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Polish Innovations in Automation and Robotics

WARSAW 2013

HUMAN CAPITAL
HUMAN – BEST INVESTMENT!

PIAP

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EUROPEAN SOCIAL FUND

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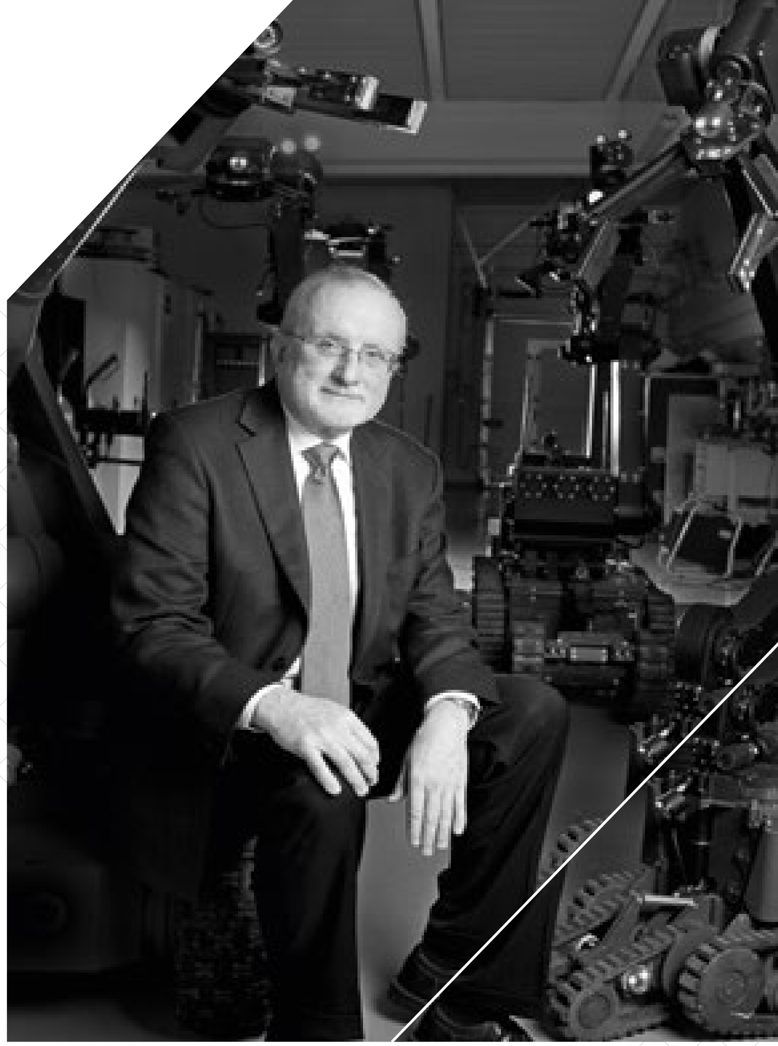

Ladies and Gentlemen!

It is a real pleasure for me to present the collection of articles about Polish innovations in the field of automation and robotics. We present selected achievements of Polish scientific teams in this publication, which were accomplished during the realization of projects by the Industrial Research Institute for Automation and Measurements PIAP and other key scientific institutions.

PIAP is the first and biggest manufacturer of high quality mobile robots for counterterrorism in Central Europe.

PIAP was established almost 50 years ago and since that time it has been gaining experience in the field of automation and robotics, also in industrial applications. PIAP has also much experience in coordinating international research projects.

PIAP is a research centre that combines two areas – science and industry - and that is exactly the place where ideas implemented on the market are formulated. The project ”Scientists Closer to Industry” with this publication is precisely one of the projects that bring these two worlds together.

I invite you to get to know the examples of Polish solutions in automation and robotics. I believe that the interesting reading will inspire you to get more detailed information about the co-operation potential with the Industrial Research Institute for Automation and Measurements PIAP and other Polish scientific centres.

Dr. Jan Jabłkowski
Industrial Research Institute
for Automation and
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December 2013

Scientists Closer to Industry

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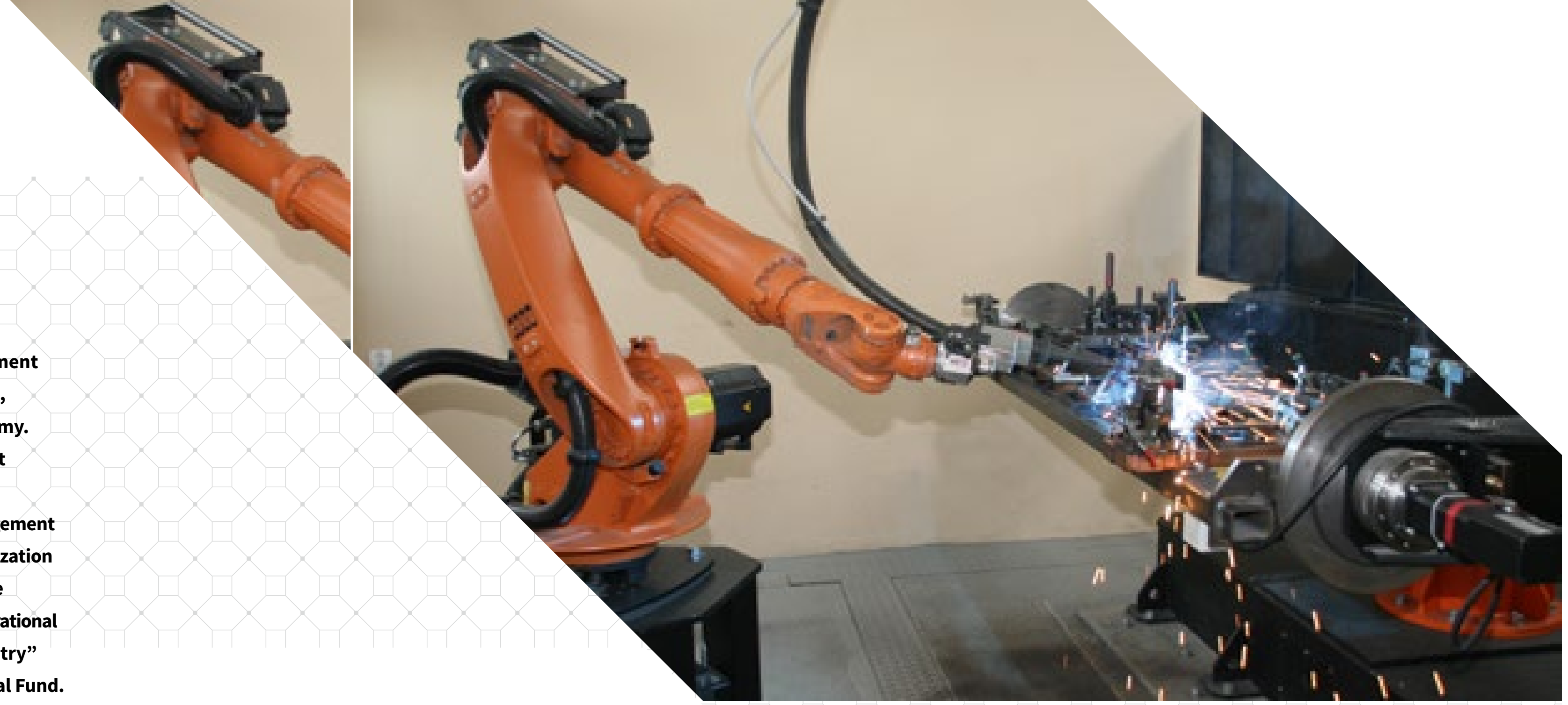
The accessibility of EU funding contributed to the improvement of operating conditions of enterprises and R&D institutions, thereby to an improvement in the functioning of the economy. The financial means for these purposes come from different sources, including subsidies. An example is the Action 4.2 "Improvement of R&D system workers' competence in management of scientific research and development work and commercialization of research work results" conducted by the National Centre for Research and Development within the framework of the operational Human Capital Programme. The "Scientists Closer to Industry" Project and its actions are co-financed by the European Social Fund.



PIAP as a scientific institution co-operating with enterprises

The Industrial Research Institute for Automation and Measurements PIAP, a state research institute in Warsaw, is an example of a Polish institution that creates innovations and co-operates with the economic sphere. The institute has more than 250 employees and its implementation projects bring an increase in investment effectivity in the industry. Currently, almost 1 % of all the Polish patents and patent applications come from the PIAP. This number confirms the mission and quality policy of the Institute in which the transfer of modern technologies to industrial enterprises is the most important element. At present, the activities of the Industrial Research Institute for Automation and Measurements focus on three areas:

- automation and robotisation of manufacturing processes,
- special purpose mobile robots,
- realization of projects within the framework of international co-operation.

Research work on new technologies is related to the design of equipment, production lines and integrated production systems. The results of the research work are usually implemented in the industry.

The "Scientists Closer to Industry" Project

This project is realized from 1 April 2012 till the end of 2013. The main objective is to increase the awareness of scientists about the significance of scientific achievements in the economic development. The project focuses on disseminating information about applications of R&D work results in the industry and the methods and forms of collaboration with the industry in the transfer of technology. The realization of this project is a consequence of the need for increasing the knowledge of solutions in management, commercialization processes and industrial implementation of results of projects carried out by scientists around the world.

Scientists, mainly those working in the field of automation and robotics, are the target group of the project. Scientists involved in the project are in direct contact with the newest scientific solutions, get to know activities of foreign centres during study visits and examples of scientists who commercialized results of their research. The project focuses on three key tasks: discussion forums, study visits and conferences.

It is important to create conditions for scientists that enable joint actions with other scientists and the industry.

Participation in this project will serve the need for increasing the awareness of scientific research adaption to changing requirements of the market due to the technological progress in the world. Scientists, during visits to leading foreign centres, will be in direct contact with the real environment of the R&D work in the field of automation and robotics.

Scientific and technological Automation and Robotisation Forum

Discussion forums in Katowice and Warsaw for scientists working in the field of automation and robotics and representatives of entrepreneurs were organized in this project. The objective of these forums was a discussion and exchange of knowledge, an increase in the awareness of scientific circles about the reliable methods and good practice of scientific research for the industry. Both editions had a similar subject matter. They began with pronouncements of industry workers on: Automation and robotisation in the industry – Industrial practice – Innovations from the perspective of entrepreneurs. The following subjects were taken up: robotisation in companies, safety in automation and robotisation, e.g. CE marking and what does it mean?

A welding demonstration (the participants programmed trajectory unassisted the welding trajectory) and a demonstration of a robot with a gripper employed in transport automation were also performed. There was also time for discussion and finally questionnaire investigations were carried out. As many as 89 % of the inquired persons wanted to participate in meetings of scientists and the industry to be organised in future.

