CONTROLLERS FOR STANDARD AND PARALLEL ROBOTS

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Abstract: There are discussed results of development of motion controllers and control algorithms for robots with standard and parallel kinematics. Reason for parallel robot kinematics research is promise to achieve higher stiffness and to lower mass of moving parts for the parallel configuration of actuators, when compared with classical serial joints and actuators connection. Computational intensive coordinates transformations and powerful enough motion controller hardware are necessary for control of parallel robots. The first practical results of our research are demonstrated on the model of planar parallel robot developed at Department of Mechanics, at Faculty of Mechanical Engineering. Comparison of low level (C language) and high level language (Matlab/Simulink) development approach to the problem of motion control algorithms is next discussed topic. The compact motion controller for educational and industrial manipulators and robots developed in cooperation with an development company is an example of successful development based on free GNU C and GNU debugger development environment.

Keywords: Robotics, controllers, electronics, algorithms and kinematics

1. INTRODUCTION

Our research and development in robotics field are focused on electronic and software parts of modern motion controller units. We are participating in a group leaded by Prof. Valášek, Department of Mechanics, Faculty of Mechanical Engineering. The group deals with research of robots and manipulators with a new perspective parallel and redundant kinematics.

2. PARALLEL ROBOTS

Main reasons for research of parallel alternative to classical serial joints and actuators connection is promise to achieve higher stiffness for the parallel configuration of actuators. It is possible to develop such configuration of actuators, for which all or almost all of the actuators do not move with the robot and do not contribute their mass to moving parts. The low mass of moving parts enables achieving higher accelerations and speeds. Parallel robots have also several disadvantages. The robot workspace is usually smaller than for serial robots. There can be more problems with collisions between more arms and with the positioned platform. Kinematics of parallel robots leads to simpler inverse transformations than serial one. Simpler inverse transformations are compensated by more difficult direct transformations.

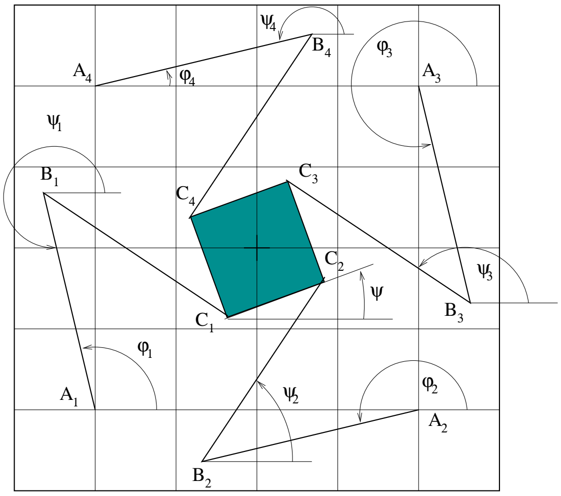

Fig. 1. Diagram of planar parallel redundant robot kinematics

2.1 *Coordinates transformations*

The problem of direct kinematics means, that computation of actual position of a gripper or a working tool from coordinates measured on actuators is difficult, could result in multiple solutions and nonlinear or polynomial equations of high order. But the computation of direct kinematic is essential for motion controller design. The computation could be bypassed only by additional planar or spatial position measurement system or by designing controller with a local actuators position feedback only. The first solution is very expensive, the second one decreases precision and is unusable for parallel kinematics structures, where inter actuators contraforces must be avoided or precisely controlled.

The problem of direct kinematics and actual position computation in the independent coordinates can be solved by tracking of actual position in the actuators coordinates with help of the Jacobian matrix of inverse transformations. This approach was taken and implemented in our case.

A planar parallel redundant robot developed at Department of Mechanics, at Faculty of Mechanical Engineering was used to learn and to prove a possibility to design motion controller for above discussed robots. Figure 1 describes kimenatics of the robot. The robot consists of four angle actuators, eight legs and a square positioned platform. Each of actuators moves one leg, other legs freely joins corners of the platform with end of previous legs.

