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Open source CNC control for parallel kinematic machine tool

Application of LinuxCNC (open-source Linux based CNC software) to control parallel kinematic machine tools is considered. A control architecture and configuration files developed for LinuxCNC parallel kinematics machine tool with Stewart platform.
parallel kinematic machines, CNC, LinuxCNC, real-time, MESA, Stewart platform

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Розглянуто використання вільної системи ЧПУ LinuxCNC з відкритим кодом для управління верстатами паралельної структури. Запропоновано структурну схему та файли конфігурації системи управління, використаної для верстата паралельної структури на основі платформи Стюарта.
верстат паралельної структури, ЧПУ, LinuxCNC, система реального часу, MESA, платформа Стюарта

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 (table 1) [1].

Table 1 – Architectures of control systems for machine tools

Architecture	Interface	System kernel
CNC	Custom processor module. External automation controller.	
PCNC-1	Personal computer	Custom processor module. Single-board automation controller.
PCNC-2	Personal computer	Personal computer. Software automation controller.
PCNC-3	Personal computer	Built-in computer. Software automation controller.
PCNC-4	Personal computer. Software automation controller.	

Most advanced industrial control systems for parallel kinematic machine tools have PCNC-2 architecture, 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 [7] – unstable timing of internal signals. It limits the stability and frequency of control impulses; therefore step rate of SoftCNC systems rarely exceeds 50 kHz. But low cost and simplicity made SoftCNC very popular for hobby and low-end industrial machine tools. Some of SoftCNC control systems can partially develop to PCNC-3 with external controllers like KFLOP and SmoothStepper for Mach3.

One of the most advanced and promising non-industrial PC-based CNC systems is LinuxCNC (EMC2 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). Currently LinuxCNC can be compiled from source or downloaded as Live-CD integrated image based on Linux Ubuntu 10.04 with RTAI kernel.

LinuxCNC has modular structure which makes it adjustable for almost any machine tool or robot with various hardware and control interfaces, low-level machine electronics such as sensors and motor drives. Basic LinuxCNC configuration is a SoftCNC architecture, which controls motor drives with step/dir signals via LPT port. With extra FPGA board LinuxCNC becomes PCNC-3 class possible of controlling both step mode or analog mode servo drives with encoder or resolver feedback. StepConf and PNCConf wizards enable fast configuration for machine tools with stepper or servo motors.

LinuxCNC 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, the most popular is AXIS GUI which displays instrument path from G-code (fig. 1, a) and TkLinuxCNC (fig. 1, b).

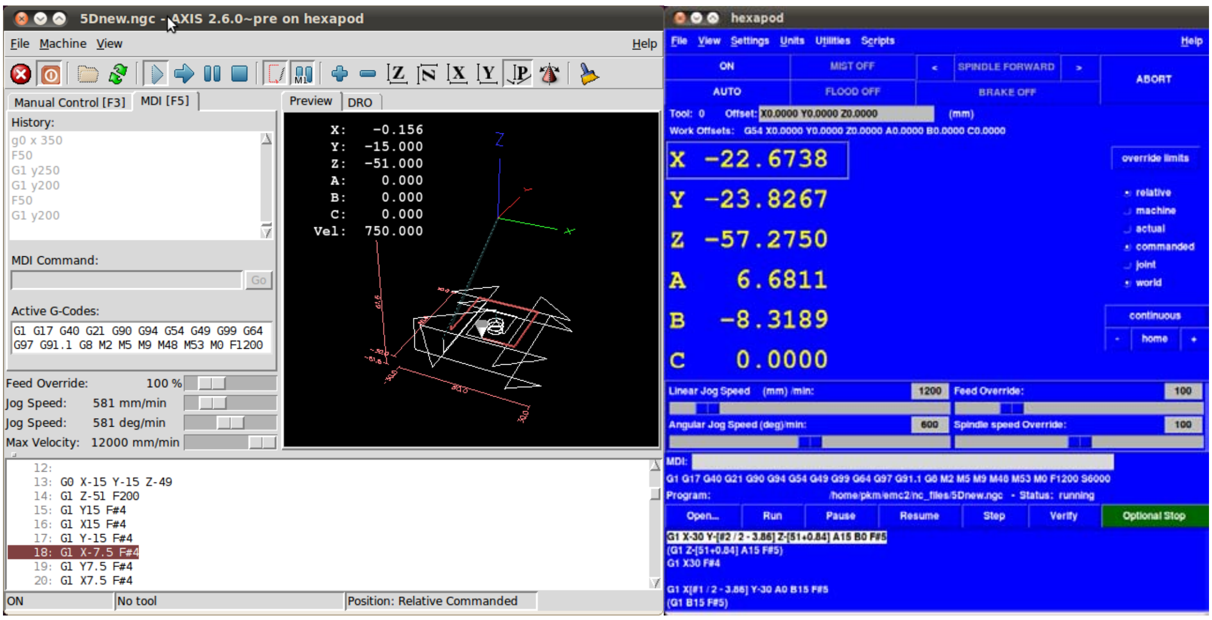


Figure 1 – LinuxCNC user interfaces: a) AXIS, b) TkLinuxCNC

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.

