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FROM MODULAR LEGACY TO OPEN INNOVATION: EVOLUTION OF THE LOLA CNC SYSTEM ARCHITECTURE

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Abstract: *This paper provides a comprehensive overview of the development, technical architecture, and practical applications of the* LOLA 30 CNC *system, a landmark achievement in domestic industrial innovation in the field of numerical control. Developed in the early 1980s by the* LOLA Institute*, the system is examined within its historical context, with particular attention to its architectural features and its broader impact on industrial autonomy and engineering education. Special emphasis is placed on its modular design, integration with the* PA512 *programmable logic controller, and representative use cases. The paper also presents a comparative analysis between the LOLA 30 CNC and the modern* LOLA ROSA CNC system*, which is based on open-architecture hardware and software. Key technological advancements of the new system, particularly in terms of reconfigurability and distributability, are highlighted.*

Keywords: *LOLA 30 CNC, numerical control, modular architecture, domestic CNC system, PA512, LinuxCNC, industrial automation, retrofitting, digital twin.*

1. INTRODUCTION

The development of computer numerical control (CNC) systems has played a pivotal role in modernizing manufacturing technologies, particularly in the context of industrial autonomy and engineering education. Among the most notable domestic contributions to this field is the LOLA 30 CNC system, developed in 1983 by the LOLA Institute in Belgrade. As one of the earliest domestic CNC solutions in the former Yugoslavia, the LOLA 30 system was implemented on over 50 machine tools and became a cornerstone of local innovation in control systems and modular design [1].

This paper provides a historical and technical overview of the LOLA 30 system (Figure 1), examining its architectural features, integration with the PA512 programmable logic controller (PLC), and its broader impact on industrial development and academic training. The system's modularity, support for up to five axes, and analog spindle interface positioned it as a versatile platform for various machine tool configurations [1]. In parallel, the paper

examines the evolution toward modern open-architecture CNC systems.