The static robot kinematics is described by eight nonlinear equations; There is no problem to solve the inverse coordinates transformation from independent coordinates (x,y.ψ) to actuators angles (φ_1, φ_2, φ_3, φ_4). The direct transformation computation results in polynomial equations of eight order. That is why Jacobian of inverse transfor-

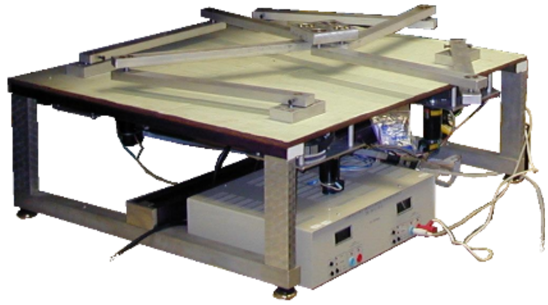

Fig. 2. Photograph of the planar parallel robot

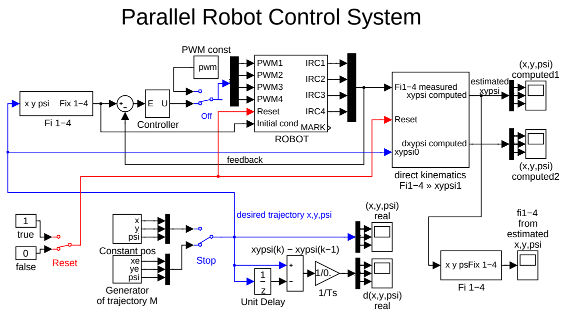

Fig. 3. Simulink representation of parallel robot controller

mation was computed and combined with an estimator of actual position in independent coordinates. These equations were rewritten for Matlab computations and then optimized and wired in blocks of Simulink model. Lengths of equations do no allow us to add them in this paper, but any interested reader can contact authors to receive more information.

2.2 *Algorithms implementation*

The control algorithms are being developed by project members from UTIA. The coordinates transformations represent a result of our cooperation as well. The realized laboratory model of the described robot is shown in Figure 2. Figure 3 contains the graphics Simulink source code of DSP program. It demonstrates simplicity of controller modifications and hides our low level interface code to actuators and angles measurement.

The first results of real experiments with the parallel robot motion are presented in Figure 4. A simple circle trajectory generator with smooth acceleration of speed and start from initial calibration position was used. The tracking of general trajectory defined by tables is prepared for next tests with advanced control rules, which is being prepared at UTIA.