Scientists that participated in the forums have formulated the following postulates:

- intensification of the responsibility of non-scientific institutions for implementation of achievements of Polish science in practice;
- obligation of national economy establishments to use Polish scientific achievements in the first place;
- increase in the participation (including financing) of economy establishments and self-governed institutions in the profiling of education at the highest level in view of the Polish industry development;
- application to relevant economy departments in order to start urgently an education to highly qualified personnel for operating the national gas system in view of the shale gas deposits.

Study visits of scientists to foreign research centres

Study visits of scientists to foreign research centres with presentations of results of know-how transfer to the industry, best practice and procedures of research project management and practical aspects of protection of intangible and legal property produced in research work were planned within the framework of the project.Scientists employed e.g. in the Industrial Research Institute for Automation and Measurements PIAP, Polish Naval Academy, AGH University of Science and Technology, Warsaw University of Technology, Silesian University of Technology and the Universities of Technology in Cracow, Poznań, Gdańsk and Białystok participated in the visits.

Study visit to VTT – Finland

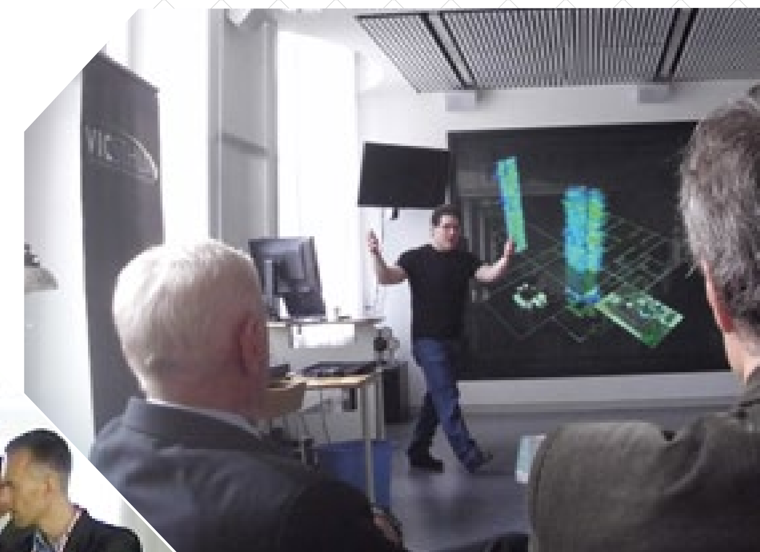
The visit to the VTT Technical Research Centre of Finland (Valtion Teknillinen Tutkimuskeskus), the largest research organization in Northern Europe, was the first one. The VTT Technical Research Centre employs more than 3000 people. During the visit, the VTT employees presented achievements related to the co-operation with the industry, methods of commercialization and current projects on M2M Internet, wireless energy transmission, vibration measurements and interactive robot operating systems. An experimental renewable energy production system for households was also demonstrated. The participants visited VTT laboratories involved in works on robotic systems, wireless networks and built-in sensor systems.

The rules of functioning of the Finnish research centre are similar to that of Polish institutions, however, it does not conduct economic activities. In case of new technology or product development the VTT transfers the innovation into private hands in return for company shares. Even 15 spin-off companies in which VTT has about 1/3 shares are established yearly.

Study visit to ESA - The Netherlands

European Space Agency (ESA) is an international organization of European countries aimed at the exploration and exploitation of cosmic space, including aspects of robotics. During the visit each of the participants had the possibility to present her/his achievements, institution and projects under way. All participants sought areas of co-operation, especially in respect of cosmic robotics. They visited also the laboratories of the European Space Research and Technology Centre (ESTEC) – e.g. the robotics laboratory and materials technology laboratory – and the Space Expo exhibition.

The participants were encouraged by a representative of the ESA Education Centre to take part in the education projects and submit new ideas, which might be co-financed. The visit to the European Space Innovation Centre that fulfils an enterprise incubator function and where new cosmic technology solutions were demonstrated was instigating.



Study visit to United States

The main objective of the visit to United States was an exchange of experience with leading centres for research and implementation in the field of automation and robotics. The established valuable bilateral contacts within the scope of science and technology will probably yield joint projects and trainings. The following institutions were visited: National Institute of Standards and Technology (NIST) in Washington, US Army Research (RDECOM-ECBC, RDECOM-ARL) in Aberdeen, University of Maryland – Robotics Center, Maryland, Carnegie Mellon University CMU – Robotics Institute in Pittsburgh, Wayne State University (WSU) in Detroit and Ford Research and Innovation Center in Detroit.

Maryland Robotics Center

is an interdisciplinary research centre. The mission of the centre is to advance robotic systems, underlying component technologies, and applications of robotics through research and educational programs that are interdisciplinary in nature. The center's research activities include all aspects of robotics including development of component technologies (e.g., sensors, actuators), novel robotic platforms, and intelligence and autonomy for manipulators. The centre consists of members of many faculties of the University of Maryland. Research projects in the center are supported by the major federal funding agencies including NSF, ARO, ARL, ONR, AFOSR, NIH, DARPA, NASA and NIST.

US Army Research, Development and Engineering Command (RDECOM) in Aberdeen, Maryland

consists of eight main laboratories and R&D centres in which for example new robotic technologies are developed. The RDECOM team has more than 17,000 employees, including almost 11,000 designers and scientists.

The development work is carried out in collaboration with academic networks, the industry and international partners. The research focuses on all aspects of soldier's environment – eating, clothing, vehicles, aircrafts.

Carnegie Mellon University CMU – Robotics Institute

Since being established in 1979, it integrates robotics technologies with everyday life. More than 50 lecturers contribute to the development of many fields associated with robotics including space robotics, computer graphics, medical robotics, machine vision, artificial intelligence and many other technologies.

Wayne State University

is a public research university located in Detroit, Michigan, United States – Michigan's third-largest university. An important project is the robot under development. It is a stand for operations with two surgical high precision manipulators, which enables a device control by means of manipulators, a voice guidance and a coupling of camera operation and surgical instrument movement.

Science and Technology AUTOMATION 2013 Conference

The AUTOMATION Conference was held at the Conference Centre of the Industrial Research Institute for Automation and Measurements in March 2013. 135 attendees including almost 100 scientists, representatives of the largest Polish technical universities, research institutes, institutions of the Polish Academy of Sciences and 5 lecturers from foreign universities participated in that conference.

Six plenary lectures and 81 lectures in 5 topical sessions were delivered at that conference:

1. Automation, robotisation, monitoring.
2. Software, hardware and application of mobile robots.
3. Methods of systems design and integration.
4. Equipment for automation and robotisation.
5. Equipment and measuring systems.

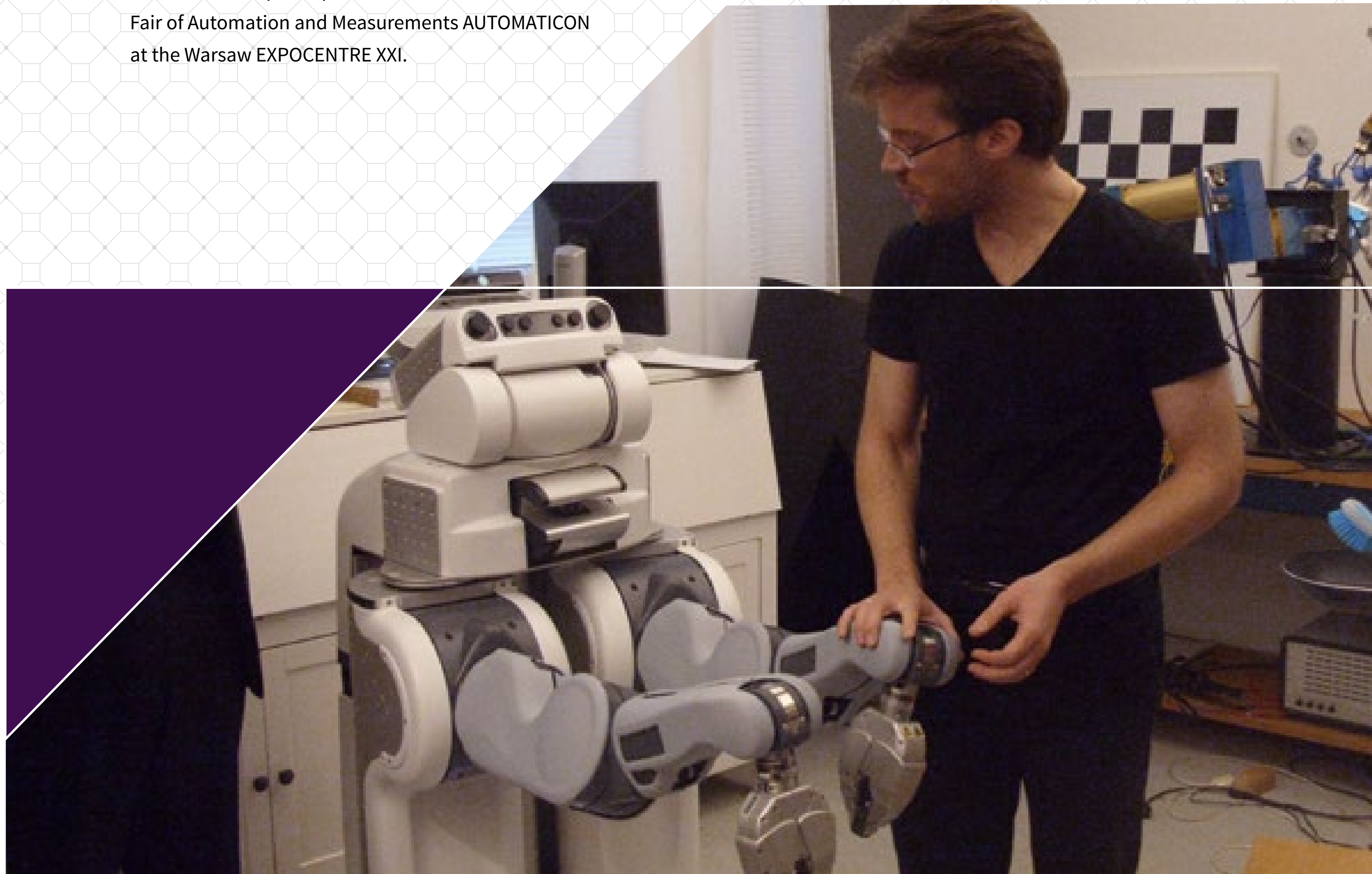
The conference participants visited the International Fair of Automation and Measurements AUTOMATICON at the Warsaw EXPOCENTRE XXI.

Recapitulation

The awareness about the significance of scientific research and development work for the industry and the importance of technical sciences in the economic development has increased in almost 78% of the 54 inquired persons that participated in the AUTOMATION Conference. The stated importance of positive answers in questionnaires after the conference was 3-5.