2. FROM CLOSED MODULARITY TO OPEN

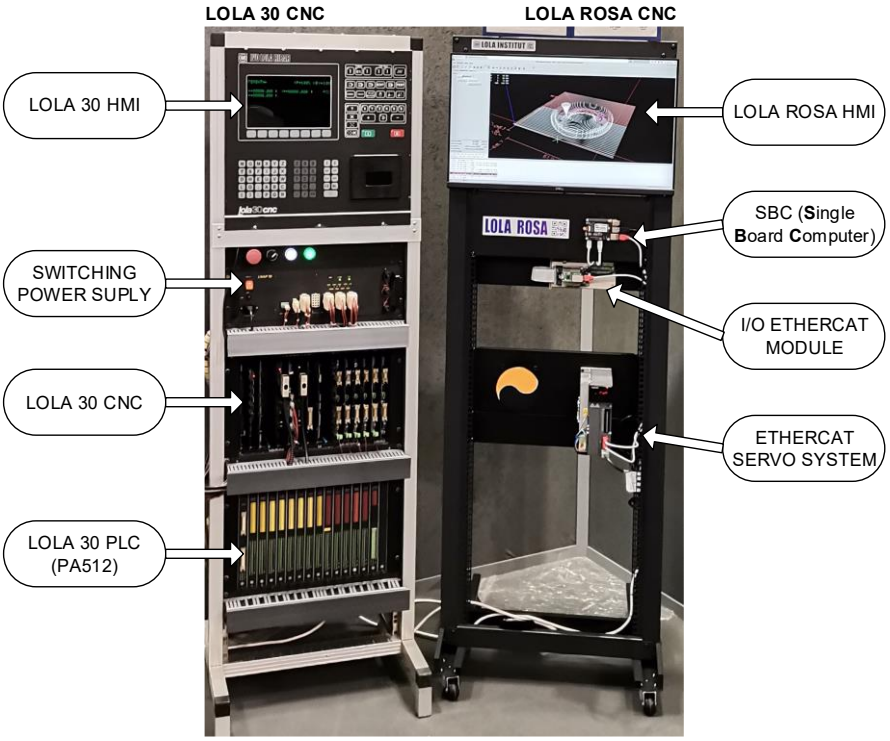

Figure 1. LOLA 30 CNC vs LOLA ROSA

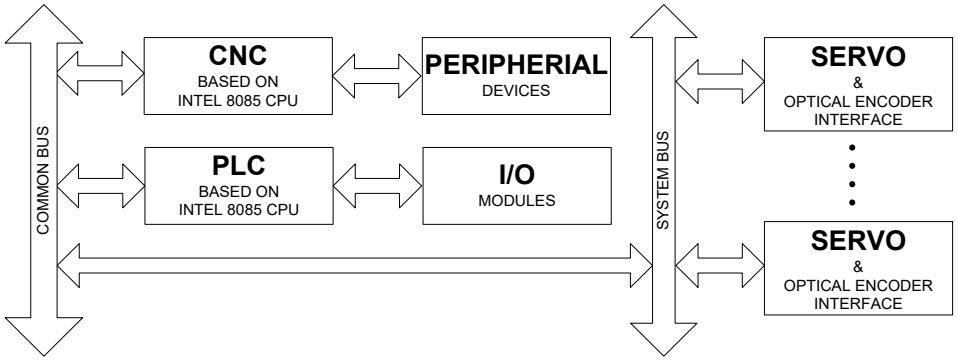

Figure 2. Simplified structure diagram of LOLA 30 CNC

New CNC systems, as LOLA ROSA CNC (Figure 1), offer enhanced reconfigurability, distributability, and integration with CAD/CAM environments, enabling virtual commissioning and digital twin applications [2,3]. A comparative analysis highlights the technological shift from proprietary to open, flexible control architectures.

By situating the LOLA 30 within the broader trajectory of CNC development, from early numerical control to contemporary cyber-physical systems, this study underscores the significance of domestic innovation in shaping Serbia's industrial and educational landscape.

RECONFIGURABILITY

The development of CNC systems in Serbia during the 1980s marked a pivotal step toward industrial autonomy and technological self-reliance. Within this context, the LOLA 30 CNC system emerged as one of the most significant domestic innovations in machine tool control. Deployed on more than 50 installations, it laid the foundation for modular control system design in the former Yugoslavia.

Technically, the LOLA 30 system was based on a closed modular architecture, supporting up to six control axes and featuring an analog

spindle interface (Figure 2). It was tightly coupled with the PA512 programmable logic controller, which handled machine-level logic and interfacing. Operating modes, including Auto, MDI, Edit, Test, Jog, and Reference Point, were selected through a physical keyboard, which functioned as one of the peripheral devices. Both the CNC and PLC control architectures are built upon the Intel 8085 microprocessor. Although reliable, the system's closed design limited adaptability and long-term scalability.

Recent developments at the LOLA Institute led to the creation of modern CNC systems built on open architecture, especially leveraging the LinuxCNC platform. These systems represent a paradigm shift toward reconfigurable**,** distributed, and interoperable architectures, with seamless CAD/CAM integration, STEP-NC support, and digital twin functionality [2,3,7,8].

In contrast to its predecessor, the modern LOLA ROSA CNC system (Figure 3) utilizes a standard industrial SBC (**S**ingle **B**oard **C**omputer) with EtherCAT-based analog/digital I/O modules [6]. Real-time performance is ensured through real-time operating system and LinuxCNC open architecture software, which supports interpolation, multi-axis motion, and flexible kinematic configurations. Such systems have been deployed in projects like the LOLA HBG 80 V3 [2], a retrofitted horizontal machining center with a virtual machine model and possible STEP-NC compatibility. The shift from the LOLA 30 to its open-architecture successors is not merely a technical upgrade; it signals a strategic evolution in control system philosophy, one aligned with Industry 4.0 principles, as shown in Table 1**.**

Table 1. Comparative Analysis: LOLA 30 CNC vs. Modern LOLA CNC System

Feature	LOLA 30 CNC (1983)	Modern LOLA CNC (LinuxCNC-based)
Architecture	Closed, modular	Open, reconfigurable, and distributed
Control Axes	Up to 6 axes	3–6+ axes, depending on configuration
Spindle Interface	Analog only	Analog and digital (PWM, VFD, etc.)
PLC Integration	PA512 (proprietary)	Soft PLC or external PLC (Modbus, EtherCAT)
Software	Proprietary, fixed configuration	Open-source, fully configurable
User Interface	Hardware keyboard and fixed panel	Custom GUI, virtual HMI, touchscreen optional
Programming Support	ISO G-code (limited)	G-code, user-defined macro support, possible use of STEP-NC
CAD/CAM Integration	Minimal or manual	Full integration (e.g., PTC Creo, STEP-NC)
Digital Twin Support	Not supported	Supported (real-time simulation and virtual commissioning)
Kinematics Support	Fixed kinematics	Flexible: Cartesian, SCARA, Delta, hybrid systems
Hardware Platform	Custom-built controller hardware	Industrial PC with standard I/O expansion
Adaptability/Retrofitting	Limited	Highly adaptable to various machine types
Educational Use	Limited (industrial focus)	Strong: supports simulation, training, and R&D environments

