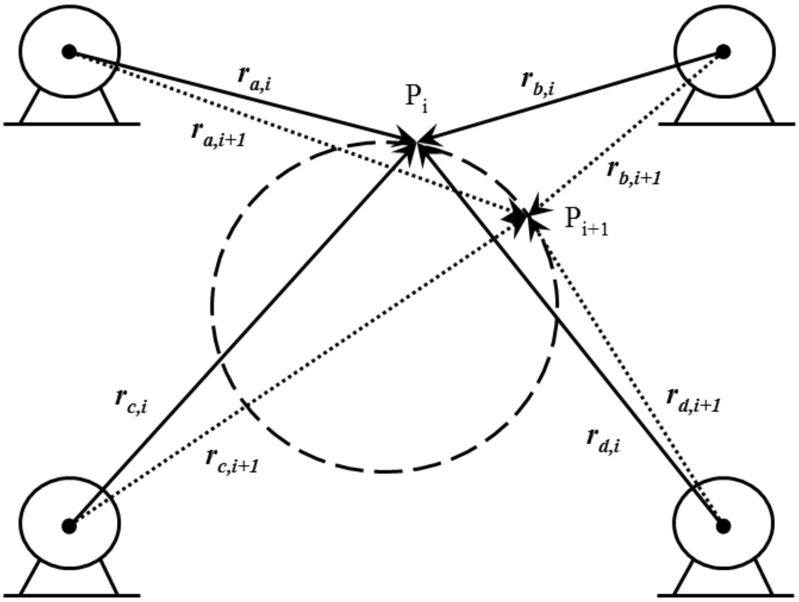

Figure 2. Displacement increment

The task of the inverse kinematics is to determine the four cable lengths for any position of the end-effector. To perform a prescribed path of the end-effector starting from a null point the length of suspending cables can be prescribed by functions. The control is not continuous, but it is performed step by step with sampling time Δt . The changes in lengths of the cables during a time step are determined by measured signals of the motor encoders.

Figure 2 shows a circular path of the end-effector. The control of the motion is based on a frequently repeated predictor algorithm, which recalculates the prediction from the instantaneous position.

The points of the planned circular path are determined by the following equation:

$$x[i] = x_k + r_k \cdot \cos\left(\frac{i \cdot 2\pi}{n_o}\right), \tag{1}$$

$$y[i] = y_k + r_k \cdot \sin\left(\frac{i \cdot 2\pi}{n_o}\right), \tag{2}$$

where r_k x_k and y_k are respectively the radius, the horizontal and vertical coordinates of the center of the circle, $x[i]$ and $y[i]$ are the horizontal and vertical coordinates of a point i of the circle path, n_o is the number of the sides of the polygon approximating the circle.

For the control the end points i and i + 1 coordinates of the polygon are required to determine the target cable length for the corresponding motor:

$$r_{a,i} = K \cdot \sqrt{x[i]^2 + y[i]^2}, \tag{3}$$

$$r_{b,i} = K \cdot \sqrt{(x[i] - h)^2 + y[i]^2}, \tag{4}$$

$$r_{c,i} = K \cdot \sqrt{x[i]^2 + (y[i] + v)^2}, \tag{5}$$

$$r_{d,i} = K \cdot \sqrt{(x[i] - h)^2 + (y[i] + v)^2}, \tag{6}$$

$$r_{a,i+1} = K \cdot \sqrt{x[i+1]^2 + y[i+1]^2}, \tag{7}$$

$$r_{b,i+1} = K \cdot \sqrt{(x[i+1] - h)^2 + y[i+1]^2}, \tag{8}$$

$$r_{c,i+1} = K \cdot \sqrt{x[i+1]^2 + (y[i+1] + v)^2}, \tag{9}$$

$$r_{d,i+1} = K \cdot \sqrt{(x[i+1] - h)^2 + (y[i+1] + v)^2} \tag{10}$$

where for the point *i*: $r_{a,i} - r_{d,i}$ are the cable lengths measured from motors *a* – *d*, *h* is the width and *v* is the height of the working space, *K* is a constant depending on the gear ratio, encoder signals per revolution and reel radius. For point *i + 1* the corresponding variables are denoted in similar way.