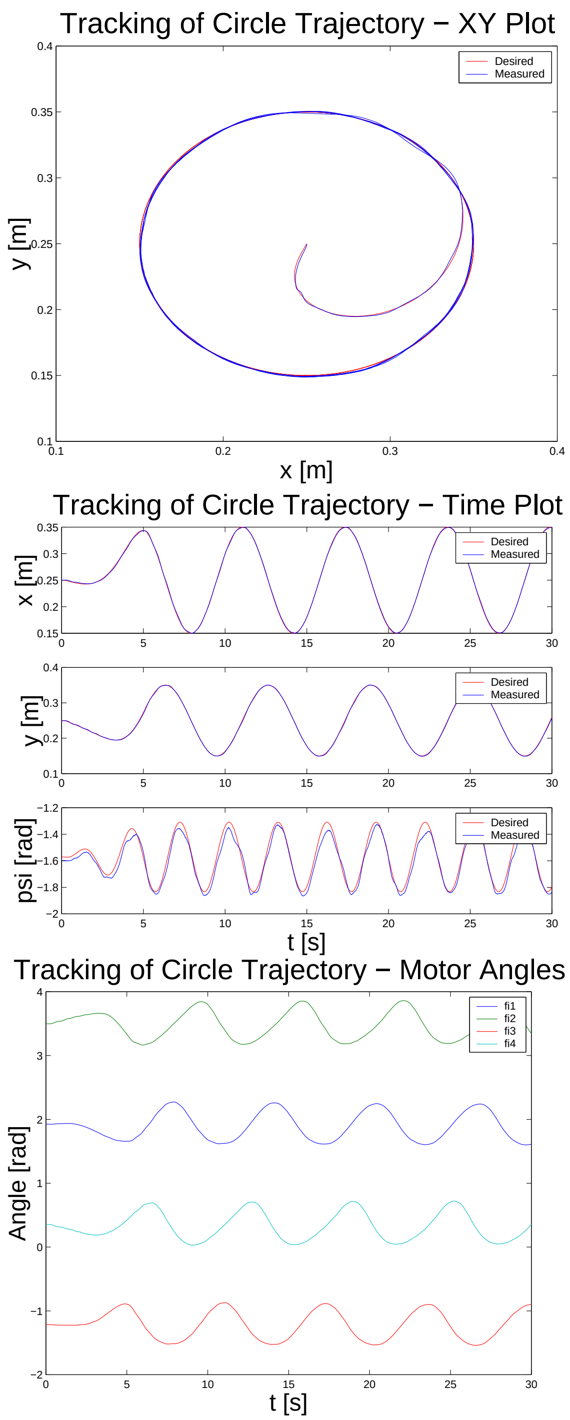

Fig. 4. Captured results of real tracking of the circle trajectory

2.3 *Hardware setup*

The modern, high-level design methods utilize Real Time Workshop, Matlab, Simulink and dSPACE DSP board for precise real-time DC motors control. There are many advantages and some disadvantages of this high level approach when it is compared to C and assembly language based development.

The real-time control algorithms run on dSPACE board based on TMS320C31 DSP. Main features of board are included in next list.

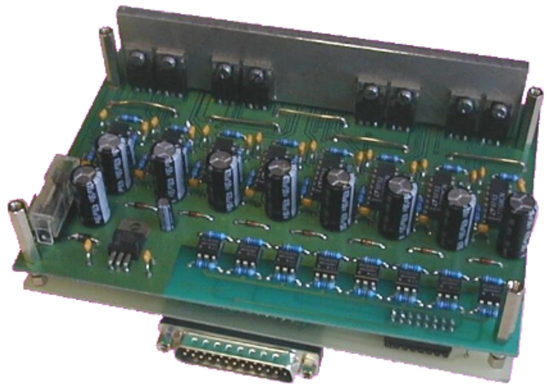

Fig. 5. The parallel robot power stage

- 32 bit floating-point DSP
- 50 ns instruction execution rate
- 128 KWords of SRAM memory
- TMS320C14 I/O coprocessor with modified firmware for external incremental encoders

The extension hardware for DSP system was constructed for control of the laboratory model of the redundant parallel robot. Figure 5 shows photograph of the power stage board stacked over the incremental encoders board. Components of extension boards

- Two CF32006 and six incremental encoders inputs
- Power stage for four 70 Watt Maxon DC motors

3. CONVENTIONAL ROBOTS

Two generations of motion controllers are other practical results of our development. The controllers are used at the Center for Machine Perception for object, camera and laser planes positioning needed for 3D scanning, reconstruction and measurements. The second generation 32-bits systems are used for educational robotics manipulators shown in Figure 6. We have developed and carried out all parts of electronic controllers including system for multiple axes coordinated movement. Energy and time optimized n-dimensional smooth movement is our next research goal. Next paragraph describe deeply designed hardware.

3.1 *Eight axes motion controller*

This motion control system based on Motorola 68376 microcontroller was developed in co-operation with PiKRON company.

