Solar Car: Example of Low Power Design

Juraj Miček, Peter Ševčík, Michal Hodoň

***Abstract*—**The paper outlines the problems associated with the increasing energy consumption of ICT (Information and communications technology) devices as well as their overall environmental footprint. Even though the area of embedded systems is not dominant in terms of energy consumption, it is necessary to highlight the need for their energy efficient design. IoT (Internet of Things) and WSN (Wireless Sensor Networks) devices are specific in that they most often operate off the power grid. Their long-term operation is ensured by batteries, often supplemented by ambient energy harvesting systems. As an example of a device based on a supercapacitor and a solar cell, a Solar Car is given, which was developed mainly to popularize the study of ICT and to demonstrate selected green computing issues.

***Keywords*—**Energy harvesting, Energy management, Green computing, Solar car, Supercapacitor.

I. INTRODUCTION

"ICT sector represents ~4 % of global electricity consumption in 2020. The ICT sector represents 1.4 % of global GHG emissions in 2020. User devices represent a majority of GHG emissions (~57 %). Embodied emissions represent 36 % of total emissions. The ICT sector has increased its emissions by about 5 % from 2015." [1]

Based on [1], it can be concluded that the ICT sector consumed approximately 4 % of the global electricity production in the use phase in 2020 and accounted for approximately 1.4 % of global greenhouse gases (GHG) emissions. Electricity consumption in the operation of ICT equipment and overall GHG emissions have increased since 2015. User equipment accounted for more than half of all GHG emissions, with equal shares for the use phase and other life cycle phases. For networks and data centers, the use phase dominates. In [2], it is stated that data centers currently consume a huge amount of energy. The Covid-19 pandemic has triggered an increased need for digital information transfer. Hybrid work is moving much more data to the cloud. Currently, the ICT sector accounts for 7 % of global electricity consumption. Many forecasts signal continued exponential growth in data traffic and the share of emissions produced by ICT is set to rise to 14 % of global emissions by 2040. The rise in energy prices over the last two years has caught the attention of large corporations. The current energy crisis, exacerbated by regional conflicts, has pushed up the price of electricity as well as other forms of energy to their highest level in 100 years. This has contributed significantly to optimizing the operation of generation systems and to lower electricity consumption.

Currently, there is controversy about the possible increase in energy consumption in the ICT sector due to the intensive use of artificial intelligence (AI) tools [3]. Most authors do not expect a dramatic increase in electricity consumption in the coming years due to the advent of AI. It should be noted that a comprehensive assessment of the environmental impact of ICT devices needs to consider their entire life cycle, from production through operation to termination or recycling.

Even though the largest electricity consumption is represented by user computers, data centers and network equipment, it is necessary to address the energy efficiency of other ICT systems such as embedded systems, Internet of Things, wireless sensor network elements, etc. The present paper focuses specifically on the area of embedded systems and devices from the

Juraj Miček, University of Žilina, Faculty of management science and informatics, Žilina, Slovakia (e-mail: juraj.micek@fri.uniza.sk).
Peter Ševčík , University of Žilina, Faculty of management science and informatics, Žilina, Slovakia (e-mail: peter.sevcik@fri.uniza.sk).
Michal Hodoň, University of Žilina, Faculty of management science and informatics, Žilina, Slovakia (e-mail: michal.hodon@fri.uniza.sk).

IoT and WSN domain.

II. EMBEDDED SYSTEMS – POWER SUBSYSTEM

The area of embedded systems is very important in terms of electricity consumption. Due to the huge number of installations, the reduction of energy consumption as well as of the materials used to produce them is significant. Often embedded systems are intended to control other devices and technological units, it is necessary to pay maximum attention during their development to optimize the energy consumption of the entire final installation.

IoT and WSN devices, unlike data centers, are often operated outside the reach of standard power grids. This fact places special requirements on the power subsystem of these devices. In practical applications, we mainly encounter the use of:

- primary power cells,
- secondary power cells,
- energy harvesting systems, in cooperation with secondary energy cells or supercapacitors.