Wrapping up, the results of all questionnaire investigations confirm that the awareness of project participants about the importance of technical sciences in the economic development has increased. Such actions are very valuable, but they will not bring about a sudden improvement in the situation. It is necessary to introduce the systemic changes suggested in the report prepared by the Chief Economic Adviser for PricewaterhouseCoopers in Poland Prof. Witold Orłowski.

We invite you to the country-wide and international co-operation within the framework of joint R&D projects!



Life Saving Robots

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Special purpose robots have been built since 1990s at the Industrial Research Institute for Automation and Measurements in Warsaw. As many as several dozens of robots of six types are used in Poland and an equal number are used abroad. In total, more than 100 robots were manufactured and sold. In Poland, they are used by, among others: the Police, Polish Armed Forces, Fire Service, Border Guard and Government Protection Bureau. These high--tech devices replace people in the performance of their duties, protecting their life and health on a daily basis.

Development of robots for detection and elimination of terrorist threats (dangerous substances, improvised explosive devices, etc.) has been promoted in recent years. At the beginning, they used to be the very simple devices developed with personal commitment of bomb technicians; later, that work was institutionalized and robot designs have become more advanced. The shape of these devices was limited by technical factors for many years. As a result of further development, which is still on-going, robots have functionalities which satisfy the requirements of their users to a larger and larger extent.

The history of Polish pyrotechnic robots started in 1999, when a prototype of the robot called Inspector was developed at PIAP. Since 2000, bomb squads of the Polish Police and Armed Forces have been successively equipped with these robots.

A typical application for Inspector is disposal of explosives placed by terrorists. Capabilities of this robot and the ability to adapt it to various tasks make it suitable for the crime prevention squads and Police SWAT units, engineering and chemical units of the Army, as well as for the border guards or mine rescue service stations.

The success of the Inspector-class robots encouraged PIAP designers to develop and implement a new robot, called Expert.

Inspector Robot

The scope of use of Expert robot is virtually the same as its predecessor's, but Expert was designed for use in confined spaces, where the larger Inspector would not be able to get in. Such spaces are, first of all, means of transport such as airliners, buses, trains and small rooms. The assumption that the robot will operate inside means of transport, first of all in aircrafts, imposed strict requirements as regards dimensions of the mobile base (it had to be small) and the manipulator itself (it had to be large).

New applications for the special purpose robots and new requirements emerged at the beginning of the 21st century, along with the conflicts in Afghanistan and Iraq. The current doctrine assumes that complex and expensive robots will be used. By 2004, in Afghanistan and in Iraq, the US Army used 162 robots, which took part in 11,000 missions.

However, it turned out that these expensive devices themselves became targets of terrorist attacks. Apart from that, it was discovered that it is not only the purchase price that is important, but also the operator training time and ongoing maintenance. After a revision of the strategy, by August 2008, the number of robots in active use exceeded 6,000.

Expert during tests

Robot designs have been simplified. In the past, the priority was the highest functionality possible and economical and ergonomic aspects were marginal. To a large extent, it was the technology that dictated the final form of the device. Contrary to that approach, new designs have been strictly optimised for purchase costs and maintenance simplicity. At the same time, they have been designed to perform functions expected by the user – and nothing more. Robots meeting the new requirements were developed also in Poland. We are talking about two robots made by PIAP – PIAP Scout® and Ibis®.

PIAP Scout® is a robot designed for quick reconnaissance of an area and places hard to access, such as vehicle chassis, rubble, ventilation shafts, spaces under seats in various means of transport and narrow rooms. It was designed for use by special police and military units. Thanks to its high travelling speed, large, modular structure, small weight and dimensions, the PIAP Scout® is an excellent support for large robots which, due to their dimensions and weight, cannot replace humans in certain situations.

PIAP Scout®

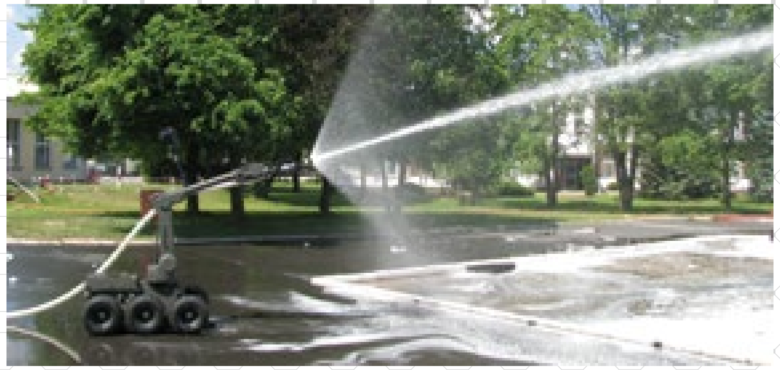
Tactical Throwable Robot TRM®

Tactical Throwable Robot TRM® is a small device used for support of operations conducted in hard to access and dangerous areas. TRM® eliminates threats connected with area and building reconnaissance conducted by law enforcement units.

PIAP Gryf®

An interesting design is the PIAP Gryf®. This robot was developed in response to a users' demand for a device with specific parameters and functionalities. It can be used for quick reconnaissance of an area and places hard to access.
Its unique characteristics include modular design and easiness of configuration in order to adapt the robot for the needs of a specific task.

Ibis is a large and fast pyrotechnic and combat robot designed for dynamic operations in difficult terrain. The robot has a six-wheel drive mobile platform. Every wheel has its own drive motor and the unique design of mobile suspension with independent balance levers ensures stability and contact of all wheels with the ground during driving off-road or on a flat surface. Ibis can accommodate pyrotechnic dispensers, chemical and radioactive contamination detectors, a bus-bar for remote detonation of explosive charges, negotiation system, wire cutters, drillers, recording devices and firearms. Ibis can also perform fire-fighting missions with the use of a fire-hose nozzle.



Ibis®

PIAP designers have not said their last word yet. Several new designs are being prepared for implementation, including a medium-class robot developed within Project PROTEUS framework - a state-of-the-art system for the counter-terrorist and anti-crisis activities. Government services activities are to be supported by, among others, three multi-function robots, an unmanned aerial vehicle and mobile command centre. The system is fully integrated, which is an innovation on a global scale and a major challenge for the engineers working on the project.

Activities performed by the rescue and law enforcement services often involve a risk of injury or even death for people participating in them directly. That is why one of the robots comprising the PROTEUS system is an intervention robot. The robot will be able to replace or support people in the performance of the most dangerous tasks, for instance, during explosive ordnance disposal operations.

Intervention robot (Project PROTEUS)

TALOS -
robots at the borders

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Transportable Autonomous Patrol for Land Border Surveillance system - TALOS is an international research project co-funded by the European Commission (EC) under the 7th Framework Programme in Security priority. The project was intended to design, implement and field-test a technology demonstrator of an adaptable and transportable border surveillance system.

The innovative concept behind the project was that the different sensors, enabling detection of people, vehicles and hazardous substances crossing the unregulated land border, are carried by unmanned vehicles (both ground and aerial) having a high degree of autonomy.

The TALOS project was executed under the leadership of PIAP by experienced research teams from industry, R&D and academia from 10 different countries: Belgium, Estonia, Finland, France, Greece, Israel, Poland, Romania, Spain and Turkey.

The Project ended in May 2012 having a successful demonstration of its results during the live field presentation in April 2012, in Poland.

Research in TALOS

The TALOS system was based on a concept of unmanned units able to tasks autonomously perform both the navigation and surveillance tasks, under the supervision of the Border Guard officers. Therefore, its three core components are: the UGV (Unmanned Ground Vehicle) subsystem, UUCC (Unmanned Units Command Centre) subsystem and the Communication subsystem. Unmanned Air Vehicle (UAV) and transportable Sensor Tower, as originally a part of the system architecture, were simulated in this phase of the project, but will be integrated with the system in the future.

The main research that has been undertaken over the four years of project works was in the following areas:

Unmanned Ground Vehicle

- Autonomous technologies, i.e.: vehicle mapping and localisation
- Navigation with and without GPS
- Artificial Intelligence / expert systems in vehicle decision making
- Dynamic vehicle path planning
- Low Level Vehicle Control
- Sensor fusion (Video, Radar, Laser)
- Payload management.

Command&Control

- Common operational picture, using data from various unmanned systems
- Mission Planning activities for various unmanned systems
- 3D Map/Terrain Model generation from different sources.

Communication

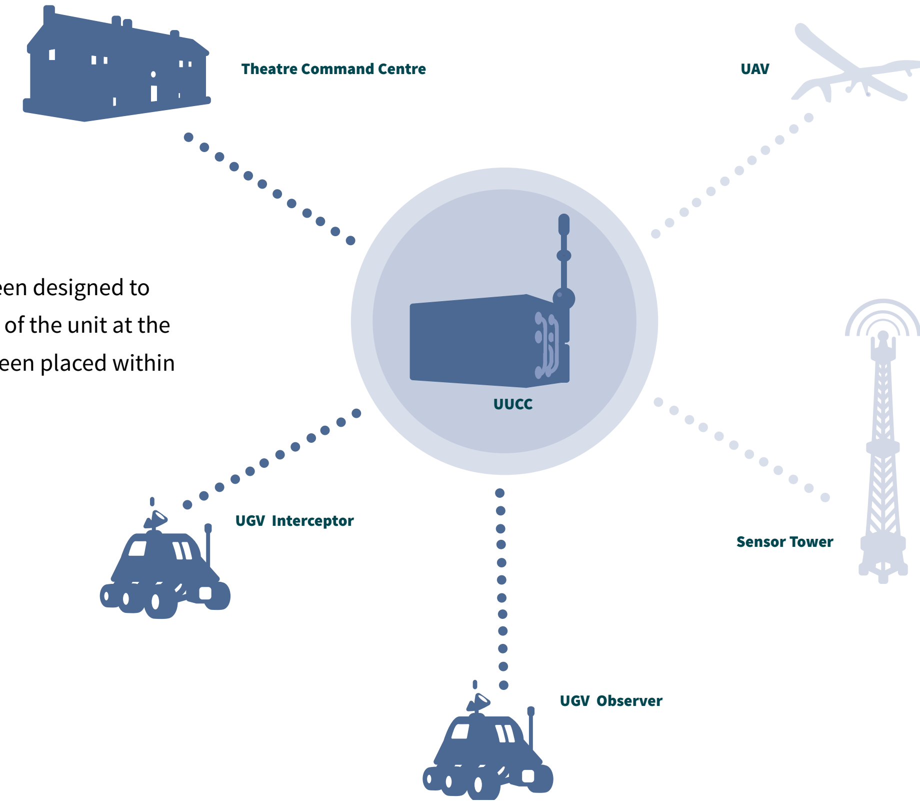
- Communication systems and technologies (including MESH, WiMAX)
- Combination of new networking protocols.

