

METHODOLOGY FOR DESIGN OF HYDROGEN ROBOT FOR MEDICAL NEEDS

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Abstract

The paper examines the concept of creating a Collaborative Service Robot powered by a Hydrogen Fuel Cell designed to assist in medical facilities. The characteristics of this robot are analyzed and its advantages are highlighted, from the point of view of ecological operation and long life during the patient service activities in a hospital facility. Some key features and benefits of Hydrogen Fuel Cell-powered robots are compared to battery-powered robots and the positives in this comparison are shown. The advantages of modern Collaborative Robots used as Service Robots in inpatient service processes in a hospital are presented. It shows the possibility, based on the competence and expertise of the authors in the field of Service Mobile Collaborative Robots, to create and implement one for the needs of human service in medical facilities, which will be powered by a hydrogen fuel cell. The main characteristics of the created mobile collaborative service robots of the “AnRI” series (Anthropomorphic Robot with Intelligence) are briefly indicated, where “AnRI-1” is equipped with a manipulator with a three-finger gripper, and “AnRI-2” is an information robot equipped with a large screen on top. The article analyzes the process of creating these collaborative robots, realizing several important elements of the control system, such as its development with elements of Artificial Intelligence.

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The advantages of hydrogen power and increased reliability of the general complex of systems in these Collaborative Mobile Robots and their possibility to be used effectively in the realization of medical care are emphasized.

Key words: cyber-physical systems, robotics, hydrogen collaborative robots

1. Introduction. Increased energy consumption is a universal driver for the improving quality of life in all societies, from developing to already developed countries. The challenge is to find highly efficient ways of producing, delivering, and using energy that will improve the quality of life without endangering the environment, the climate, or geopolitical relations. The technology using Hydrogen Fuel Cells is the subject of continuous research and development. Hydrogen Fuel Cells have been explored as a clean and efficient alternative to traditional internal combustion engines, especially in the transportation sector.

The energy that hydrogen brings is an alternative to fossil fuels with the potential to achieve these goals. Hydrogen is found in many chemical compounds, such as water and organic biomass, and burning them produces only heat energy – no pollutants or carbon dioxide. Hydrogen combines with oxygen in the electrochemical reactions of fuel cells to produce electricity. The most efficient use of hydrogen is the conversion of its chemical energy into electrical energy in so-called “Fuel Cells”. The high conversion efficiency of Fuel Cells, up to 60%, makes them attractive compared to other fossil fuel-based electrical alternatives, which are about 34% efficient on average. The high efficiency of Fuel Cell engines (typically over 90%) makes them attractive for transportation. Structurally, Fuel Cells consist of two electrodes (Fig. 1), separated by an electrolyte. In the case of a Hydrogen Fuel Cell, hydrogen enters the anode, acting as a fuel, and oxygen

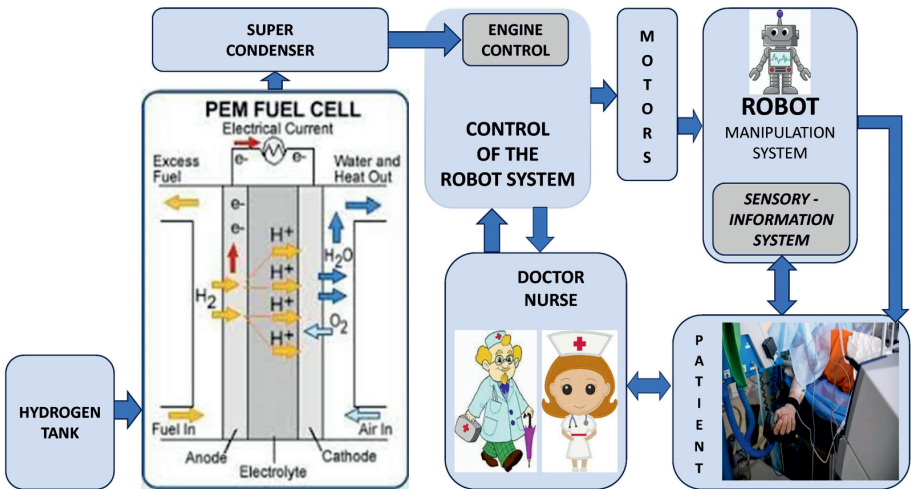


Fig. 1. Scheme of a Collaborative Robot with Hydrogen Fuel Cell

or, most often, air enters the cathode. Aided by a catalyst, molecular hydrogen initially dissociates on the electrode surface into two hydrogen atoms. Giving up an electron, hydrogen atoms are oxidized to hydrogen cations (protons). To reach the cathode, the resulting electrons and protons take different paths. Protons pass through the membrane and electrons are captured by the outer circuit of the cell and represent ready-to-consume energy. On the side of the cathode catalyst, the protons together with some of the electrons and oxygen form the waste product (water vapour or pure water) from the operation of the fuel cell.