Let us compare the properties and parameters of primary and secondary cells. Primary cells are also known as disposable cells. In primary cells, electrochemical energy is generated by the decomposition of electrodes and electrolytes. The electrochemical reactions taking place in the cell are irreversible. Therefore, it is necessary to replace the primary cell with a new one when it is discharged. Alkaline manganese, silver/zinc oxide, lithium/manganese dioxide and thionyl chloride are some common components of primary cells. Primary cells are expensive and not environmentally friendly as they need to be disposed of at the end of their useful life. They use chemical reactions that are generally not reversible. Once the chemical components are exhausted, the battery stops producing electricity. For example, in alkaline batteries, zinc and manganese dioxide react to produce a flow of electrons until one of the reactants is completely consumed.

Secondary cells are also known as rechargeable cells, these electrochemical cells can be recharged repeatedly. These cells find application in areas where the electrical potential in terms of specific power and specific energy seems to have reached a limit with current state-of-the-art primary lithium-ion batteries. Reversibility of secondary cells is achieved by various chemical processes such as the movement of lithium ions between the anode and cathode in lithium-ion batteries. The ability to reverse this reaction makes these batteries rechargeable.

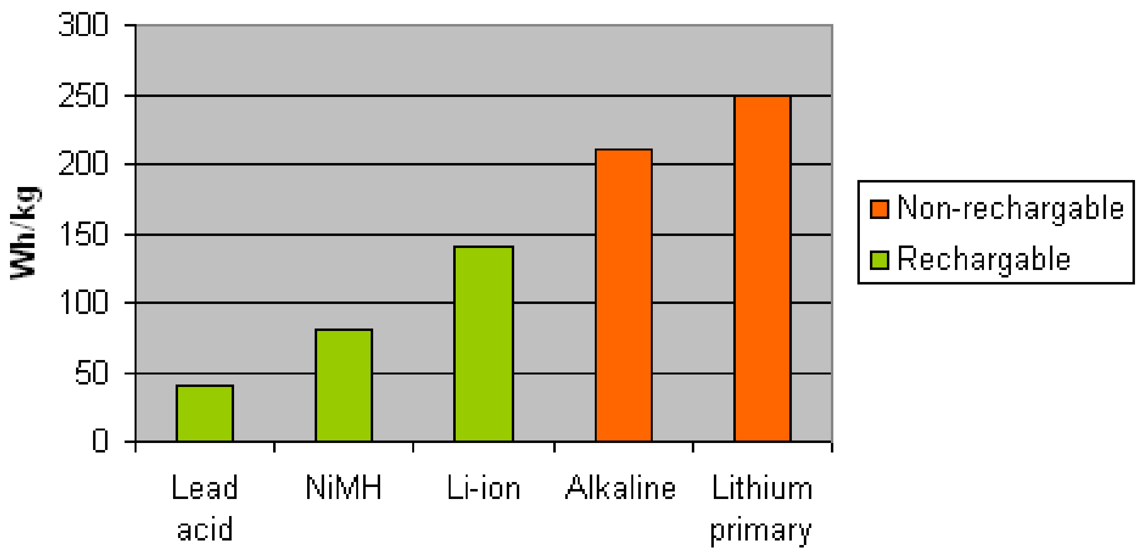

Fig.1 Gravimetric energy density Wh/kg, [5]

In general, primary batteries have a higher energy density than rechargeable batteries, which means they store more energy with respect to their size or weight, as shown in Fig.1. Primary batteries are cheaper per unit of energy but can be more expensive in the long run due to the need for frequent replacements. Secondary batteries, although initially more expensive, can be more economical over time due to their rechargeability. Primary batteries can provide a theoretical energy density 1.5 to 5 times higher than secondary batteries [4]. Primary batteries are typically used in applications where long lifetime is required. Secondary batteries, due to their rechargeability, are suitable for long-term applications despite having a lower energy density.

Supercapacitors store energy through two mechanisms: electrostatic and electrochemical. In electrostatic storage, charge separation occurs at the electrode-electrolyte interface, leading to the formation of an electrical double layer of ions. This double-layer capacitance stores energy without any chemical reactions inside the cell. The energy stored in this way can be quickly released when needed. The electrochemical mechanism involves redox reactions where charge is stored by the movement of ions between the electrolyte and the electrode. Supercapacitors may use one or both mechanisms.