TALOS system demonstrator

The TALOS system demonstrator contains of two UGVs and one UUCC. The vehicles are able to operate simultaneously, based on the same mobile platform, and differentiated with regard to the vehicle's function. First UGV (Observer), as designed for the performance of the surveillance and detection missions (preset patrolling route and observation tasks), is equipped with specialised surveillance sensors (including the Doppler radar and the observation camera, with a FLIR capability and the automatic video tracker (AVT)). The second vehicle (Interceptor) is intended for interception of the suspicious objects (individual, vehicle etc.) and to follow them until the manned Border Guard patrol will arrive to intervene. Communication with the tracked intruder is possible via the interrogation system if needed.

Both UGVs are equipped with high-and low level computers, enabling the platform control and sensors data transfer; as well as the specialised navigation devices (including precise GPS, INS and 3D laser scanners) for autonomous driving.

Unmanned Units Command Center has been designed to enable an easy transport and deployment of the unit at the desired border section. Therefore, it has been placed within the standard 12 ft container.



TALOS System Architecture

TALOS Partners

Nº	Partner	Country
1	Industrial Research Institute for Automation and Measurements PIAP (Coordinator)	
2	ASELSAN Elektronik Sanayi ve Ticaret A.S. – ASELSAN	
3	European Business Innovation & Research Center S.A. – EBIC	
4	Hellenic Aerospace Industry S.A. – HAI	
5	Israel Aerospace Industries – IAI	
6	ITTI Sp. z o.o. – ITTI	
7	Office National d'Etudes et de Recherches Aérospatiales – ONERA	
8	Defendec – DF	
9	Société Nationale de Construction Aérospatiale – SONACA	
10	STM Savunma Teknolojileri Mühendislik ve Ticaret A.Ş. – STM	
11	Telekomunikacja Polska SA – TP	
12	TTI Norte S.L. – TTI	
13	Technical Research Centre of Finland – VTT	
14	Warsaw University of Technology – WUT	

Technology for metal recovery from waste electrical and electronic equipment

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Plasma technology enabling effective recovery of metals, including precious metals, from waste printed electronic and electrical circuits and WEEE (waste electrical and electronic equipment) small devices has been developed at the Industrial Research Institute for Automation and Measurements PIAP in Warsaw.

This technology makes processing of waste without a need to crush it immediately after separation from WEEE devices possible. The process has several steps. The waste is fed by means of a gas-tight feeding device into a reactor chamber in which under the influence of the temperature of 1600 °C and action of three plasma streams generated by plasmatrons the waste is incinerated and melted. The molten metal together with molten slag flow off into a mould from which they are collected as the final product. The combustion gases after leaving the plasma reactor chamber undergo after-burning in an after-burning chamber and come into a combustion gas purification system that ensures a fulfilment of the required emission standards.

The main products of the process are:

- metallic alloy that contains melted metals and precious metals from the waste,
- fused slag,
- heat.

Metallic alloy segment obtained from waste printed electronic circuits

The metallic alloy composition depends on the initial composition of the waste: copper makes up from 65 % to 90 % and it contains also silver Ag, gold Au, palladium Pd, tin Sn and lead Pb. The metal recovery rates are up to 76 %. Slag constitutes the environmentally neutral process waste which, according to its metal oxide content, e.g. iron Fe, tin Sn or lead Pb oxides, can be utilized in metal production processes from primary raw material in plants. On the other hand, heat can be used for heating objects.

The energy consumption during the process is 2–2.6 kWh/kg of processed waste and up to 20 m^3 of compressed air is used up per hour additionally.

The Industrial Research Institute for Automation and Measurements PIAP is equipped with a demonstrator device, which enables testing and research as well as presentations of the developed technology. The demonstrator device renders testing of amounts of up to 800 kg/day in respect of processing and recovery of metals from waste possible. Its stand is automated and furnished with measuring equipment, which enables process steering from the computer screen by means of the SCADA software.

PIAP is interested in implementing the developed technology at WEEE processing plants. The prepared demonstrator device with the processing capacity of 0.8 Mg of waste electronic equipment per day meets the needs concerning waste processing in 9 of 16 Polish voivodeships.

The economic benefits of using the offered technology result from WEEE processing, recovery of metals, market value of metals (metals including Au, Pd, Cu, Ag make up 25 % of the waste mass on the average and these metals constitute about 92 % of the value of the obtained alloy) and recovery of thermal energy from the process.

As regards the environmental protection, the use of the developed technology enables a considerable reduction of the mass – down to 40 % of the initial waste mass and also a significant reduction of the waste volume – down to 10 % of its initial volume.

The presented technology for metal recovery from **waste electrical and electronic equipment** was awarded a prize in the ‘Pantheon of Polish Ecology’ contest in 2013.

_Szewczyk R., Szałatkiewicz J., Budny E., Missala T. and Winiarski W., Identification of selected parameters of plasmotronic plasma reactor, Pomiary Automatyka Robotyka, 11/2012, 68–72 (in Polish).
_Szewczyk R., Szałatkiewicz J., Budny E., Missala T. and Winiarski W., Construction aspects of plasma based technology for WEEE management in urban areas, Procedia Engineering, Modern Building Materials, Structures and Techniques, Vol. 57, 2013, 1100–1108.

Robotization of chamfering metal sheets and plates Custom-cut metal plates

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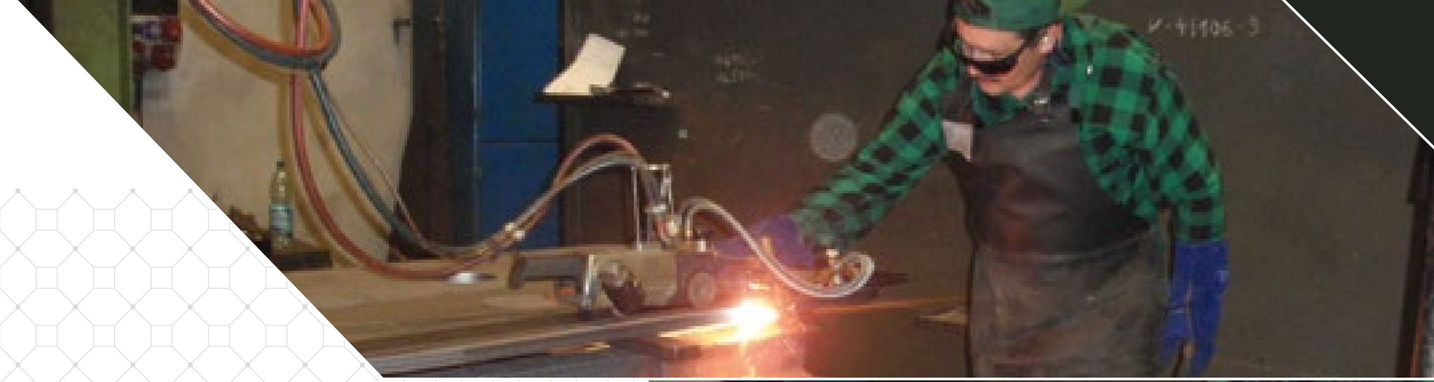

Technology of robotized chamfering of the metal plates and sheets by means of plasma cutting is successfully used for production of structural components for linings for mining applications, made of thick metal plates which are joined by means of arc welding. We can expect that this technology used in other industries – production of heavy vehicles, building machines, ships, and railway rolling stock, will turn out to be equally effective.

Production of steel structures begins with cutting elements out of metal plates, pipes or sections. Next, these elements are joined by welding. Preparation of elements to be welded features an important stage that impacts welds quality, strength and life. Chamfering of their edges is one of the technological operations used while joining elements with wall thickness greater than 3 mm. Traditionally, this operation is made manually using different methods of thermal cutting. Some devices, as special torch carriages that facilitate to guide a torch, are in common use today.

The operation carried out this way is very labour-consuming, and its quality is often unsatisfactory, especially, in zones where the straight line chamfer passes into a curve or vice versa, the chamfer's geometrical parameters are disrupted, and often some pitting occurs. Manually chamfered element must be cleaned thoroughly and evened up in the next operation. This increases the manual chamfering process time. Additional actions connected with treatment of element's other edges – manipulations and changing the way of its fastening decrease effectiveness of this process. Stands for manual chamfering are characteristic of very heavy working conditions, and the operator works directly next to the flame. He is exposed to harmful fumes and vapours, to noise, to burns from chips and hot element. He has to manipulate the elements frequently, which creates a risk of crushing.

Automated chamfering of the metal plates and sheets

The chamfering operation is often a bottleneck of the production process of steel structures. Because of this fact, attempts have been made for years to automate it. Portable devices for pipe chamfering usually use mechanical cutting. To chamfer elements of a hall (batch production), the CNC machines are used, e.g., classical CNC cutting machines with additional head that enables chamfering or specialised CNC chamfering machines. The chamfering head has two or three controlled degrees of freedom, which enables setting an angle for the three-dimensional chamfers very precisely.

The highest development stage of chamfering technology is construction of special robotized stands. The robotized technology ensures high and very stable quality of cutting. The robotized stands also ensure the definitely higher productivity. Additionally, the fact of moving an operator away from the process eliminates the substantial part of the health and safety risks.

Robotized chamfering stand with plasma cutting

The plasma technology ensures the highest quality and efficiency for cutting steel of thickness from a few to several dozen millimetres. The designed robotized chamfering stand for plasma cutting is composed of the following devices:

- industrial robot,
- plasma cutting set,
- stand control cabinet,
- operator's control desk,
- two work tables,
- mobile protective cabin,
- two jib cranes – left and right,
- ventilation system.

The robot is located between two work tables which are ventilated from the bottom part. A track runs along the stand on which the protective cabin moves. The cabin's side walls are made from solid material that muffles noise generated during plasma cutting. Two front walls of the cabin have doors with welding curtains. The cabin doors are locked after closing. A sensor mounted next to the lock informs the control system that the door is closed. The robot will not start the automatic operation if doors on both sides of the cabin are not closed. If any door opens during automatic operation, the robot will stop operation and will switch the plasma cutting set off. Warning sets are mounted on four corners of the cabin – three-colour beacons, alarm horns with warning lamps and EMERGENCY STOP pushbuttons. Bumper type stop switches are connected to the warning sets, mounted on each corner of the cabin (painted in yellow-black strips). They protect the cabin against possible collision.

The operator's control desk is mounted on the wall behind the cabin. The stand's operation is supervised by the control system placed in a separate cabinet, which includes:

- PLC controller that controls the operation of the stand,
- safety controller that supervises safety devices of the whole stand,
- two drive controllers that control movement of the cabin.

The ventilation unit is mounted on the stand. It is equipped with the separate control system and is switched on separately. The ventilation unit cleans the air drawn in from the bottom - from under the tables' grates and from above – through the opening in the cabin roof. During automatic operation of the stand, the operator's work is limited to putting on new elements, taking off chamfered elements and supervising the operation of the stand. Plasma torch is guided by the robot . The programmed path of the cutting tool movement guarantees that metal plate is cut along the edge, under the required angle.