The predicted signal frequencies of the encoders for motor *a*-*d* are calculated as:

$$f_a = \frac{r_{a,i} - r_{a,i+1}}{\Delta t} \tag{11}$$

$$f_b = \frac{r_{b,i} - r_{b,i+1}}{\Delta t} \tag{12}$$

$$f_c = \frac{r_{c,i} - r_{c,i+1}}{\Delta t} \tag{13}$$

$$f_d = \frac{r_{d,i} - r_{d,i+1}}{\Delta t} \tag{14}$$

where Δt is the sampling time, which is set by the user.

PWM values of the motors *a*–*d* are determined by $f_a - f_d$ using linear interpolation based on measurements. It is noted that a DC motor requires a minimal voltage to start and the relation between the rotational speed and voltage is not perfectly linear.

Figure 3 demonstrates the strategy of the repeated prediction method, where dashed line denotes the ideal cable length curve as a function of time. Dot-dash lines represent the predicted change of the cable length while thin solid lines give the performed length of the cable, which is a string polygon.

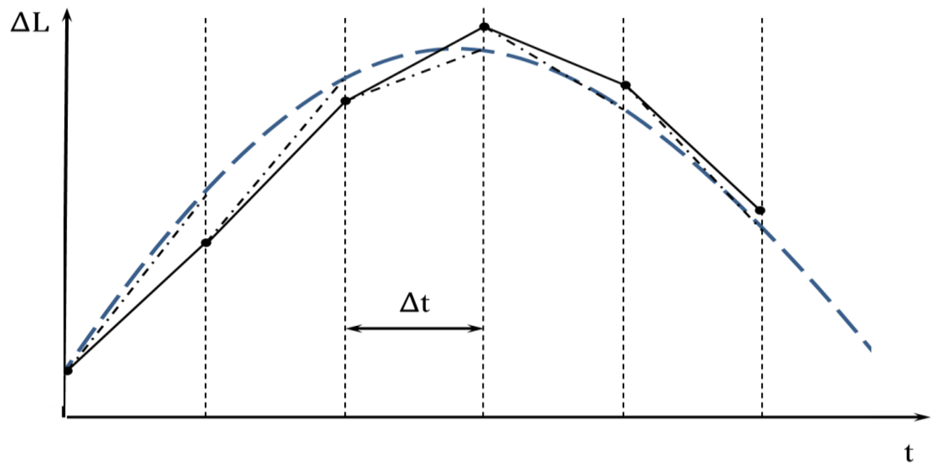

Figure 3. Strategy of the repeated prediction method

3. Control and programming on PSoC

The Cypress Semiconductor CY8CKIT PSoC 5LP microcontroller was chosen for the development of the proposed control system because it can process four PWM blocks, four Quadrature Decoders, a Timer and four Control Registers at the same time. Further advantage is that each of the inputs and outputs can be arbitrarily set to digital or analog, the number of all pins is 46. The program and logic design are written in a PSoC Creator 4.2 designer program, which has a user friendly interface.

Velocities of the motors are set through H-Bridges via PWM values. The direction of rotation is controlled by two digital outputs through H-Bridges. Position of the end-effector can define with encoder signals, which are two digital inputs for the Quadrature Decoder function block for each motor. The microcontroller, PWM blocks and Quadrature Decoders work with 24 MHz, 125 kHz and 12 MHz, respectively. Interrupt output signal of the timer is set to 0.3 second as a result of optimization. This time step is short enough to achieve a high accuracy and it provides a smooth motion. The UART and LED help to check the process. *Figure 4* shows the structure of control system in PSoC Creator 4.2.

Interrupt signal of the timer makes a step by step velocity correction based on the actual position. *Figure 5* presents the program process with respect the priority. The definitions, path approximation, PWM values calculation and start of function block are called in the main program. When the timer counter is full it sends an interrupt signal, which starts the interrupt program part. In this program part the controller recalculates the velocity values based on actual position and refresh the PWM outputs. Then the pointer is jumping to the next command of the main program to continue it. Hardware of the control system is shown in *Figure 6*.