Supercapacitors store much less energy per unit volume or mass compared to conventional batteries. Supercapacitors can deliver a large amount of energy in a short time, making them ideal for applications requiring fast energy consumption. Such applications are, for example, the rapid acceleration of electric vehicles, or camera flashes. Supercapacitors typically have a higher cost per watt. They discharge energy very quickly and therefore can be inefficient in some applications.

Batteries have a much lower self-discharge rate compared to supercapacitors. Thus, batteries are more suitable for applications requiring long-term energy storage without frequent recharging. In batteries, a chemical reaction corrodes the components - so while supercapacitors can handle more than 1,000,000 charge/discharge cycles, a conventional rechargeable battery will only last about 2,000 to 3,000 cycles. The mining of lithium, nickel and cobalt, which are needed for lithium-ion batteries, raises environmental concerns about waste and pollution. In contrast, supercapacitors can use more sustainable materials, such as activated carbon from biomass sources, which are more renewable, less harmful to the environment, and easier to recycle, [6].

Energy harvesting is a relatively new technology for harvesting energy from the environment. Energy harvesting should be defined as the collection of local naturally available energy for local use. Most often energy harvesting systems are small-scale systems with small amounts of energy with power ranging from nanowatts to hundreds of milliwatts. The main area of application is wireless devices. The applicability of energy harvesting to specific devices depends on the type and amount of ambient energy available, as well as size constraints. Motion, temperature gradients, light, electromagnetic radiation, and chemical energy can all be used as sources for energy harvesting. Three different mechanisms are available for motion using electromagnetic, electrostatic or piezoelectric principles. Thermal systems use the thermoelectric effect (also known as the Seebeck effect), light systems use the photoelectric effect, while electromagnetic energy harvesting systems use induction. Chemical systems can use various chemical reactions on the surface of electrodes, etc. A more detailed discussion of the principles and applications of ambient energy harvesting systems is well developed in the literature [7, 8].

When designing the power subsystem of the device under development, it is necessary to select the optimal power supply method while respecting all constraints arising from future operation and economic requirements.

In a second step, it is essential that the whole system is designed to minimize the overall power consumption and to operate in an energy efficient manner. Minimizing power consumption is often a fundamental task in device development. It is often necessary to ensure the long-term operation of systems without operator intervention (electronic labels, heat and water metering systems, and possibly other applications from IoT and WSNs). However, energy efficiency touches every device today, so it is necessary to pay increased attention to addressing this issue.

It should be noted that the energy efficiency of the whole system needs to be addressed at both hardware and software level. The above-mentioned efforts towards energy efficiency and minimizing the ecological footprint of ICT systems are now often referred to as "Green Computing". Geen Computing is of particular importance in the development of IoT devices and WSNs as we are dealing with limited energy resources while maintaining long autonomous operation times [9].

We want to highlight the importance of energy-optimal design of electronic devices with the project "Solar Car", which was previously developed in our department.

III. Solar Car Project

The Solar Car project was created to support the teaching of embedded systems programming. Using the example of energy-efficient application development, the project addresses a range of issues that a developer will encounter in the process of developing a device. The Solar Car is powered only by a solar panel and a supercapacitor. The car is shown in Fig.2.

