OPEN SOURCE CNC SOFTWARE FOR PARALLEL MANIPULATORS

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The application of open-source LinuxCNC software for parallel kinematic machine tools and parallel manipulators is considered. Control architecture and LinuxCNC configurations were developed and successfully tested for Stewart platform machine tool and delta robot.

Unlike control systems for traditional machine tools, those for parallel kinematic machines should possess some extra capabilities:

— real-time coordinate transformation from end effector to actuators and contrariwise (world to joint coordinates and vise versa, inverse and forward kinematics);

— limiting for both joints and world positions according to machine workspace;

— preventing parallel manipulator singularities;

— avoiding collisions of struts to themselves or end effector.

Control of parallel kinematic machine tool is possible with any PCNC architecture [1]. Most advanced industrial control systems for parallel kinematic machine tools belong to PCNC-2 class, for example Siemens SINUMERIK 840D (Tricept, VERNE), Power Automation PA8000 (Гексамех-1), Andron Andronic 2000 (METROM P800). Those systems include two personal computers carrying real-time system kernel and interface. PCNC-3 architecture's interface computer incorporates real-time computer on PCI or PCI-e bus. Examples of such systems are Delta Tau PMAC, Bosch PNC, Indramat MTX. All named are complex commercial CNC systems with powerful capabilities to control any machine.

Last years a lot of PC-based control systems were developed in SoftCNC class. Most popular of these are Artsoft Mach3, WinCNC, NCStudio, PlanetCNC etc. Main disadvantage of SoftCNC control systems is significant jitter [2] – unstable timing of internal signals, which limits the stability and frequency of control impulses. Therefore step rate of SoftCNC systems rarely exceeds 40-50 kHz. But low cost and simplicity of SoftCNC systems made them very popular for hobby and low-end industrial machine tools. A few SoftCNC control systems can develop to PCNC-3 with external controllers like KFLOP and SmoothStepper for Mach3.

One of the most advanced and evolving non-industrial PC-based CNC systems is LinuxCNC (EMC2, Enhanced Machine Controller before 2011), developed as NIST project which became open-source in 2003. LinuxCNC [3] is a free software control system with open source code for machine tools and robots. Current versions of LinuxCNC are entirely licensed under the GNU General Public License (GPL) and Lesser GNU General Public License (LGPL).

LinuxCNC has modular structure adjustable for various hardware and control interfaces, low-level machine electronics such as sensors and motor drives. It incorporates four key components [3]: a motion controller (EMCMOT), a discrete IO controller (EMCIO), a task executor which coordinates them (EMCTASK) and several text-mode and graphical User Interfaces. Built-in G-code interpreter works with the RS-274 machine tool programming language. A real-time motion planning system supports look-ahead and trajectory blending. LinuxCNC includes a few graphical and text user interfaces.

Each machine is described in LinuxCNC with several configuration files. Hardware abstraction layer (.hal) file contains complete information about the way LinuxCNC interacts with connected hardware: actuators, spindle, home and sensors, control inputs and outputs etc. Machine configuration file (.ini) describes machine parameters: coordinates, joint limits, home positions, joints and axes velocities and accelerations, PID gains, encoder scales etc. For a machine with nontrivial kinematic it's necessary to provide kinematics file (.c) which performs inverse and forward coordinate transformations. The modular structure and open source code of LinuxCNC enable adjusting kinematics for any machine, which makes LinuxCNC suitable to control parallel kinematics machine tools as Stewart platform, tripod etc [3]. There are several possible scenarios for LinuxCNC to control parallel kinematic machine tool. Basic LinuxCNC configuration is a SoftCNC architecture, which controls motor drives with software step generator via LPT port. This configuration has rather unstable and limited step rate, which can not provide sufficient velocity and (or) high resolution.

This is why the optimal LinuxCNC configuration includes external FPGA card for realtime control and input-output, evolving to PCNC-3 class possible of controlling both step mode or analog mode servo drives with encoder or resolver feedback. A variety of FPGA boards with daughter I/O cards [4] provide low-cost hardware interface for servo drives with analog velocity/torque control or pulse/direction control, incremental encoders, limit switches etc. Latest cards also support serial protocols SSI, BISS etc.

