Development of analog, digital and hybrid computing in Serbia 1950–1970

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***Abstract*—In times when Serbian computer engineers and scholars celebrate the 60th anniversary of digital computing, we turn to the very beginnings, and analyze how the experiences from early developments of analog, digital and hybrid computing in Serbia influenced the further development of economy, science, and education in the country. The goal of the article is to provide a comprehensive overview of the main Serbian projects of analog, digital and hybrid computers in the period 1950-1970, and describe their practical applications. The first analog computer in the Republic of Serbia was TARA-50, used for solving complex mathematical problems in various domains. Later, digital computers have become widely adopted, CER-10 being the very first computer used for statistical processing of information and cryptography for the government and scientific institutions. Finally, hybrid computers try to combine analog and digital technology. The most important model of a hybrid computer in the Republic of Serbia was HRS-100, developed in cooperation with the Russian Academy of Sciences, and used for research, educational, health, and military applications in both countries. The presented projects have set up good research and educational basis and shaped the further development of computer science in Serbia, resulting in the fact that computer and IT services have become one of the most important factors of Serbian export during the 2010s.**

Keywords— history of computing, Serbia, TARA-50, CER-10, HRS-100

I. INTRODUCTION

In the period 1950-1970, development of the computers was strongly connected with the engineers' capabilities to design the architecture and integrate available components. In the beginning, analog computers were in the focus. However, the characteristics of analog computers that can solve nonlinear systems of differential equations in real-time, have been successfully combined with the precision of digital computers into a new type of "hybrid computers" that have found application in solving many problems, from theoretical ones, to solving specific differential equations, aircraft management, nuclear reactors, chemical processes, electricity and water management, and process modeling in industry, which were a challenge for the science and economy in Serbia of that time.

In the period 1950-1970, Serbia was a leading Yugoslav republic in the research and development of analog computers. The country's military and nuclear ambitions were the motive for the foundation of the two research institutes: the Institute of nuclear sciences Vinča, and the institute Mihajlo Pupin, a leading Serbian R&D institution in computer science and information and communication technologies. In cooperation with professors from the Faculty of Organizational Sciences and the Faculty of Electrical Engineering, the most of work on the development of analog, digital and hybrid computers was done within these institutions. At the time, Serbia was one of five European countries at the time that developed their own computers [51].

This article aims to describe the development and practical application as well as to provide a comprehensive overview of analog, digital and hybrid computers developed in Serbia in the period 1950-1970, as well as to discuss implications on the later events and results achieved in the field of computer science.

II. ANALOG COMPUTING IN SERBIA

Analog computers use an analogy between physical phenomena that can be described by similar mathematical formulas to solve problems. They have been known since ancient times [1], and until the development of digital computers, they were practically the only means of solving complex mathematical problems. They are suitable for solving problems related to dynamics in astronomical, physical, technical and organizational systems. One of the better-known analog computers was made in 1873 by Lord Kelvin [2], who used a model based on the synthesis of complex periodic functions to predict tides. One of the first applications of analog computers to solve differential equations was to model the mobilization process in the United States [3]. The rapid use of analog computers began with the development of the aviation industry and nuclear research, and reached its maximum in the period from 1950-1970. The analog computers of that time were able to solve complex systems of nonlinear algebraic and differential equations in real time, which still pose a challenge for the most powerful supercomputers.

The development of analog computers in Serbia was a result of the country's ambitions to develop a nuclear program. TARA-50 was the first-ever analog computer built in the Republic of Serbia [4]-[6]. The chief designer and the lead researcher was Professor Pavle Pejović, from the Faculty of Organizational Sciences in Belgrade [7]-[10][52]. The complete computer was finished in 1964 and put into operation at the Institute of Spatial Technique in Belgrade.

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During 1965 and 1966, two more advanced versions of the analog computer TARA-50 were completed, one for the University of Novi Sad, and the other for the High Technical School of the Army in Zagreb. Later, several analog computers were made based on TARA-50, which were extended by the elements of hybrid computers.

According to the notes from that period, different types of integral equations were solved on this computer and a new approach was developed for iterative solving of integral equations on an analog computer [12]-[16]. The computer was applied for solving problems in the field of biochemical engineering [17][18], water supply modeling [19], and others [20][48]. The documentation was detailed [21]-[23], and it served as a basis for the first university handbook in analog computing in Serbian [24][48].