Results of robotization of the metal plates chamfering

In general, profits from using the robotized metal plate chamfering technology with plasma cutting may be summed up in three groups:

Increase of productivity – decreasing retooling time, possibility to make chamfers from the bottom and from above without the need to change fastening of the element, quicker cutting process, and short time of process initialization.

Stabilization of quality on a high level – a substantial improvement in quality of chamfers due to sure, precise torch guiding by the robot, especially on curves and on passages curve-straight line, fixed width of chamfers on straight as well as on curved segments, repeatability of chamfers on next elements, excellent quality of surface after plasma cutting.

Improvement in the working conditions – moving an operator away from the thermal cutting process decreases risks of burns, breathing fumes and metal oxides, and being exposed to noise.

Recapitulation

Numerous advantages of this technology were confirmed by its first application – the robotized chamfering stand with plasma cutting implemented in the TAGOR SA Company in Zabrze (Poland) by the Industrial Research Institute for Automation and Measurements PIAP. The robot's range makes it possible to carry out chamfering on tables with work area 1600 mm × 3200 mm. A mechanism that controls torch distance from the element being chamfered maintains fixed width of the chamfer even in case of distortions or thermal deformations of the element.

In 2013 the project team was awarded the Polish Prime Minister 1st Prize for their outstanding national achievements in the field of science and technology. High technical level of this developed technology was appreciated at numerous competitions, presentations and fairs. Scientific and innovative level of this technology is confirmed by patent applications and many publications.

Controller for multivariable system with dead-time

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Designing industrial control systems, e.g. in sugar factories, power stations, etc, one always encounters systems with dead time. In such a system after change of control input one observes change of output signal after dead time.

Industrial automatic control systems

It is known that it is more difficult to design asymptotically stable control system, controller, for dead-time system than a system without dead time. PID controller is used usually in the industrial practice. Designing a PID control system we may achieve an asymptotically stable system for single input single output system with dead time. However, one cannot design a control system for a multi-input multi-output control plant with dead time this way. In industrial practice usually one can solve this problem in a different way, one designs a number of single input single output PID control systems for multi-input multi-output system. This control system works properly; however, it is not an optimal system; it is particularly easy to see if there are large dead-times. In this case, in order to obtain better quality control, one can use a multivariable controller for dead-time system.

Controller for dead-time system

Analysing control problem for multivariable control system, it was invented multivariable controller for dead-time system. System model can be described by the transfer function:

$$y(s) = G(s)\,u(s) + w(s)$$

where

$$G(s)=\begin{bmatrix} G_{11}(s) & \dots & G_{1m}(s) \\ \vdots & & \vdots \\ G_{p1}(s) & \dots & G_{pm}(s) \end{bmatrix} = \begin{bmatrix} G_{011}(s)e^{-T_{011}s} & \dots & G_{01m}(s)e^{-T_{01m}s} \\ \vdots & & \vdots \\ G_{0p1}(s)e^{-T_{0p1}s} & \dots & G_{0pm}(s)e^{-T_{0pm}s} \end{bmatrix}$$

and

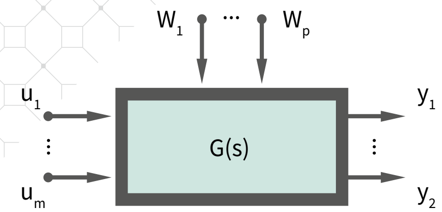
$$G_{ij}(s) = G_{0ij}(s)e^{-T_{0ij}s} = \frac{y_i(s)}{u_j(s)}$$

or state-space model

$$\dot{x}(t) = Ax + \sum_{i=1}^{l} B_i u(t-T_i) + w_x(t)$$
$$y(t) = Cx(t) + w_y(t)$$

where $x \in R^n$ is a system state space vector, $u \in R^m$ control input vector, $y \in R^p$ output signals vector and $w \in R^p$, $w_x \in R^n$ i $w_y \in R^p$ are vectors of disturbance signals.

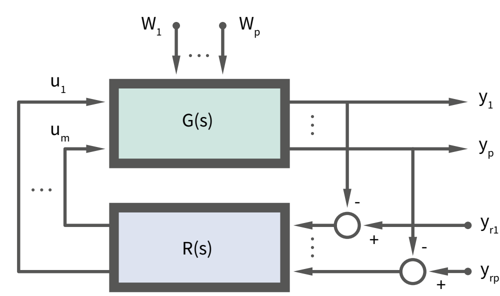
In real systems disturbance w usually is unknown, non-measurable, however frequently one knows its nature, e.g. step input or sinusoidal signal, but one does not know its value.



Block diagram of control plant

Assuming that system disturbances are non-measurable, the control problem is formulated as follows: given reference output y_r, e.g. step input or sinusoidal signal, design controller $R(s)$, such that the system output y tends to the reference output y_r in the presence of the disturbance w with known nature, e.g. step input or sinusoidal signal

$$y_i(t) \to y_{ri}(t) \quad \text{for} \quad t \to \infty,\ i = 1, \dots, p$$



Block diagram of control system

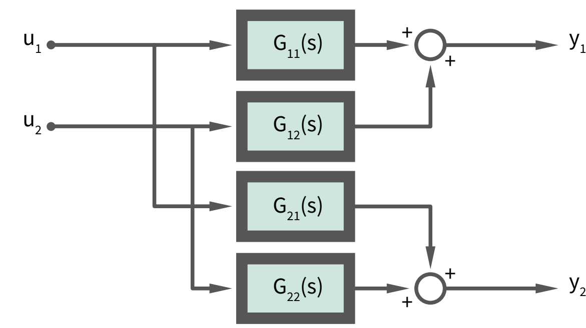
Solving such control problem involved invention of controller for system with dead time.

Control system for Shell heavy oil fractionator

Shell heavy oil fractionator, can be described by the simple following multivariable model with dead time:

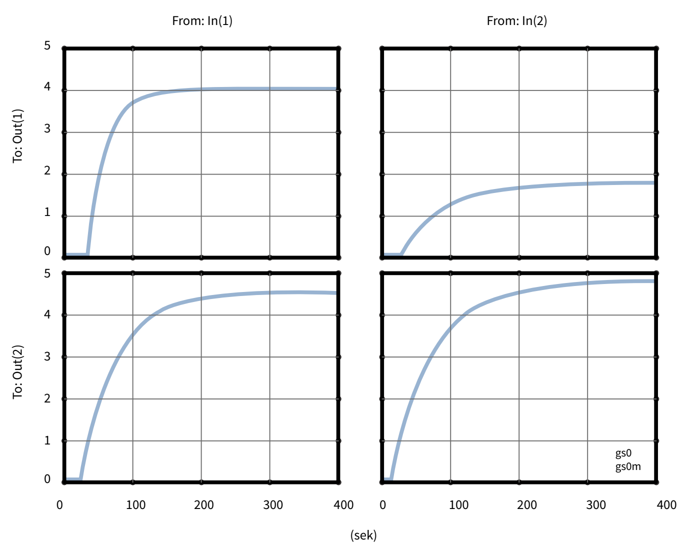
$$G(s)=\begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} = \begin{bmatrix} \frac{k_{11}}{T_{11}s+1}e^{-T_{011}s} & \frac{k_{12}}{T_{12}s+1}e^{-T_{012}s} \\ \frac{k_{21}}{T_{21}s+1}e^{-T_{021}s} & \frac{k_{22}}{T_{22}s+1}e^{-T_{022}s} \end{bmatrix}$$
$$= \begin{bmatrix} \frac{4.05}{27s+1}e^{-27s} & \frac{1.77}{60s+1}e^{-28s} \\ \frac{5.39}{50s+1}e^{-18s} & \frac{5.72}{61s+1}e^{-14s} \end{bmatrix} \qquad (1)$$

where output signals y: *top end point* and *side end point*, and control signals u: *top draw* and *side draw*.



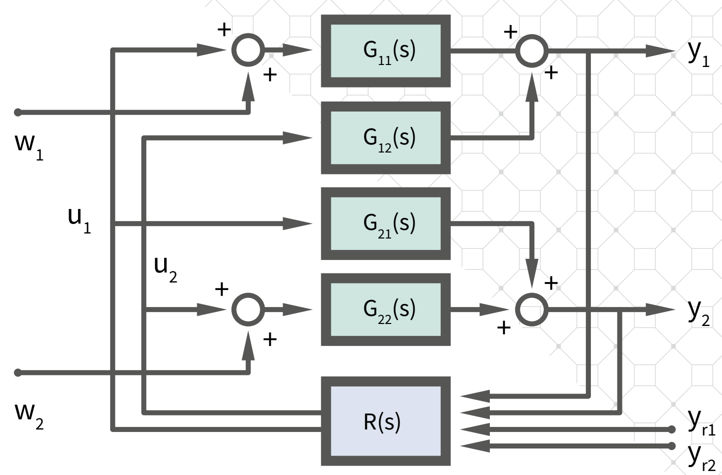
Block diagram of Shell heavy oil fractionator

The system has 2 input signals and 2 output signals. In control lines there are 4 different dead-times. Because there are also strong internal signal couplings and it is difficult to design 2 single input single output PID control systems. In next figure there are presented system step responses, plots of output signal with step control signals. It is easy to see that they are quite different.



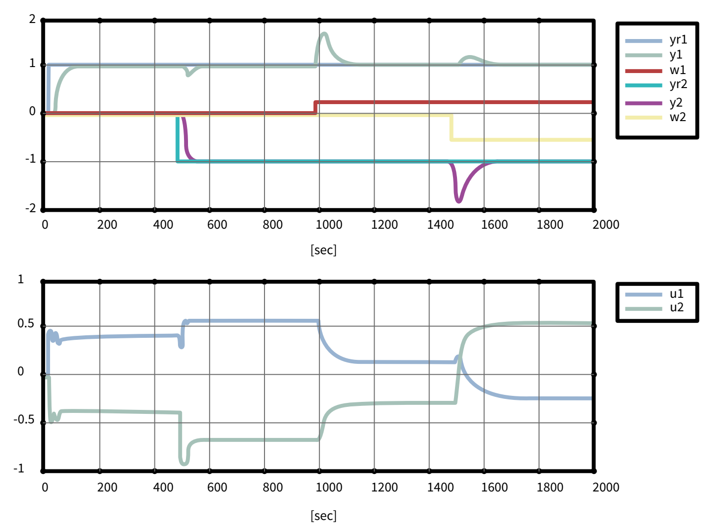
Step response of Shell heavy oil fractionator (1), $G_{11}(s)$, $G_{12}(s)$, $G_{21}(s)$ i $G_{22}(s)$

For the system it was designed the presented multivariable controller for system with dead-time with assumption that reference output and disturbance signals are step input signals. Next it was modelled on computer control system under the assumption that disturbance signals w_1 and w_2 are non-measurable.