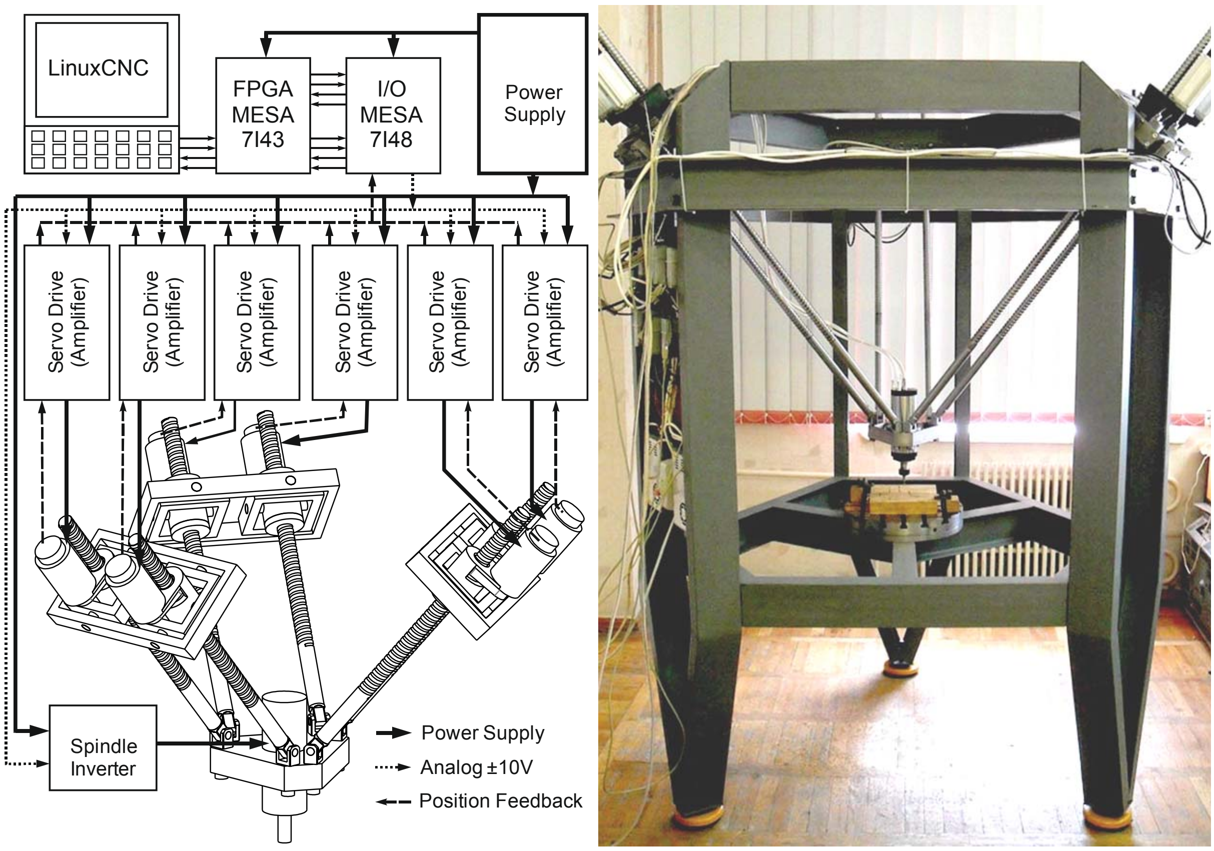
Machine configuration file (.ini) describes machine parameters: coordinates, joint limits, home positions, joints and axes velocities and accelerations, PID gains, encoder scales etc. For a machine with nontrivial kinematic it's necessary to provide kinematics file (.c) which performs inverse and forward coordinate transformations.

The modular structure and open source code of LinuxCNC enable adjusting kinematics for any machine, which makes LinuxCNC very suitable to control parallel kinematics machine tools as Stewart platform, pentapod, linear delta etc [3, 4].

There are several possible scenarios for LinuxCNC to control parallel kinematic machine tool. The simplest case provides control for step motors via LPT port with software step generator. This configuration has rather unstable and limited step rate (40-60 kHz), which can not provide sufficient velocity and (or) high resolution. Besides, without position feedback it's impossible to actually control the trajectory following of the end effector.

This is why the optimal LinuxCNC configuration includes external FPGA card for realtime control and input-output. FPGA cards with PCI, PCI-e and LPT can be used, for instance Motenc [5] and MESA [6]. A variety of MESA FPGA boards with daughter I/O cards 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 SPI, BISS etc. MESA FPGA cards provide step rate up to 10MHz.

Common control architecture for parallel kinematic machine tool (fig. 2 a) includes a PC with LinuxCNC and connected via LPT port MESA 7I43 FPGA card with 7I48 6-axis analog interface card.



a) b)

Figure 2 – Control system: a) general schematics, b) installed on Stewart platform hexapod

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 Stewart platform hexapod machine tool [7] (fig. 2 b). Kinematics module genhexkins.c, hexapod.ini and hexapod.hal configuration files were adjusted to completely describe the machine kinematics.

LinuxCNC is a constantly developing system. Current stable version of LinuxCNC works with RTAI real-time kernel, but the developers are working to switch to Xenomai kernel with support for latest Ubuntu versions, including x64. There is also ongoing work to port LinuxCNC on low-cost ARM computers like BeagleBone [8] which combine ARM CPU and several Programmable Real-Time Units in a small board with a lot of I/O pins.

Conclusion: LinuxCNC is a powerful open source CNC software capable to control various machines including parallel kinematic machine tools. Several control architectures were suggested for parallel kinematics machine tool architecture parallel kinematics machine tool were tested with Stewart platform hexapod.

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Свободная система ЧПУ для станка параллельной структуры

Рассмотрено использование свободной системы ЧПУ LinuxCNC с открытым исходным кодом для управления станками параллельной структуры. Предложены структура и файлы конфигурации системы управления, использованной в станке параллельной структуры на основе платформы Стюарта.

станок параллельной структуры, ЧПУ, LinuxCNC, система реального времени, MESA, платформа Стюарта

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