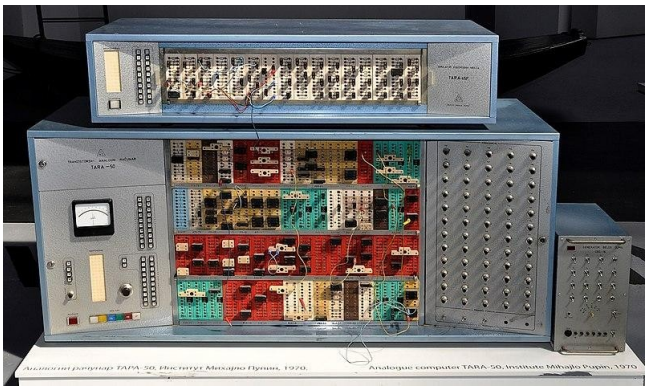

Fig. 1 Tara 50 analog computer [46]

III. DIGITAL COMPUTERS

The beginning of the digital era in Yugoslavia dates back to 1956, when Yugoslavia was one of the five countries in Europe that owned its own production of digital computers. The Yugoslav product CER-10 (in Serbian: Cifarski Elektronski Računar – Digital Electronic Computer) was a vacuum tube, transistor and relays-based computer [25]-[27][30][32]. The development of the first computer in this area lasted for four years, from 1956 to 1960. The team that participated in the development of CER was composed of seventy people - engineers, programmers, technicians and specialists. After the initial prototype testing in Vinča, the construction continued in the Institute "Mihailo Pupin" in Belgrade, where the machine was extended with the so- called Statistical Unit, so by the end of 1962 the project was finished.

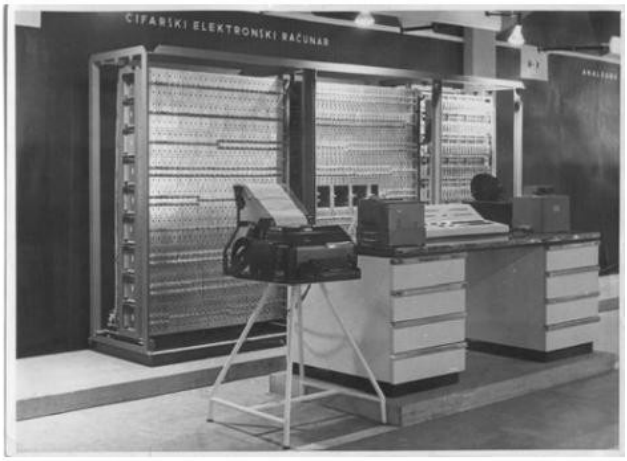

Fig. 2 CER-10 at Belgrade Technical Fair, 1960

The team of designers and engineers included Dušan Mitrović, Rajko Tomović, Ahmed Mandžić, Tihomir Aleksić, Petar Vrbavac, Vukašin Masnikosa, Dušan Hristović, and Milojko Marić [27][31].

CER-10 was employed for statistical processing of information and cryptography for the Yugoslav Federal Government, including Federal Secretariat for Internal Affairs and the national news agency TANJUG, as well as for solving mathematical problems, related to the scientific projects in the Federal Commission for Nuclear Energy in Vinča [25].

Fig. 3 CER-10 digital computer at Tanjug, 1963

CER-10 could be classified as a one-instruction machine with an average processing speed of about 50,000 simple operations per second and about 1,600 additions per second. CER-included the following components: electronic tubes of types ECC 81, EL 83 etc. (approx. 1.750 pieces); Transistors 2N396, OC 76, OC 44 (1.500 pieces); Ge-diodes OA 85 for logic circuitry, (approx. 14.000 pieces); Electronic relays type Schrack (approx. 650 pieces); Pulse transformer core D25 (approx. 1.700 pieces); Delay pulse Lines (approx. 850 pieces), etc. [28][32]. The hardware components were developed from scratch.

After the construction of CER-10, Institute Mihajlo Pupin developed and produced the whole family of CER computers (CER-11, CER-22, CER-200, CER-12), which have been applied for data processing in multiple enterprises, banks and federal agencies [27][28] used for bookkeeping and banking applications, CER-30, described in [29] was something completely different. It was a predecessor of programmable electronic calculators. The last CER computer remained functional in the Vojvođanska Bank-Zrenjanin until the late 1980s when it was replaced by the VAX minicomputer [25].

CER mobile constructions and realizations were also developed, to be used in transport vehicles. CER-11, CER-101-Kosmos and CER-111 were military mobile computers, installed in special vehicles and tested according to the strictest MIL standards [28].

Regarding the system software, CER computers didn't have a classical operating system, but had a very rich kernel with good libraries and program modules. CER-12, for example, had symbolic languages and compilers, input/output programs, programs for sorting, additional routines, a set of test programs, a library with standard mathematical operations, programs for linear programming and network planning, libraries for various applications and subprograms [28]. Later, there were attempts to develop Fortran and Cobol

compilers for CER computers, but these projects were not successful.

The development of computers from the CER family was completed in 1975 when CER-11 was realized in the version of integrated circuits as CER-111.

IV. Hybrid computers in Serbia

The intensive development of hybrid computers in the middle of the 20th century is the result of work on solving problems in the areas of object movement control, modeling and optimization of automatic control systems, development of complex simulators, etc. The individual use of analog and digital computers for this set of problems was not effective, so the approaches that provide the best of both worlds were sought. Hybrid computing systems are an attempt to combine all the best inherent in analog and digital technology, and to avoid their shortcomings.