Common control architecture for a parallel kinematic machine tool (fig. 1 a) includes a PC with LinuxCNC and connected via LPT port MESA 7I43 FPGA card with 7I48 6-axis analog interface card.

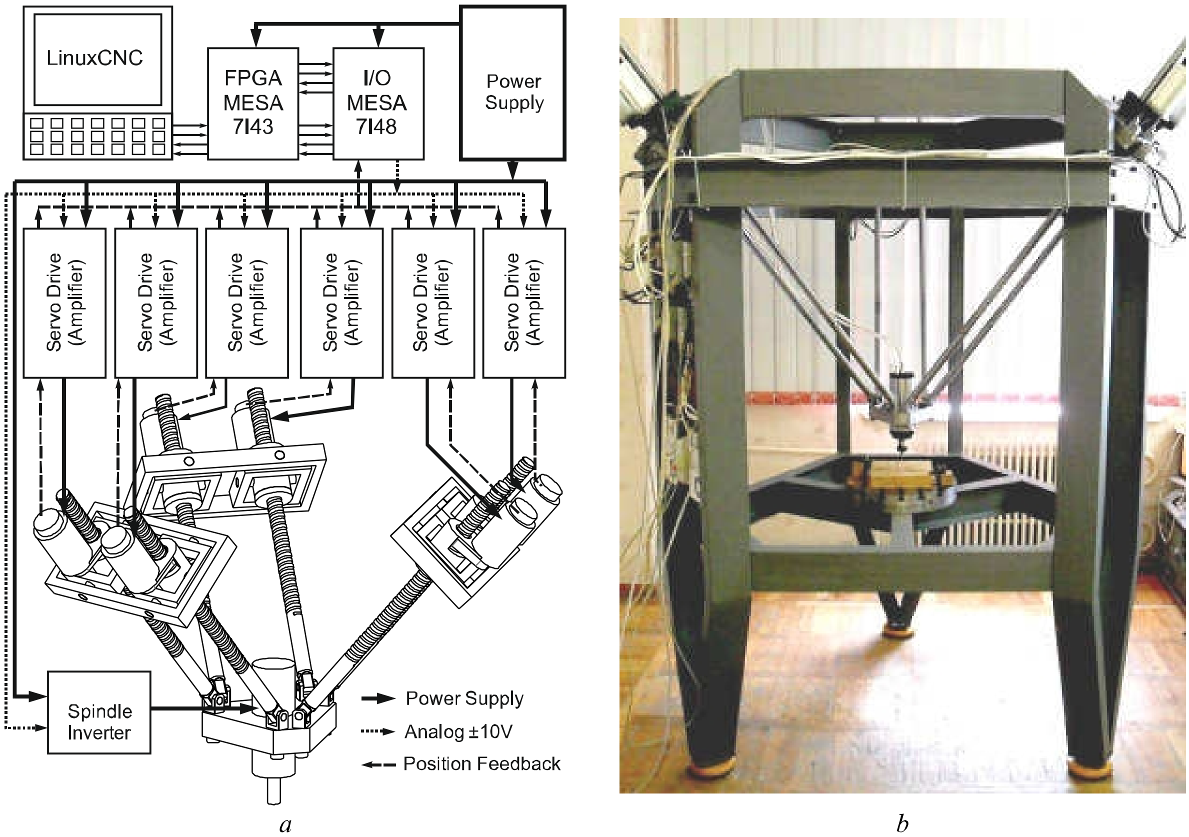
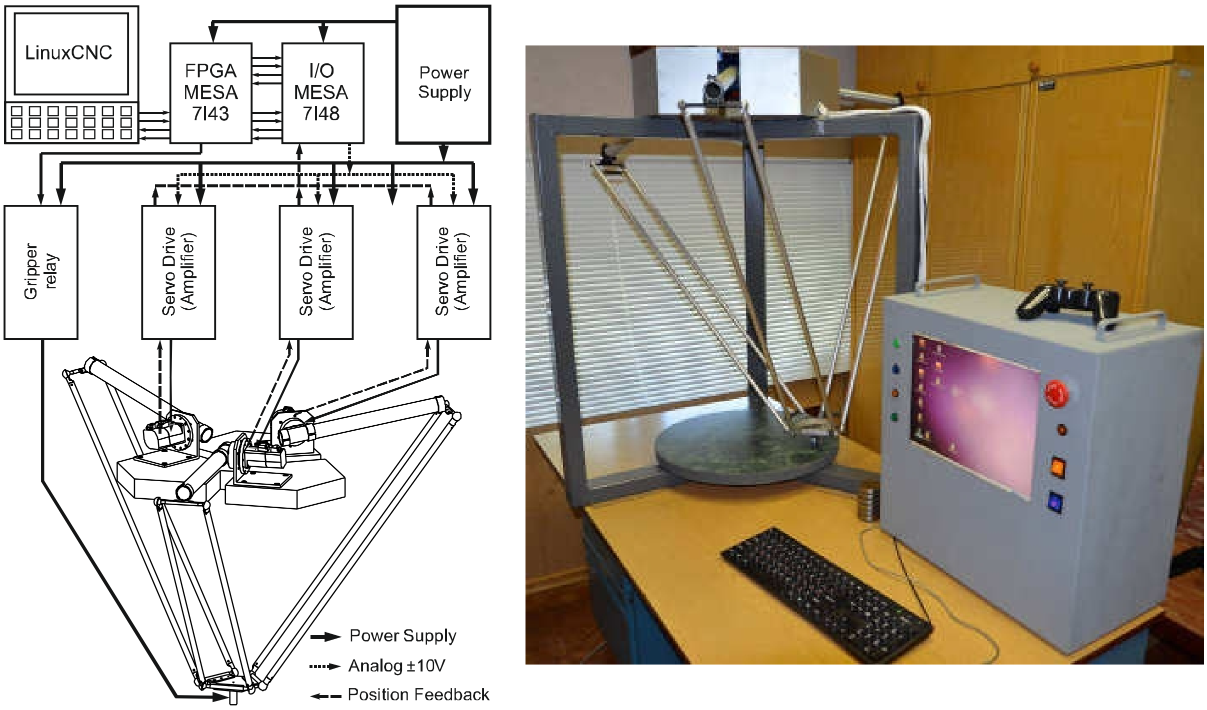


