Computers and Electrical Engineering 000 (2016) 1–11

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Development of an electronic controller applied to a robotized manipulator☆

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A R T I C L E I N F O

Article history:
Received 23 July 2015
Revised 18 January 2016
Accepted 19 January 2016
Available online xxx

Keywords:
Controllers
Embedded systems
dsPIC
SPI
Robotics
Programming

A B S T R A C T

The design and implementation of an embedded control system using DSC (Digital Signal Controller) devices of the dsPIC type, applied on a four-DOF (Degrees Of Freedom) model OWI-535 robotic manipulator is presented. A control structure based on a Master/Slave configuration between two dsPIC30F4013 through the SPI (Serial Peripheral Interface) protocol is developed. In such a system, algorithms are implemented: PID (Proportional Integral Derivative) with anti-windup, and generation PWM (Pulse-Width Modulation) and data acquisition, in the DSC master and slave, respectively. The proposed methodology greatly simplifies the development of an autonomous control system based on DSCs that communicate with each other. Taking advantage of the high transmission speed of SPI communications and of the quick response of the dsPIC30F4013 DSC which makes up the embedded system, it is possible to reduce the correction time error of the robot's joint position and to eliminate the vibrations of the actuators, achieving settlement of the desired position quickly and smoothly.

1. Introduction

Serial to Peripheral Interface (SPI) technology was developed to replace parallel interfaces so that a parallel bus does not have to be routed around a Printed Circuit Board (PCB); it provides high speed data transfer between the devices [1,2]. SPI is a popular communication protocol because of its interfacing simplicity and its speed, which allows easy data transfer communication [2]. So nowadays SPI is a common technology used for communication with peripheral devices where data needs to be transferred speedily and under real time constraints.

Embedded systems, thanks to the currently available large variety of hardware and software development tools, have become a fundamental part in a vast range of industrial activities like automobiles, avionics, telecommunications, aerospace, automation, robotics, etc. [2–6]. As an example of this, it is estimated that 98% of the 32-bit processors made are meant for the embedded systems market [7]. From an economics viewpoint, according to a BBC Research report, massive investments in research are being made around the world, forecasting that the global market for embedded technology was estimated at $142.8 billion in 2013. The market is expected to have a projected Compound Annual Growth Rate (CAGR) of 5.4% over the next five years, to reach a total of $152.4 billion by 2014 and $198.5 billion by 2019 [8].

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. A. Chaudhary.

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http://dx.doi.org/10.1016/j.compeleceng.2016.01.020
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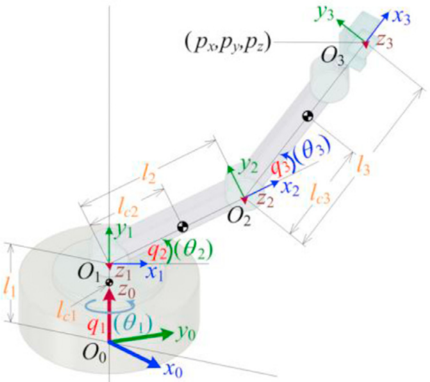

Fig. 1. Schematic diagram of the model OWI-535 robot considering the arrangement of the systems of coordinate axes and the centroids.

Embedded systems are heterogeneous systems whose hardware and software is designed to solve a specific problem within a larger system to which they belong. Those systems are mainly composed of programmable or configurable chips such as microprocessors, microcontrollers, Digital Signal Processors (DSPs), DSCs, Field-Programmable Gate Arrays (FPGAs), etc. [9,10].

In the field of robotics, and according to the specifications of each robot, the control systems used in robotic manipulators are implemented by means of embedded systems, as in the case of the IRC5 Compact. This is a controller developed by ABB enterprises that has trajectory control abilities, a friendly programming unit, flexible RAPID language, and vast communications possibilities as major features, all this packed in a small size [11–13].

The present work is organized as follows: in Section 2 we introduce the main features and the kinematic and dynamic models of the OWI-535 manipulator robot. Section 3 refers to the Cartesian trajectory test applied to the robot. Section 4 explains the design of the embedded control system, including the hardware configuration. Section 5 describes the control algorithm used, and the SPI communications form that was selected. Finally, the results and conclusions are presented in Sections 6 and 7, respectively.

2. Four dof robotic manipulator

The robotic manipulator considered in this study includes four revolving joints, plus the actuator in the gripper. For analysis, design, and implementation purposes we include the first three joints and the gripper's actuator.

Fig. 1 shows the robot's schematic diagram, considering the arrangement of the coordinate axes systems and the centroids for its kinematic and dynamic modeling, where q1, q2, q3 and l1, l2, l3 represent the generalized coordinates and the length of the first, second and third links, respectively, and lc1, lc2 and lc3 express the length from the origin to the centroid of the first, second and third links, respectively.

Direct and inverse kinematic models are obtained by applying the Denavit–Hartenberg and geometric methods, respectively [14]. The results are presented in Eqs. (1–4):

$$\mathbf{T} = \begin{bmatrix} c_{23}\cdot c_1 & -s_{23}\cdot c_1 & s_1 & (l_2c_2 + l_3c_{23})c_1 \\ c_{23}\cdot s_1 & \dfrac{c_{123}-c_{-123}}{2} & -c_1 & (l_2c_2 + l_3c_{23})s_1 \\ s_{23} & c_{23} & 0 & l_1 + l_2s_2 + l_3s_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$\theta_1 = \arctan\left(p_y/p_x\right) \tag{2}$$

$$\theta_3 = \arctan\left(\frac{\pm\sqrt{1-c_3^2}}{c_3}\right);\ c_3 = \frac{p_x^2 + p_y^2 + (p_z-l_1)^2 - l_2^2 - l_3^2}{2l_2l_3} \tag{3}$$

$$\theta_2 = \arctan\left(\frac{p_z-l_1}{\pm\sqrt{p_x{}^2 + p_y{}^2}}\right) - \arctan\left(\frac{l_3s_3}{l_2 + l_3c_3}\right) \tag{4}$$

where: $s_1 = \sin\theta_1$, $s_2 = \sin\theta_2$, $c_1 = \cos\theta_1$, $c_2 = \cos\theta_2$, $s_{23} = \sin(\theta_2+\theta_3)$, $c_{23} = \cos(\theta_2+\theta_3)$, $c_{123} = \cos(\theta_1+\theta_2+\theta_3)$, $c_{\text{-}123} = \cos(-\theta_1+\theta_2+\theta_3)$, and (P_x, P_y, P_z) is a Cartesian coordinate system that specifies the gripper's TCP (Tool Center Point) position in space.