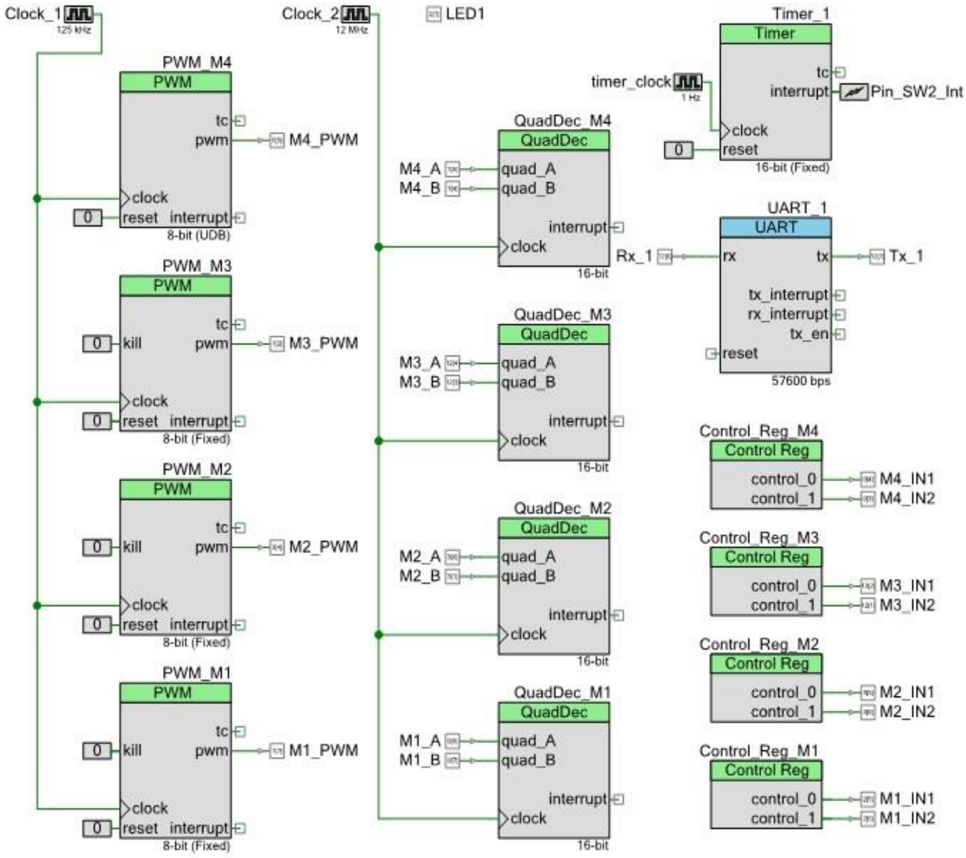

Figure 4. Structure of control system in PSoC Creator 4.2

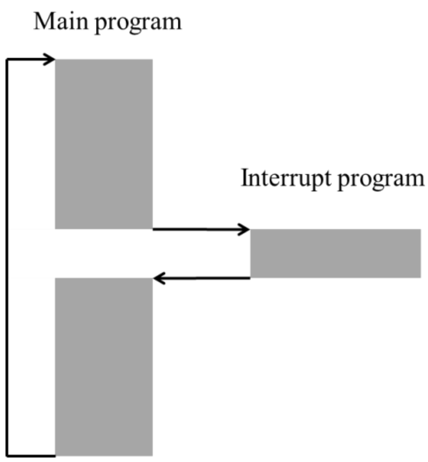

Figure 5. Interrupt handling structure

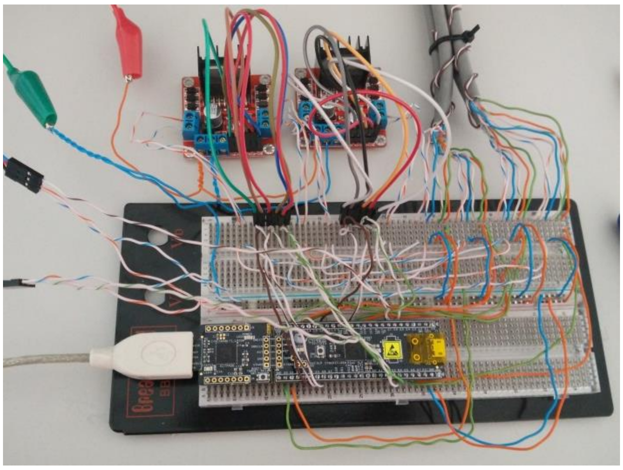

Figure 6. Hardware of the control system on breadboard

4. Summary

This paper dealt with a 2D cable robot. The end-effector driven by four DC motors, which are controlled by a single PSoC Cypress microcontroller. The path of the end-effector is prescribed by a string polygon of uniform sections. The goal is to move the end-effector along sections of the polygon step-by-step. The strategy of the control based on the difference between the actual position and the prescribed polygon position. The program computes the increments in the cable lengths, which determine the PWM values for corresponding motors. This method provides a smooth, continuous motion of the end-effector.

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