Fig. 1. Stewart platform: general schematics of control (a), working prototype (b)

Analog control signals (±10V) go from 7I48 to servo drives (or amplifiers) velocity inputs, along with enable signals which power up the motors. ABZ incremental signals from motor encoders connect to encoder inputs on MESA 7I48 providing feedback for joint positions. Thus servo loop is closed within LinuxCNC, joint PID regulators with position error as input provide output velocity signals for the motors. PID parameters can be independently adjusted for each motor. Each actuator home and limit sensors connect to 7I43 inputs providing automated home position search when machine is initialized. The spindle inverter is controlled via Modbus or analog interface enabling stepless spindle speed control from within G-code program.

Above described architecture was successfully used to control the prototype of Stewart platform machine tool [5] (fig. 1 b). Kinematics module genhexkins.c, hexapod.ini and hexapod.hal configuration files were adjusted to completely describe the machine kinematics and actuators.

Similar LinuxCNC based system (fig. 2, a) is used to control a pick-and-place delta robot prototype (fig. 2, b) with electromagnetic gripper.



a *b*

Fig. 2. Delta robot: general schematics of control (a), working prototype (b)

Thus, LinuxCNC is a powerful open source CNC software capable to control various machines including parallel kinematic machine tools. Control architecture and LinuxCNC configurations were developed and successfully tested for Stewart platform machine tool and pick-and-place delta robot, more machines under development.

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