Block diagram of Shell heavy oil fractionator

In next figure there are presented results of the simulation. It is easy to see that the control system works properly – control outputs after short transient period are equal to the reference output and disturbances are compensated by the change of control inputs.



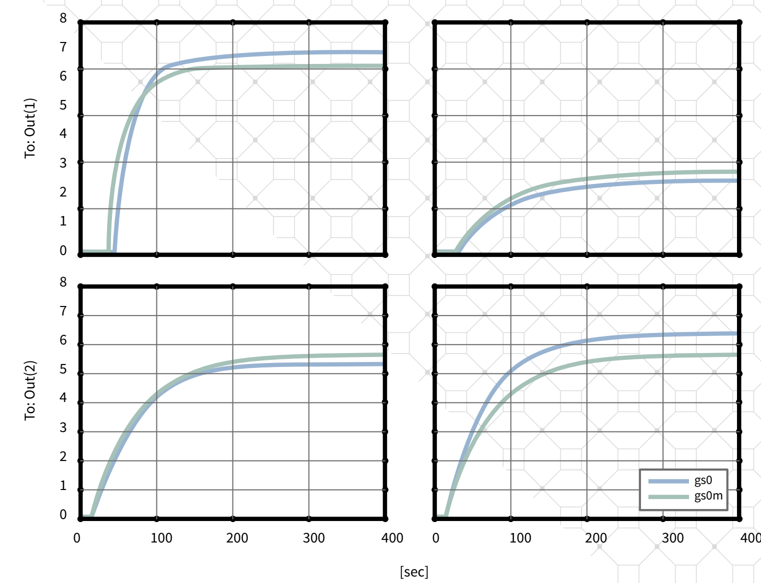
Results of Shell heavy oil fractionator control system with controller for dead-time system

Next the control system was modelled with designed controller and control plant, Shell heavy oil fractionator, with changed parameters as follows.
It is easy to check that control plant parameters are changed by about 5–10 %:

$$G(s)=\begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix}=\begin{bmatrix} \frac{k_{11}}{T_{11}s+1}e^{-T_{011}s} & \frac{k_{12}}{T_{12}s+1}e^{-T_{012}s} \\ \frac{k_{21}}{T_{21}s+1}e^{-T_{021}s} & \frac{k_{22}}{T_{22}s+1}e^{-T_{022}s} \end{bmatrix}$$

$$=\begin{bmatrix} \frac{4,293}{28,62s+1}e^{-35.1s} & \frac{1,664}{67,2s+1}e^{-31.4s} \\ \frac{5,228}{48,5s+1}e^{-14.8s} & \frac{6,406}{53,68s+1}e^{-13.2s} \end{bmatrix} \qquad (2)$$

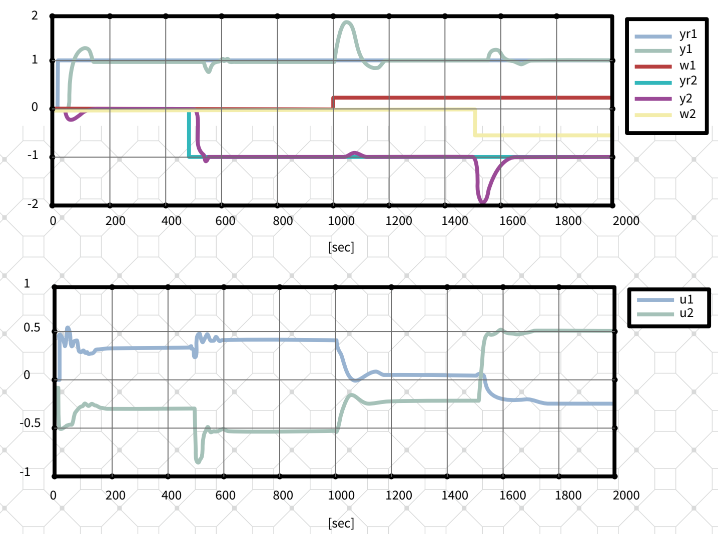
In next figure there are presented step responses of control plant model (1) (gs0m) used for controller design and control plant – Shell heavy oil fractionator with changed parameters (2) (gs0). It is easy to see the difference between both systems.



Step response of Shell heavy oil fractionator (1) and changed fractionator (2), $G_{11}(s)$, $G_{12}(s)$, $G_{21}(s)$ i $G_{22}(s)$

Next, there are presented results of control system with changed control plant (Shell heavy oil fractionator).

It is easy to see that the control system works properly in real conditions since in industrial practice control plant model uncertainly is always calculated. Control plant parameters can also change, for instance after 2 years work or after repairs. One can see that signals flow are very similar to flows of unchanged system – control outputs after short, but longer than previously, transient period are equal to the reference output and disturbances are compensated by the change of control inputs.



Results of Shell heavy oil fractionator control system with changed parameters and with controller for dead-time system

Concluding remarks

The invented controller for system with dead time works properly. One can design in a simple way the asymptotically stable control system for multivariable plant with dead time. It can be used for SISO system with large dead time. In those situations it is difficult to find parameters for PID controller, frequently too big oscillations occur there. New controller can by applied in automatic control systems for large objects, it is equipped in anti-windup mechanism. Now such problems are solved with predictive controller, but it is difficult for implementation.
The invented controller for system with dead time has been submitted to Polish Patent Office.

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Virtual beings aid designers in the real world

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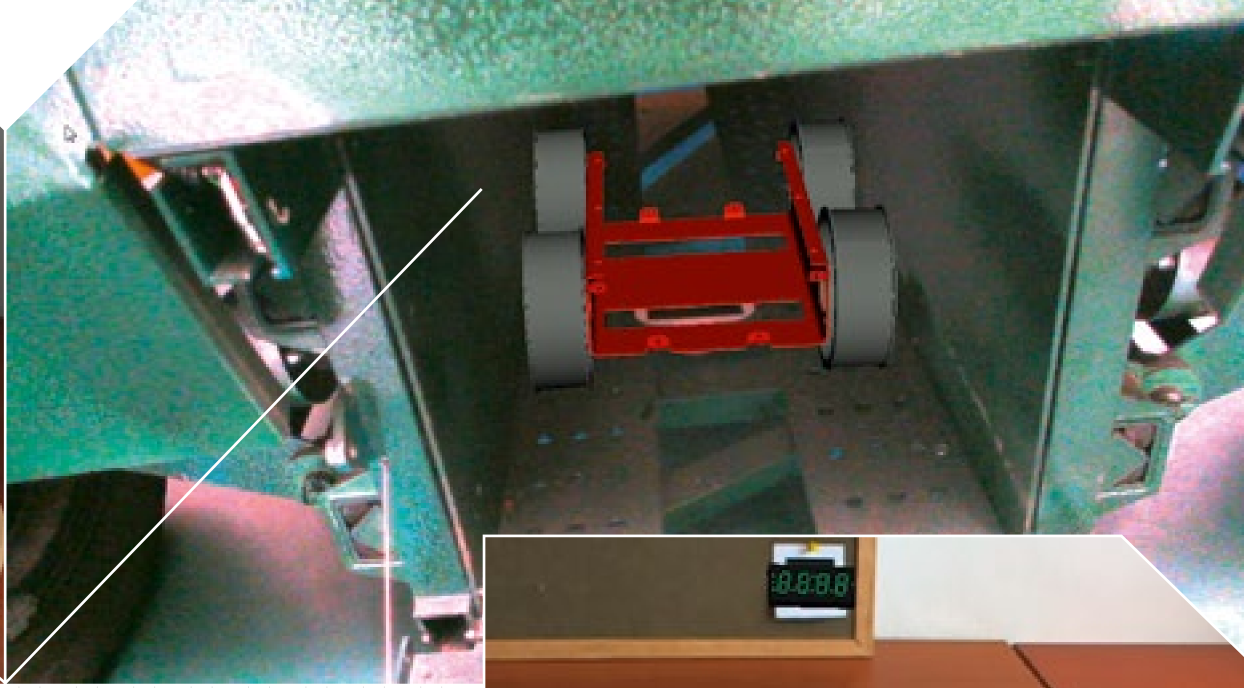


I'm driving out of the garage. I'm placing my smartphone with its display directed upward at the windscreen of the car. I move on. The application launched projects data about the spot travelling speed on the windscreen, informs about coming maneuvres and even warns that I'm exceeding the allowable speed just now. Mobile technologies make everyday life easier and attractive, but also provide designers, operating engineers with new functionalities.

The latest issue of the technical and scientific Measurements Automation Robotics **Pomiary Automatyka Robotyka (PAR)** monthly magazine is laying on the desk. I'm activating my smartphone's PAR+ application, I'm pointing the lens towards the page of interest for me and I'm seeing the additional objects (motion pictures, animations, galleries of photos), which are not contained in the paper edition on the display.

At last, after one work week I went for a trip to the mountains. And again, I'm taking advantage of the smartphone – pointing it towards a glade I'm passing by and what can be seen? Ruffians are dancing on that glade and I can interact with them in many ways.

One can reflect - maybe by chance it is magic? No, these are the effects of using the ultramodern computer technology, named Augmented Reality (AR). Thus, we have a reality, which surrounds us, but this reality is supplied by additional VIRTUAL objects. There is no display installed in the windscreen, no additional pages with photos appear when looking over the magazine and the ruffians do not exist.

What are the components of an AR system? A user furnished with the appropriate equipment (here a Head-Mounted Display [HMD]) observes the real-world environment in which the virtual objects augmenting this reality will appear at specified places. The AR computer system identifies the place at which the user looks, which is designated with special markers observed by a camera that is installed in the HMD. A virtual object (here a mobile robot) is "put" into the marker's place. Manipulating the marker enables "manipulating" a virtual object. A glove fulfils such a function and ensures coupling the constructor and the object being designed.

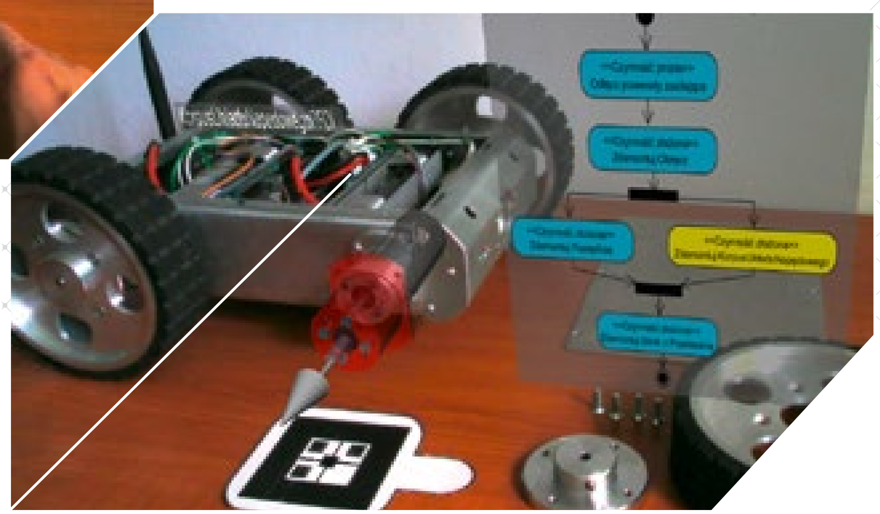
The AR technology aids also the design process. We started research in this field in 2006 at the Department of Machine Technology of the Silesian University of Technology. Modern design is aided by computers by means of CAD systems. 3-D objects are usually designed. Nowadays, we do not begin with standard "flat" drawings projected onto three planes, but model a three-dimensional object instead.