The reactions that take place in the fuel cell are the following:

- (1) On the anode: $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$;
- (2) On the cathode: $2\text{e}^- + 2\text{H}^+ + 0.5\text{O}_2 \rightarrow \text{H}_2\text{O}$;
- (3) Total for cell: $\text{H}_2 + 0.5\text{O}_2 \rightarrow \text{H}_2\text{O}$.

The first Fuel Cell was developed in 1839 by the English scientist William Grove. After 60 years, Mond and Langer managed to improve the construction of the Fuel Cell. The Fuel Cell used hydrogen and oxygen, delivering a current density of 3.5 mA/cm^2 and a voltage of 0.72 V . Although the Fuel Cell was developed so long ago, it found more serious application in the early 1960s in the last century in manned flights of the US space programme as a source of electricity and water. At the modern stage, there are new solutions for the Hydrogen Fuel Cell, which significantly increase the degree of its efficiency when using different elements as process improvers [1].

Here are some key features and benefits of Hydrogen Fuel Cell-powered Robots compared to a classic battery-powered robot:

- **Clean energy.** Hydrogen Fuel Cells produce electricity with water vapour as the only byproduct, making them a clean and environmentally friendly energy source. This is particularly important for applications where reducing carbon emissions is a priority.
- **Longer run time.** Hydrogen Fuel Cells can provide longer run times than traditional batteries. This is especially useful for robots that need extended periods of operation between recharges.
- **Fast refuelling.** Refuelling a Hydrogen Fuel Cell is usually faster than recharging a battery, providing a faster turnaround time for the robot to resume its tasks. This is an advantage in applications that require continuous or near-continuous operation.
- **Scalability.** Hydrogen Fuel Cells are scalable and can be designed to meet the power requirements of various types of robots, from small Unmanned Aerial Vehicles (UAVs) to larger Ground Robots.

- **Reduced weight.** Hydrogen Fuel Cells can have a higher energy density than traditional batteries, resulting in a reduction in overall weight. This can be critical for applications where weight is a critical factor, such as drones or other mobile robots.
- **Versatility.** Hydrogen Fuel Cells can be used in various types of robots, including Industrial Robots, Drones, and Autonomous Vehicles. Their versatility makes them suitable for a wide range of applications.
- **Hydrogen can be stored and transported easily.** This makes it a valuable energy carrier. It is particularly useful for areas where direct power transmission may be challenging or inefficient.

Despite these advantages, it is important to note that there are also challenges and considerations, such as ongoing production costs, infrastructure development, and the energy required to produce hydrogen. Ongoing research and development efforts are aimed at addressing these challenges to further improve the viability of hydrogen fuel cells as a sustainable energy solution. An important property is the recombination of the Hydrogen Fuel Cell, where at the cathode protons, electrons and oxygen from the air combine to form water. Production of water and heat are the only byproducts of this electrochemical process. The water can be released as steam and the heat can be dissipated or in some cases used for other purposes. The advantages of Hydrogen Fuel Cells include zero emissions (they only produce water vapour), high energy density, and a relatively fast refuelling process.

A robot powered by a Hydrogen Fuel Cell will work by converting hydrogen gas into electricity through a chemical reaction. The robot stores compressed hydrogen gas in a tank. This hydrogen is the fuel that will be used in the Fuel Cell. As the electrons flow through the external circuit, they can be used to do work, such as powering motors and other electrical components in the robot. This is the electrical energy that drives the robot's functions. These characteristics make Hydrogen Fuel Cells suitable for certain applications, including Robotics, where long run times and clean energy are important considerations. Hydrogen Fuel Cell technology and applications are known to be constantly evolving, and researchers are exploring ways to improve efficiency, reduce costs, and improve the overall performance of these systems [2].