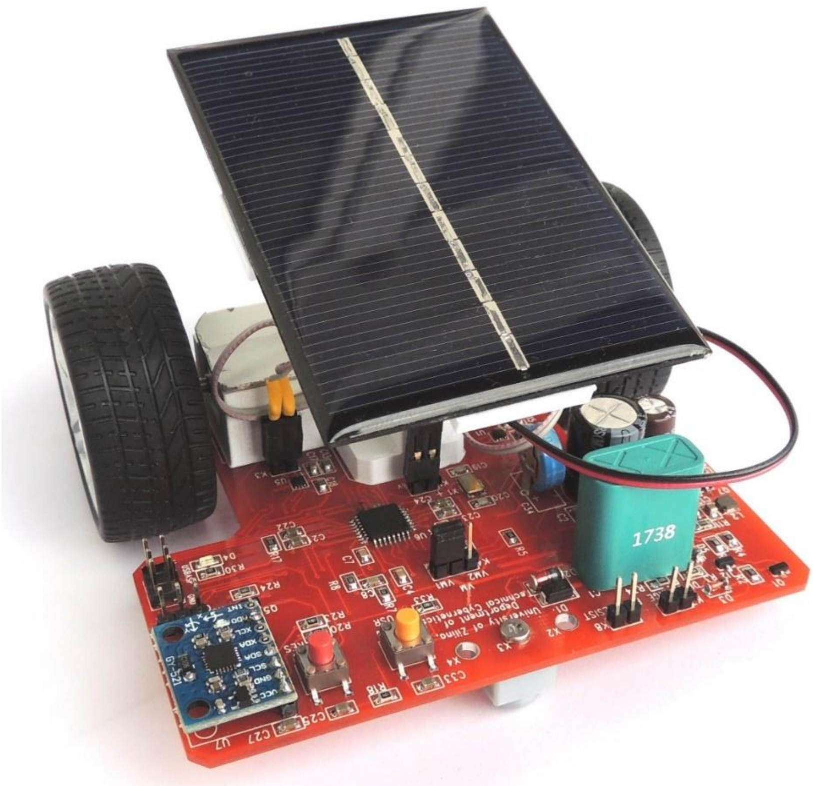

Fig.2 Solar Car

We will briefly describe the circuit design of the Solar Car. Fig.3 shows the block structure of the power supply circuits of the Solar Car. The supercapacitor C1 is charged gradually from the solar panel. It is used to store energy. When the voltage across its electrodes reaches a value of approximately 1.4 V, the DC/DC converter starts working, which increases the input voltage to 3.4 V. This voltage is then used to power all the circuits, including the microcontroller (MCU). This is all implemented by circuit means.

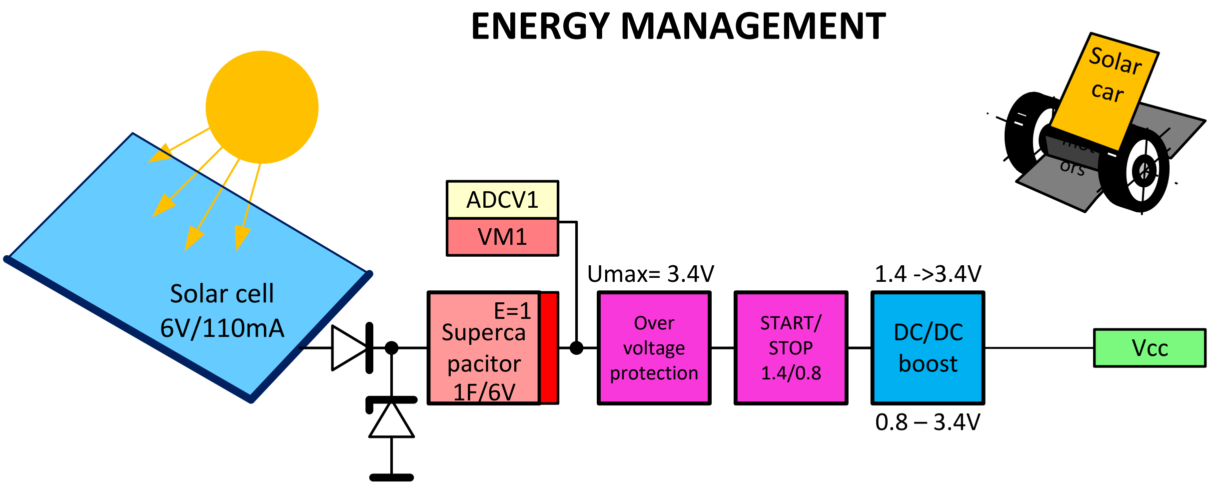

Fig.3 Block structure of Solar Car power supply circuits

From the moment the DC/DC converter starts working, the further operation of the Solar Car can be controlled by the program to minimize the power consumption and at the same time accomplish the task at hand. The control circuits of the car can also be powered via the USBASP programmer from the USB port of the computer. This method of powering the car is used during program development and debugging.

In addition to the power supply circuits, the Solar Car includes a microcontroller, DC motors with control circuits, optical sensors to measure the reflectivity of the surface on which it is standing, a three-axis gyroscope, an accelerometer, and a photoresistor. The entire block structure is shown in Fig.4.