Let us imagine an aircraft design. We want to ENTER the cabin of this aircraft, CHECK whether it is easy to place the luggage and EXAMINE whether a specified switch is at the appropriate place. And if something has been designed wrongly, it is proper to INDICATE where the switch, high-pressure pipe or arm-chair control handle for changing the inclination should be mounted. How to do this since this aircraft is NON-EXISTENT? This question is answered by VR (Virtual Reality) environments in which a human moves only in a virtual world and is separated from the real-world.

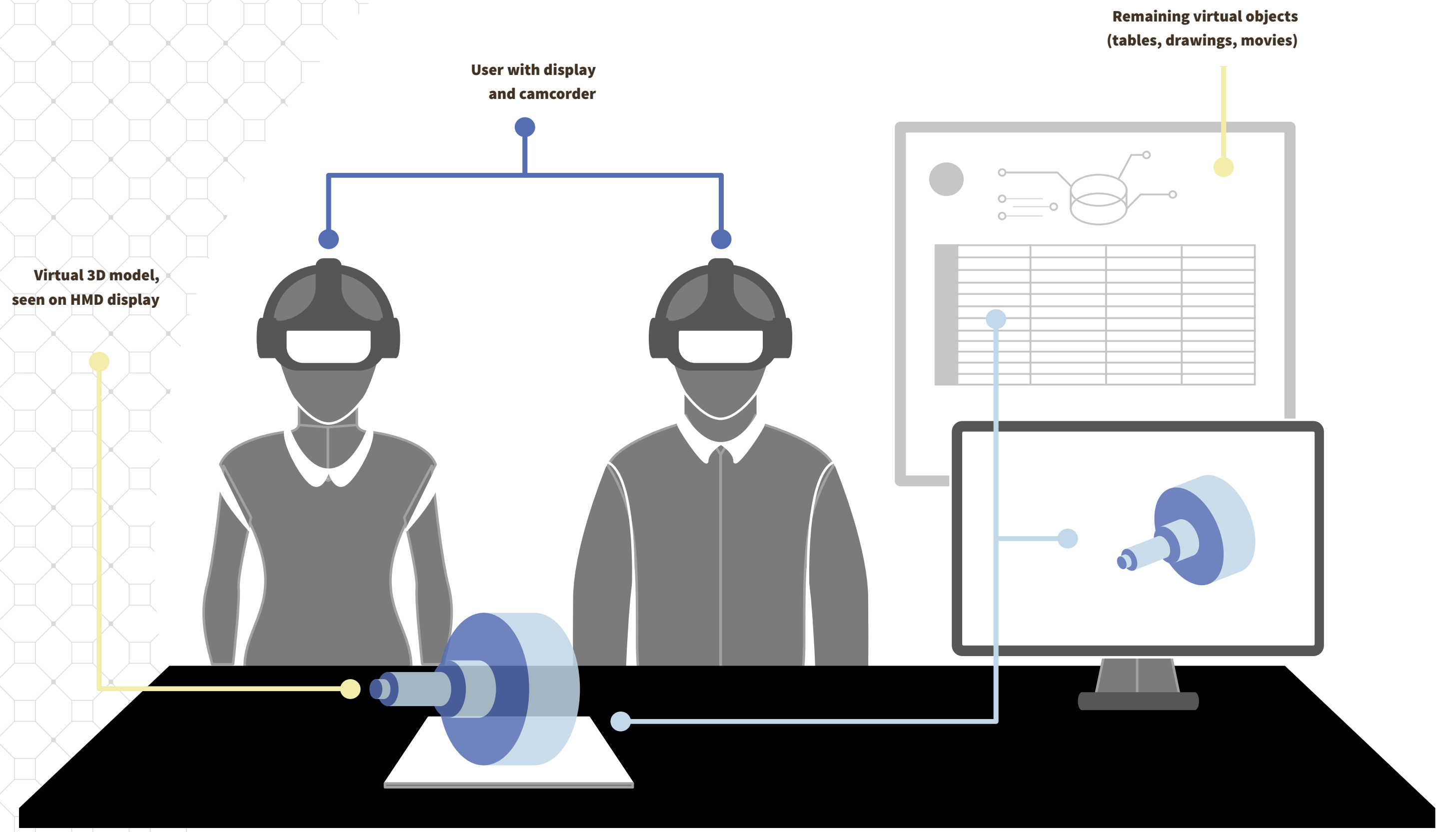
Our solution differs essentially from the well-known VR system solutions. Here, the planners and designers act in a real-world environment in which only the virtual objects APPEAR.

Thus, it is possible to fit a virtual robot to the existing loading space of a real robot. An AR system enables also an appropriate arrangement of switches, push-buttons, signal lamps, clocks and the like, and an assessment of their legibility

Very interesting uses are associated with the preparation of maintenance instructions. Our example is a repair of a mobile robot in which one of the wheels is damaged. The suitable tools that can be selected from a virtual tool board have to be used. The repair operations should be performed with these tools. The sequence of operation is presented in the form of an UML (Universal Modeling Language) scheme and relevant animations. It is easy to imagine other channels for transfer of the appropriate instructions, e.g., a sonic channel transferring the verbal instructions. Virtual objects advising the method of realizing the subsequent operations appear at appropriate places (next to the part of the object where an operation is being done) and at the appropriate time (when they are needed).



The use of AR systems offers many advantages to team-work. In case of project team assessment of a solution under development, each of the designers can view the effects of work in the AR mode intuitively from her/his perspective and in any scale (also 1:1), as if a real prototype would be placed in front of her/him. The team members can obtain the additional data about the solution being analysed from different knowledge sources. This data is presented in the space around the team. All of the team members may freely change the perspective of viewing the projected objects and manipulate these objects, which makes understanding of proposed solutions easier and aids the collective decision making by the project team.



All possible AR applications in the design process were not shown in the represented examples. We are carrying out further research on the development of methods of design assistance using AR. We put special emphasis on the feedback between the virtual world, represented by virtual objects and the real world in which changes made in virtual objects are introduced. The design of sensor and execution system arrangement on mobile robots is a good example. The installations can be spaced appropriately within the virtual environment and coupling the AR and CAD environment enables updating project documentation of a complete product.

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Fuel cells as alternative power source for autonomous underwater platforms

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Deeps of seas and oceans are still the less explored regions of our planet than its surface. This is the effect of the technological barriers caused by restrictions and requirements of the aquatic environment. The manned, and unmanned autonomous underwater platforms may be a solution to this problem. Such platforms, equipped with specialised systems and devices, may be used for research and exploration of the underwater environment. Realisation of these purposes depends on the power supply.

Sources of power for underwater platforms

Due to restricted access to atmospheric air on autonomous underwater platforms there is no possibility to apply the commonly used power supply system that uses the internal combustion engines. The most commonly used source of power for underwater systems are at present chemical storage cells, i.e. rechargeable batteries.

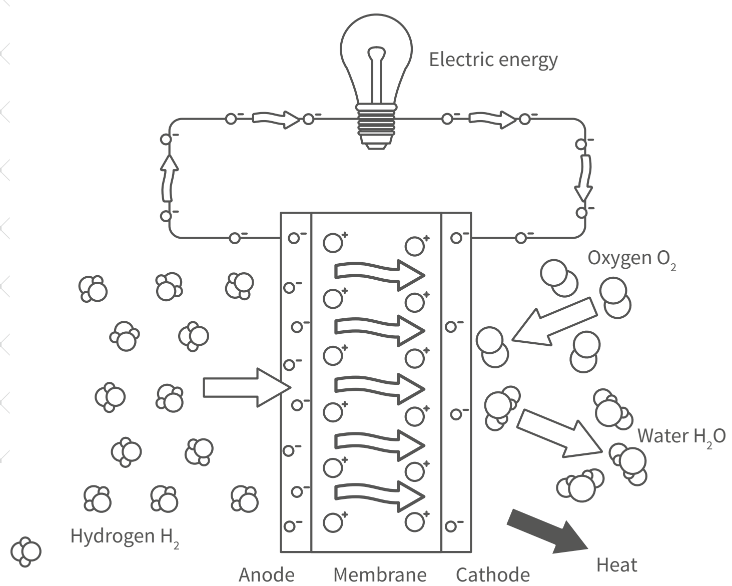
Despite the dynamic development of technology of storing energy in galvanic cells, the quantity of energy stored inside them is insufficient for carrying out any long-lasting missions. The use of galvanic cells as power source for the mobile underwater platforms leads to paradox often, where the weight of power supply system makes bigger part of the whole platform's weight.

Development of the inexpensive and easily available high efficiency power sources for underwater platforms is the subject of many research projects. Apart from research on development of galvanic cells of different types (lithium ion, magnesium, phosphate, etc.), the research on alternative power sources is also carried out. At present, fuel cells seem to be the most prospective solution and are more and more used for different technical solutions, civilian, as well as the military ones.

The main advantage of these cells, in comparison to the galvanic ones, is their even two times higher energy storage density, related to mass and/or volume unit. This feature was noticed in the world and fuel cells were used for supplying underwater objects with electricity, as for example, the Urashima Japanese autonomous underwater vehicle or the U-214 German submarine.

Fuel Cell System

The fuel cell is a device that combines features of a rechargeable battery and a combustion engine. It is a source of electric energy (as a rechargeable battery) and operates continuously if fuel is supplied (as combustion engine). The electric energy is generated in controlled chemical reaction between the fuel and oxidizer, which occurs in presence of catalyst on two electrodes – anode and cathode – separated by electrolyte. During operation of the fuel cell thermal energy is generated with water as a product of reaction between hydrogen and oxygen.



Principle of fuel cell operation

The advantage of fuel cell compared to the traditional sources of electric energy is its zero-emission of toxic waste and combustion gas – they are the environment-friendly sources of electric energy. Their advantage is lack of moving parts, what ensures high reliability, low maintenance costs and potentially long service life.

The main classification of fuel cells results from the electrolyte used, which determines the character of chemical reactions, operating temperature and structure of the auxiliary subsystems. Analysis of the available fuel cells technologies shows that the PEM (Proton Exchange Membrane) fuel cells, in which a proton-conducting membrane acts as an electrolyte, are the most suitable ones for use on underwater platforms. These fuel cells are characterised by the highest, among all types of fuel cells, efficiency of conversion of chemical energy into electric energy, low operating temperature that enables quick start-up and loading, good scalability of the system, and diversity of possible applications.