2. Objectives of the robot. The dynamic and unpredictable nature of the world we live in makes it difficult to design an Autonomous Robot that can adapt effectively to any circumstances. Therefore, robots of various shapes, sizes, and capabilities such as unmanned Aerial Vehicles, unmanned Ground Vehicles, Humanoids, and others are designed to cooperate with humans to successfully perform complex tasks. The "Internet of Things" (IoT) has enabled these diverse devices to be connected in a smart network, greatly increasing the range of automated tasks. The integration of these devices is entering almost all fields,

including human services in medical facilities, where it eases labour, minimizes costs, and produces quality services [3].

The goal of the project team is based on the competence and expertise it has in the field of service mobile Collaborative Robots, to create and implement one for the needs of human service in medical facilities, which will be powered by a Hydrogen Fuel Cell. This is an innovative solution in the drive subsystem of the robot, which is very suitable for implementation in hospitals in strict compliance with the requirements of the EU2019/2088 Regulation. The project methodology complies with the principle of “doing no significant harm” about each of the six environmental objectives set out in Article No. 9 of Regulation (EU) 2020/852 establishing a framework for the facilitation of sustainable investments and amending Regulation (EU) 2019/2088. Regulation (EU) 2019/2088, known as the Taxonomy Regulation, establishes a framework for the classification of environmentally sustainable economic activities. It aims to create a taxonomy that can be used by financial market participants to disclose information about how their activities align with environmental sustainability goals. Data and research results (excluding publications) will be widely disseminated under non-exclusive and non-discriminatory conditions and managed by the principles of discoverability, accessibility, interoperability, and reusability, i.e. known by the acronym FAIR (Findable, Accessible, Interoperable, Reusable). The FAIR principles, which stand for Findable, Accessible, Interoperable, and Reusable, were developed to address the challenges of managing and sharing scientific data. These principles aim to improve the efficiency and effectiveness of data sharing and to encourage the wider use and reuse of resulting research data. Against the background of these factors, the Robotics of human service in medical facilities has received much attention in scientific research and much effort has been devoted to its development. In particular, the use of Collaborative Robots would allow for an increase in overall performance and service efficiency. It will contribute to improving the quality and safety of work [4].

3. The Collaborative Robots. Collaborative Robots have been a natural evolutionary fork in Robotics in recent years. These robots (also called “Co-Bots”) are designed to work in a shared workspace with humans and assist them in performing various tasks, without the traditional enclosures, cages, and barriers that typically separate industrial Robotic Systems from workers. Innovative approaches to humanize robots and facilitate mechanical tasks have fuelled the demand for collaborative robots in recent years. It is one of the cutting-edge technologies in automation that is rapidly gaining popularity due to its many advantages over conventional industrial robots. Decreasing prices of computer technology and sensors are among the reasons why collaborative robots are increasingly available and widely used not only in industry but also in service robotics.

Sensor devices are key to the integration of robots into industrial machinery and equipment. Presence sensors are widely used, including capacitive and in-

ductive proximity and distance sensors, ultrasonic and photoelectric sensors, etc. Precise miniature sensors provide robots with spatial information about the positioning of the object being handled. Through technologies such as Laser Distance Sensors (LIDAR) and Machine Vision Systems, robots can extremely precisely grasp and handle the desired product or component, as well as avoid collisions with staff or patients and various objects in the work area.

4. Implementation of Collaborative Service Robot. The robots of the “AnRI” (Anthropomorphic Robot with Intelligence) family are implemented as Collaborative Robots with the possibility of being powered by a Hydrogen Cell. Creating a Service Robot to help healthcare is a difficult and responsible task. This activity aims to investigate to what extent the proposed development of a robot will help to ensure the quality of patient care in a hospital facility, as well as to ensure a dignified and independent life for people with disabilities. The functional characteristics of the created robot have been analyzed and designed according to the set goals for serving people in a healthcare facility. These are some specific characteristics of the robot manipulator, such as planning a safe trajectory in a dynamically changing environment in which the service person is located [5]. For this purpose, the robot uses sensory information from built-in sensors such as “Infrared” sensors and “Ultrasonic” sensors, video sensors, and “End-Off” sensors to prevent collisions in the working environment. On this basis, a database is built with the inclusion of libraries of ready-made programs for the execution of submitted standard commands. A module was also created for speech recognition and synthesis and execution of voice commands with the use of elements of artificial intelligence.