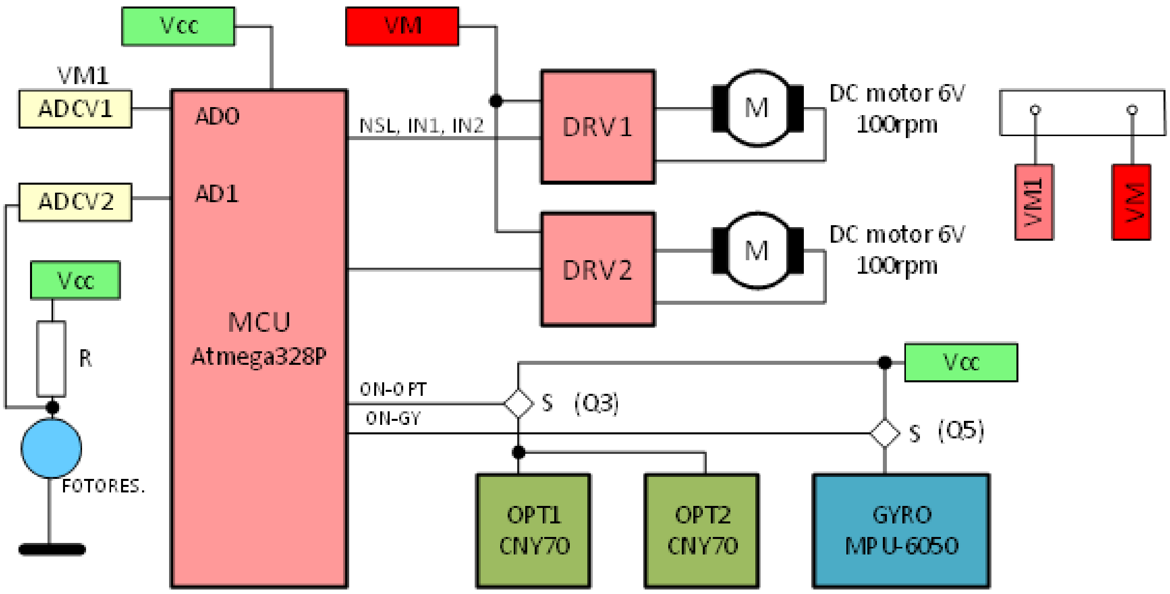

Fig.4 Block diagram of Solar Car control parts

To develop the Solar Car software, the following technical resources are required:

- Solar Car,
- Computer (PC, Notebook, etc.) with two free USB ports,
- USBASP programmer,
- USB/UART converter module.

IV. Typical Task

The students are provided with complete technical documentation about the car so that they can solve the problems given. One typical task is the task of tracing a black line on a white background. The line is approximately 2 meters long and the car must cross it in the shortest possible time. The power of the solar panel is not large enough to move the car based on the power of the solar panel alone. The energy needs to be stored in a supercapacitor ($E_{max} = \frac{1}{2}CU^2$). In our case, a supercapacitor with a capacity of 1 F is used to store energy. Its maximum stored energy is 18 J at 6 V. This is not enough energy to travel the entire specified path. It is necessary to stop and wait for the supercapacitor to recharge. The voltage on the supercapacitor (VM in Figure 3) can be measured using the MCU. It is necessary to decide at what voltage it is appropriate to stop the motion, recharge the supercapacitor and start moving again. Other questions to be answered are: When is it appropriate to turn in the direction of maximum illumination when charging? Should the point of maximum solar cell power be considered? How to track the line using optical sensors? Is it worth turning them off and on? What MCU clock frequency to choose? Which MCU peripherals should be switched off and which not? Is it also worth using gyro information or leaving it off?

These and many other questions need to be answered during application development. Knowledge of electronics, programming, physics and the ability to use them effectively are required to solve the above task. Usually, the students' work ends with a final competition, during which there are always problems that have been forgotten in the course of the solution. But also many new possibilities for solving the problems. Figure 5 illustrates the progress of the parallel slalom competition.