Control electronic consists of three board:

- MO_CPU1 (155mm x 80mm x 15mm)
  - · CPU mc68376 @ 21 MHz, 1 or 2 MB of SRAM, 1 or 2 MB of FLASH,

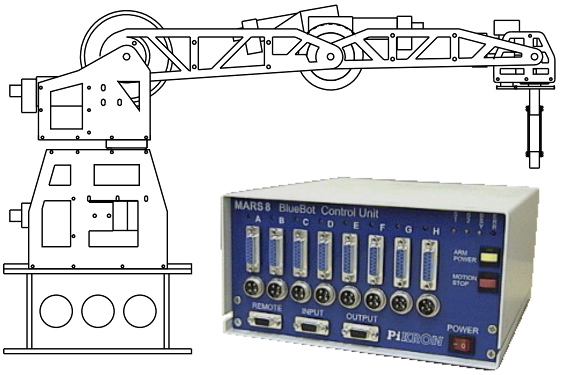

Fig. 6. Educational robot and eight axes controller

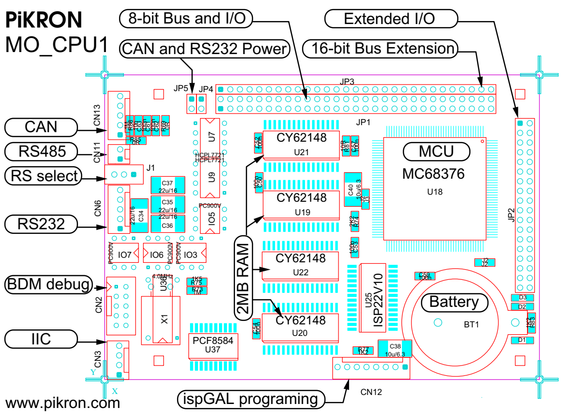

Fig. 7. Motorola 68376 based microcontroller board

- · 32 kB of CMOS SRAM and RTC which are battery back-upped
- · headers for BDM and on two sides of board almost all MCU pins
- · IIC communication interface with PCF8584
- · isolated RS-232, RS-485 and CAN communication
- · ispGAL is used to lower number of used chipselects

• MO_PWR1 (128mm x 93mm x 25mm)
- · isolated power stage with 8 full bridges for DC motors up-to to 30 VDC and 2 or 5 AMPS with over-current protection
- · DCDC converter from 15 up-to 30 VDC to 5 VDC for CPU, 5 VDC for isolated communications and helper supply for bridges.
- · 8 channel 8-bit ADC for current measurement

• MO_CTR1 (105mm x 80mm x 12mm)
- · eight 24-bit IRC counters with two index and mark inputs per motor
- · TTL or differential RS-422 encoders could be used
- · ADC inputs, SPI connector and some logic signals and ability to connect our local keyboard on 8-bit bus

The basic software for velocity and position control with trapezoid speed profile is developed. Up to eight servo motor axes can be controlled with sampling frequency 1 kHz. Unit is directly compatible with MAXON 10 - 70 W motors equipped with HEDL or HEDS incremental encoders.

More complex systems with local keyboard, display, digital and analog I/O and with CAN or RS485 network can be assembled from developed boards and software routines.

Some parts of control system can be used standalone. The MO_CPU1 boards can be used for laboratory instrument or other embedded devices control or for educational purposes. For example, the controller for eight 24 or 60 VDC motors for up to 20 Amps is being prepared to replace old industrial robot electronics.

4. CONCLUSION

Our work shows some possible ways to develop motion controllers and leaded to more practical results. The Simulink diagram graphical language was proven to be good interchange platform for communication between control theory scientists and hardware and software designers. On the other hand, it is difficult to describe some algorithmically defined computations and sequential control tasks. The dSPACE board with its predefined Real Time Workshop target and additional monitoring and development environment is user friendly. But problems appears, when low level changes into environment an communication with the board are necessary, because of closed and undocumented implementations.

There are no such disadvantages for C and assembly language based development on open hardware and open software systems and development tools. Development started on new board without any third party provided support has been demonstrated on our educational robot controller. Disadvantages of this approach is slower development and need to implement and change the controller structure in C source.

The experience with both methods leads to conclusion that both approaches can and should be combined for achievement of optimal results. We want to test open PowerPC based board and write our own Real Time Workshop target and use prepared environment for one of our other research project in future.

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