4.1. Reliability requirements of service robots “AnRI”. In the operation of the human service robot to assist healthcare, the reliability requirements are increased compared to the standard operation requirements of industrial robots. As is well known, the human-machine interface is of utmost importance as robots of this type work close to and in contact with the person being served. There is also an increased responsibility for the performance of the assigned tasks, for which there is no alternative solution and their failure to perform can lead to unpredictable and sometimes tragic consequences. On the other hand, a deviation from the normal operation of the robot can lead to specific injuries and damage to health in direct contact with the person served. Therefore, it is extremely important to create such work methods in the operation of human service robots that guarantee the accurate and precise operation of these facilities [6].

4.2. Description of the design of the robot “AnRI-1”. The robots of the “AnRI” family are realized as structures on mobile platforms with four wheels, two of which are directly driven by electric motors and two are independent, “free” wheels, with the ability to rotate around a vertical axis. The “AnRI-1” robot also has such a design. The wheels are mounted in the form of a horizontal “triangle”. At the front of the two vertices of the triangle are the driven wheels, and at the

third vertex at the rear are the two paired “free” wheels with a distance between them of 150 mm. This makes the system stable and it is impossible to lose balance during movement. This wheel layout scheme ensures that the mobile platform is easily steerable with increased mobility, which is particularly important for the patient care process. The “AnRI-2” robot has a different design. The wheels are located in the form of a “cross”, with the two driving wheels located on both sides of the platform and the two free wheels located one at the front and the other at the rear side. The hubs of the driven wheels have built-in electric motors, supplied with direct current from the hydrogen cell via a supercapacitor. For the drive wheels of the robot platform, “worm” reducers are used, which do not allow reverse movement due to the built-in “Braking Effect”. An anthropomorphic “hand” type manipulator with three regional and three local degrees of mobility is mounted in the upper part of the “AnRI-1” robot (Fig. 2). The manipulator ends with a three-finger gripper with three separate independent drives. Based on Servo Controllers with feedback from incremental sensors, located in each degree of mobility, the control of a manipulator of the robot is realized. All regional grades are equipped with Electromagnetic Brakes. The robot “AnRI-2” (Fig. 3) is equipped with a large screen on top of the robot to be used as an Information Robot. With its capabilities using Artificial Intelligence Elements, it can be an advisor to doctors, especially in the diagnosis process.



Fig. 2. Robot “AnRI-1” with anthropomorphic manipulator



Fig. 3. Robot “AnRI-2” equipped with a screen on top

4.3. “AnRI robot” control system. The AnRI robot control system is hierarchical and distributed. The connection between all modules is realized through a serial interface RS 232. The Processor Module for controlling the robot is a 32-bit microprocessor block with the architecture of the Cortex-M family of processors. A Digital Signal Processing (DSP) block with floating-point processing support is integrated into the Processor Module to create a fast and energy-efficient algorithm. Therefore, Cortex-M4 is used in digital robot control applications such as motor control, sensor information synthesis [7], and power supply control. In the created control original, a universal I/O (Input/Output) board is used and the control of a set of digital and analogue inputs, 10/100 Ethernet Interface, and PWM control using CAN, SPI, and I2C Buses are realized.

The research team aims to build a mobile platform for a Collaborative Robot powered by a Hydrogen Cell that ensures harmless and long-lasting operation while reducing battery charging times. To overcome the challenges, the team will develop a management system with elements of artificial intelligence. Computer algorithms as well as hardware for positioning, manipulation mapping, route planning, and obstacle avoidance will be optimized according to the environment [8], taking into account the therapeutic plan for the respective patient.

5. Conclusions. The expected result is the creation and implementation of a Service Mobile Collaborative Robot for the needs of medicine, which will be powered by a Hydrogen Fuel Cell. Using a Hydrogen Fuel Cell as a power source in a robot designed to work in a hospital setting is an innovative process. Using the advantages of such a drive, it is possible to significantly extend the period of operation of the robot, while at the same time, there will be no release of pollutants since in this process the only released elements are water and heat. They can be used secondarily in the work processes of the hospital facility as environmental elements.

In addition, in the process of creating this Collaborative Robot, several important, from the point of view of science, elements of the control system are realized, such as its development with elements of artificial intelligence.

The overall complex of systems in this Collaborative Robot can be effectively used in the realization of medical care [9]. This will significantly improve the quality of service and facilitate the work of the medical teams.

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