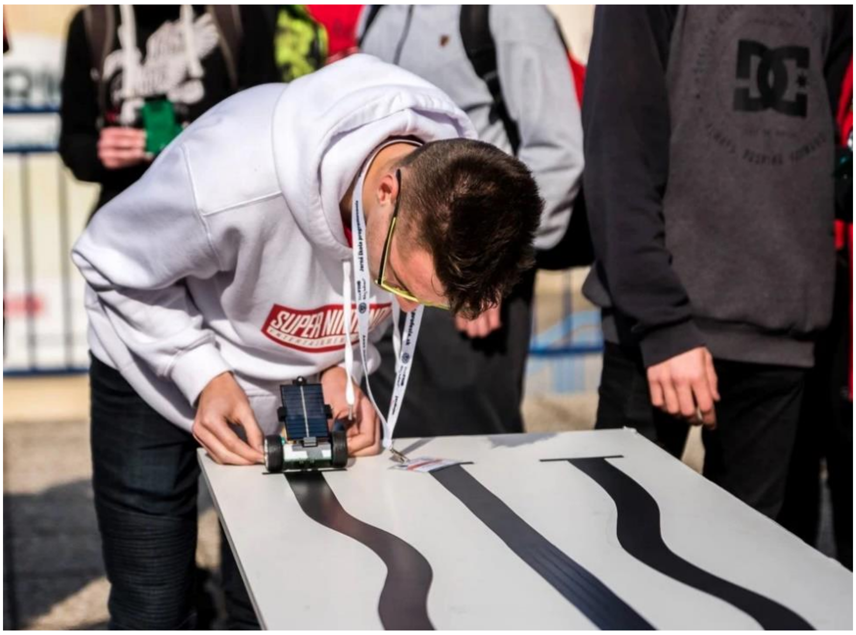

Figure 5 Solar Car, parallel slalom

V. Conclusion

The primary objective of the Solar Car project was to increase the interest of students in studying the technical fields of ICT, specifically Computer Engineering. The students were to learn about the development of a programmable MCU-based device in a fun way. It was not the development of a professional device. We focused on such a way of solving the task to make it accessible to a wide group of high school students without much professional knowledge. Obviously, the choice of a very simple ATmega328 microcontroller and the C/C++

programming language was also subordinated to this intention. Parallel to the Solar Car project, several projects of a similar nature have been developed (Rail Gun project, WiFi Boat and others). In conclusion, we can say that the interest of students in taking a one-week course resulting in a "live" product is very high.

ACKNOWLEDGMENT

This article was created in the framework of the National project „IT Academy – Education for the 21st Century", which is supported by the European Social Fund and the European Regional Development Fund in the framework of the Operational Programme Human Resources, ITMS code of the project: 312011F057.

REFERENCES

[1] J. Malmodin, N. Lövehagen, P. Bergmark, and D. Lundén, "ICT sector electricity consumption and greenhouse gas emissions – 2020 outcome," *Telecommunications Policy*, vol. 48, no. 3, Apr. 2024.

[2] P. Valerio, "Energy efficiency is crucial for the ICT infrastructure," *EE Times*, Apr. 24, 2023. [Online]. Available: https://www.eetimes.com/energy-efficiency-is-crucial-for-the-ict-infrastructure/. [Accessed: 30-Nov -2024].

[3] H. Ritchie, "What's the impact of artificial intelligence on energy demand?" *Sustainability by Numbers*, Nov. 18, 2024. [Online]. Available: https://www.sustainabilitybynumbers.com/p/. [Accessed: 30-Nov -2024].

[4] "What's the difference between a primary and secondary battery?" *PK Cell Power*, Apr. 26, 2024. [Online]. Available: https://www.pkcellpower.com/news/whats-the-difference-between-a-primary-and-secondary-battery/. [Accessed: 30-Nov -2024].

[5] "Will secondary batteries replace primaries?" *Battery University*. [Online]. Available: https://batteryuniversity.com/article/will-secondary-batteries-replace-primaries. [Accessed: 30-Nov -2024].

[6] U. Tiwari, "What is the difference between supercapacitors and batteries?" *Malvern Panalytical*, May 7, 2024. [Online]. Available: https://www.malvernpanalytical.com/en/learn/knowledge-center/insights/what-is-the-difference-between-supercapacitors-and-batteries. [Accessed: 30-Nov -2024].