The hybrid computing system (HCS) is a complex of several computers or computing devices (analog and digital), united by a single control system, for modeling complex systems, optimizing automatic control systems, solving nonlinear partial differential equations, etc. The dismemberment of the computational process into separate operations performed by the AC and DC reduces the volume of computational operations imposed on the digital computer, which significantly increases the overall speed of the HCS.

HRS-100 hybrid computer was one of the most successful hybrid systems developed in the 1960s [33]-[37][47]. The computer was developed aiming to enable solving a plethora of engineering problems, including the modeling of complex economic systems. Bringing together the world's achievements in the field of analog and digital computer technology with a range of original solutions, this system achieved the capabilities and performance of the world's top-class computers of the time. The HRS-100 has been implemented in 1971 in the VLSI technology and represented the modern system of the third generation with many original solutions [33][35].

The HRS-100 consisted of 1) a digital part, 2) an analog part, 3) an interface that connects them, and 4) peripherals [33]-[35][38][39]. This universal hybrid computer was jointly developed by Yugoslav experts from the Mihajlo Pupin Institute and Soviet experts from the Trapeznikov Institute of Systems Management [47][49]. Principal researchers were Professor Boris Kogan from Institute of Control Sciences from Russia, and Petar Vrbavac and Georgi Konstantinov from Mihajlo Pupin Institute in Serbia. Chief designers were: Svetomir Ojdanić, Dušan Hristović, A. Volkov, and V. Lisikov for the digital part; B.Kogan, N.N. Mihaylov, Slavoljub Marjanović and Pavle Pejović for the analog part, Milan Hruška, Čedomir Milenković and A.G. Spiro for the link; E.A. Trahtengerc, S.J. Vilenkin, V.L. Arlazarov and Nedeljko Parezanović for the software [33][34][47][49].

The analog part of the HRS-100 was a system consisting of seven analog subsystems connected to a common control panel [33]. It contained all the elements needed to solve linear and nonlinear differential equations, by direct and iterative methods. The analog computer consisted of the following units: elements for linear analog calculations, elements for nonlinear analog calculations, parallel logic elements, potentiometer, calculation module and parallel logic control system, periodic block, control system, addressing system, measuring system, board with programming, power supply. Elements for linear calculations provided an accuracy of 0.01% in static and 0.1% in dynamic mode, for signals up to 1kHz. The accuracy of nonlinear elements was 0.1%. The analog part of the HRS-100 computer had its own peripherals: a multi- channel ultraviolet printer, a tricolor oscilloscope, and an X- Y drawing device. [33][37].

Fig. 4 The photo shows an analog part of the HRS-100 computer, a box with A / D and D / A converters, a table with a control console and part of the development team. Source: [40]

At the Trapeznikov Institute for Systems Management, HRS-100 was used to conduct research in various fields of science and economy. Under the guidance of Professor Boris Kogan, with the help of this computer, spiral waves were discovered on a model of the heart muscle, which was later confirmed through physiological examinations. By studying stationary spiral waves, a kinematic theory of stationary spiral waves has been developed [41]. One HRS- 100 computer was also installed in the Siberian branch of the USSR Academy of Sciences, and was used there in research into chemical and physical processes [42]. HRS-100 was used in the USSR for a large number of researches in the fields of astronautics, energy, microelectronics, telecommunications, biomedicine. It was also used in teaching at the Moscow Institute of Physics and Technology [36].

Fig. 5 HRS-100 at the Trapeznikov Institute of Systems Management, USSR Academy of Sciences [43] [44]

HRS-100 was used also to study dynamical systems in real and accelerated scale time and for efficient solving of a wide array of scientific tasks at the institutes of the A.S. of USSR (in the fields: Aerospace-nautics, Energetics, Control engineering, Microelectronics, Telecommunications, Bio-medical investigations, Chemical industry etc.).

Nowadays, with the development of the Internet of Things (IoT) and newer, more precise analog electronic circuit

technologies, the limitations of former hybrid computers have been greatly overcome, and the possibility of a new distributed IoT generation of hybrid supercomputers, with much lower power consumption, opens up [45][50].

V. Conclusion

This article tried to present the main achievements in computers developments in the period 1950-1970 in the Republic of Serbia. At the time, the country was one of a few European countries that developed their own computers. The work was mainly done at the two research institutes, Vinča and Mihajlo Pupin, and with leading roles performed by professors from the Faculty of Organizational Sciences and Faculty of Electrical Engineering. Several decades later, in the 2010s, these institutes and faculties still represent the centers of excellence for the research and development in the field of ICT in the Republic of Serbia [53], as well as for the education of high-quality experts in the field of computer science and ICT.

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