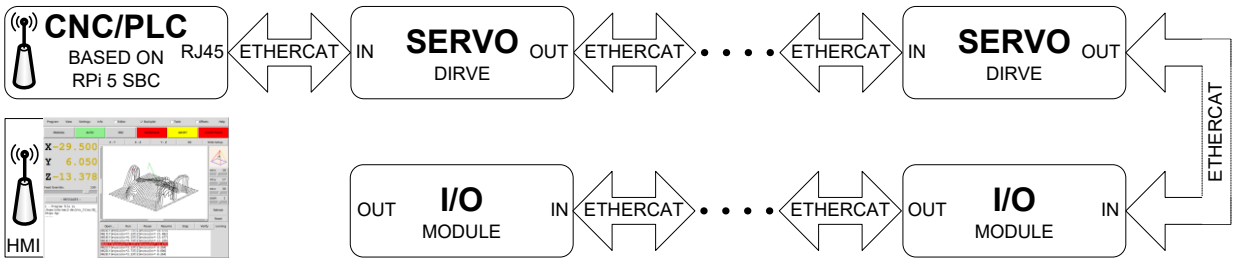

Figure 3. Simplified structure diagram of LOLA ROSA

3. SOFTWARE ARCHITECTURE AND DIGITAL INTEGRATION

The modern LOLA CNC systems are powered by LinuxCNC, an open-source real-time control platform derived from the NIST EMC2 initiative. The architecture provides deterministic motion control, with a real-time core managed via the Real-Time Application Programming Interface (RTAPI) and the Hardware Abstraction Layer (HAL). Motion planning, G-code interpretation, and kinematics configuration are modular and highly adaptable.

The system's reconfigurability is one of its defining advantages. Machine kinematics, tool changers, safety routines, spindle interfaces, and I/O mappings are all defined through text-based configuration files. All of this makes the architecture especially suitable for retrofitting diverse machine types, ranging from 3-axis mills to custom multi-axis platforms and woodworking centers [3].

Integration capabilities include:

- G-code and STEP-NC programming, supporting semantic and feature-based process planning [4],
- Modbus/EtherCAT protocols for external PLC and real-time I/O extensions,
- Digital twin environments, including ROS, Siemens NX, and custom-built virtual models.

LOLA's latest control systems feature custom-developed user interfaces, a virtual HMI that mimics the physical panel, and full synchronization with CAD/CAM and simulation environments, such as PTC Creo and STEP-NC Machine. For example, the LOLA HBG 80 V3, BACCI MX6, EMCO F1 [2,3,7,8] etc., incorporates digital twins for toolpath simulation, process monitoring, and virtual program validation [2,7].

By combining open-source control, semantic interoperability, and virtual feedback loops, the modern LOLA CNC architecture, built around EtherCAT communication capabilities, offers a robust solution tailored for demanding industrial environments. Its reconfigurable structure enables rapid adaptation to diverse machining tasks and evolving production needs, while its distributed design ensures seamless integration of modular components across decentralized systems. Additionally, the architecture provides a flexible platform for engineering education and applied research.

4. CONCLUSION

The trajectory of CNC development at the LOLA Institute reveals a compelling fusion of technological heritage and forward-looking innovation.

The original LOLA 30 system provided a resilient, modular platform during a time of domestic industrial consolidation. Though constrained by its closed architecture, it fostered technical expertise and served as a national milestone in automated control.

By contrast, the modern LOLA CNC systems based on open platforms like LinuxCNC reflect Serbia's alignment with global cyber-physical manufacturing trends. These systems support a broad range of applications, from conventional machining to hybrid digital twins, and integrate tools like STEP-NC, ROS, and CAD/CAM environments with ease.

More than a generational shift in technology, the evolution from LOLA 30 to its open successor embodies a new philosophy:

one that values openness, adaptability, and knowledge-sharing. These CNC platforms continue to serve as bridges between industry and academia, theory and practice, legacy and innovation.

As Serbia pursues its industrial transformation, initiatives like LOLA CNC underscore the significance of local engineering achievements and their potential to make a meaningful contribution to the global manufacturing ecosystem.

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