Fuel cells – classification depending on electrolyte used

Classification of fuel cells		AFC	PEMFC	DMFC	PACF	MACF	SOFC
Electrolyte		Alkaline	Polymer membrane		Phosphoric acid	Fused carbonates	Solid metal oxides
Operating temperature	Low	100 °C	80 °C	100 °C	-	-	-
	Medium	-	-	-	650 °C	-	-
	High	-	-	-	-	650 °C	650 °C
Pressure	Atmospheric	X	X	X	X	X	X
	Higher pressure	-	-	-	-	X	X
Fuel	Gas	-	-	-	-	X	X
	Liquid	-	-	-	X	-	-
	Solid	-	-	-	-	X	-
Oxidizer	Oxygen	X	X	X	X	X	X
	Air	-	X	X	X	-	X
	Air + CO2	-	-	-	-	-	X
Applications	Automotive	-	X	-	-	-	-
	Portable devices	-	X	X	-	-	-
	Special	X	X	X	-	-	-
	Power engineering	-	-	-	X	X	X

Source: Sałaciński J. Miller A., Milewski J., Przegląd Energetyczny 4/2006

Fuel cell stack

Typical PEM fuel cell consists of the proton-conducting membrane, electrodes with the catalyst, gas-diffusive layers and bipolar plates with gas channels. A single cell generates a voltage of about 1 V; therefore, to achieve a higher voltage value, it is necessary to connect several or several dozen single cells in a series in a so called fuel cell stack.

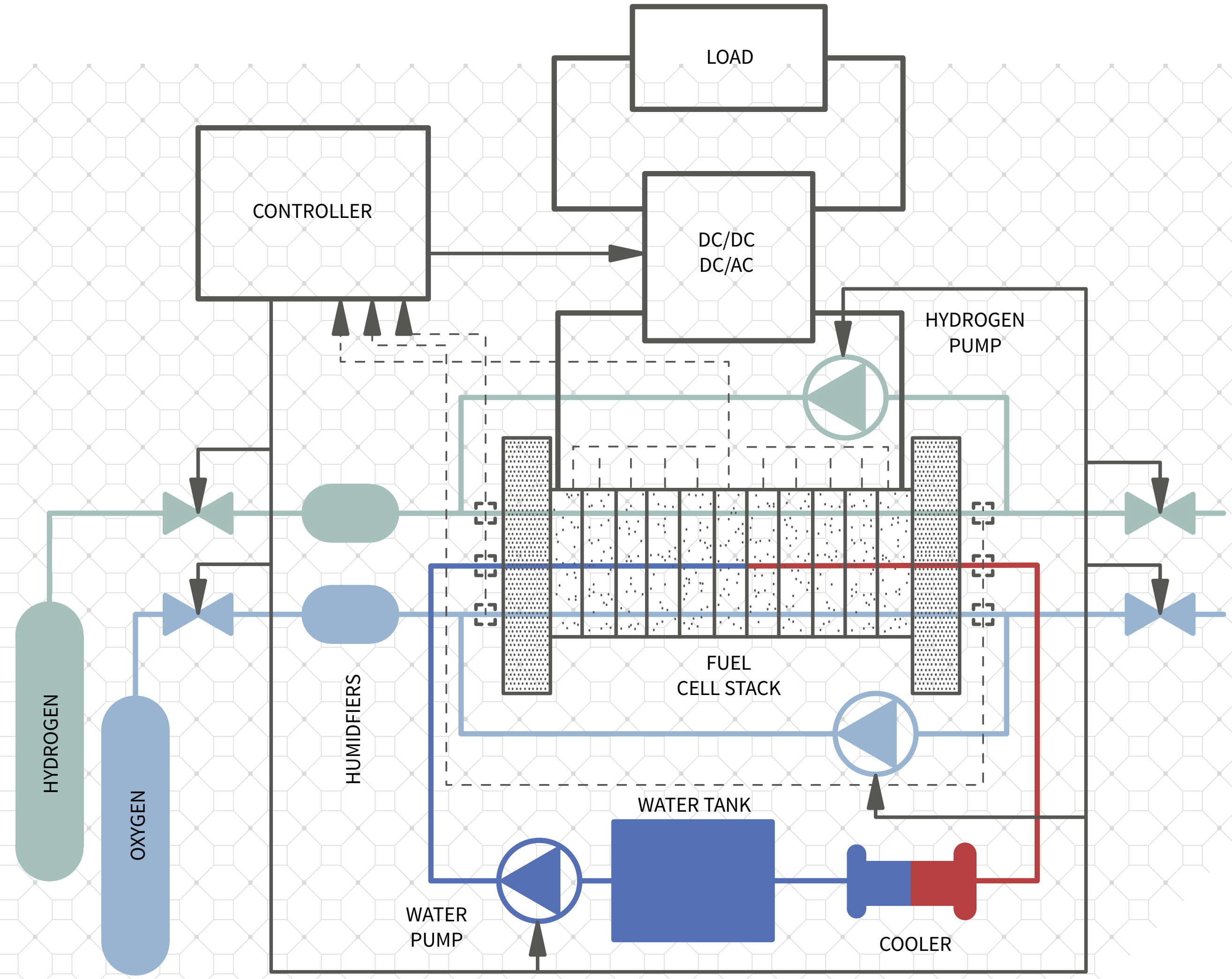
Power supply system with PEM fuel cells for underwater platforms

The fuel cell stack does not operate independently – it needs many auxiliary devices which enable its suitable operating conditions, including: suitable pressure of reaction gases and their flow rate, humidification level of membrane, fuel cell temperature.

The task of fuel cell auxiliary subsystems is to maintain these parameters on a correct level. The most important subsystems are as follows:

- fuel supply subsystem,
- oxidizer supply subsystem,
- heat management subsystem,
- water management subsystem,
- control and monitoring subsystem.

These subsystems together with the fuel cell stack constitute the so called fuel cell system.



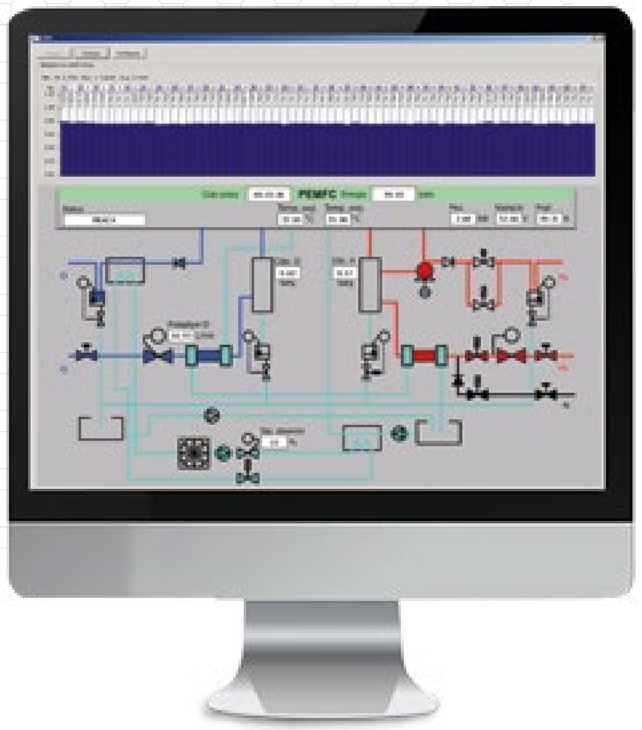
Functional diagram of power supply system for underwater platform with PEM fuel cell

The PEM fuel cell system for supplying autonomous underwater platforms with electricity was designed and constructed at the Institute of Electrical Engineering and Naval Automatics of the Polish Naval Academy. The XXL8.0 fuel cell stack manufactured by the Dutch company Nedstack was used, consisting of 68 individual cells. This PEM fuel cell system can supply loads with DC power of up to 8 kW, when supplied with the sufficient quantity of reaction gases for electrodes, and the suitable working conditions are ensured.

Due to the fact that this system is dedicated for operation in the underwater environment, it has to operate with no access to the atmosphere. This is ensured by storing the fuel (hydrogen) and oxidizer (oxygen) in cylinders. Some restrictions were taken into account while designing this system, like the limited weight and space available for the power supply source on the underwater platform.

Operation of the fuel cell system is supervised by a microprocessor system, which monitors and controls operation of the power supply system and ensures its correct working conditions.

Simulation and laboratory tests of the fuel cell system made it possible to define the technical parameters of its individual components. Further improvement of its subsystems is now in progress and is oriented towards enhancement of the general efficiency and increase of the energy density factors.
The developed power supply system with fuel cell has the modular structure and may be adapted easily to user's requirements, in respect of the power needed, as well as of the load type. The research team of the Polish Naval Academy can design and construct a power supply system based on the PEM fuel cells dedicated not only for underwater objects.



Window of an application that supervises operation of the fuel cell system

Power supply system using the PEM fuel cell independent of the laboratory air

Storage of operational gases of the fuel cell system independent of the surrounding air

MTracker robot for scientific, research, and educational use

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MTracker is a result of the long standing research on mobile robotics carried out at the Department of Control and Systems Engineering at the Faculty of Computing of the Poznan University of Technology. Due to the solid and rigid structure made of high quality materials and highly dynamic drives this device makes it possible to carry out the scientific and educational experiments.

Build a robot MTracker

The main controller of the robot is a single board computer whose central unit, the Texas Instruments TMS 320F28335 signal processor with 150 MHz clock, is equipped with a number of peripherals. There are the on the board 256 kB RAM and 128 kB flash memories. The robot has the reflective proximity sensors operating in the infrared band, with a range of up to 200 mm and optionally may be fitted with the two dual-axis acceleration sensors and a gyroscope. In the basic version, the robot height is 65 mm and its diameter is 170 mm.

This robot's functionality may be extended by mounting the additional modules on one of the platforms: PC computer with Windows CE or Linux operating systems, like a digital camera, a laser range-finder or other devices. This makes it possible to implement complicated algorithms enabling the robot to operate autonomously. Multiple interfaces (including the wireless one with the high transfer capability) making it possible to carry out operations in the master-slave architecture (e.g. virtual structures algorithms, leader following methods), and in the scattered architecture, where robots operate as the independent agents (e.g., behavioural methods).

Features of the MTracker robot:

- simple and robust mechanical structure,
- high quality components,
- high dynamics,
- modular structure (easy mechanical, electronic and software expandability),
- easy implementation of new functionalities, also the ones needing the high computational capacity,
- many communications interfaces: RS-232, USB 2.0, radio cc2500, and Wi-Fi in the extended version.

Parametry techniczne robota zostały Specification of the MTracker robot:

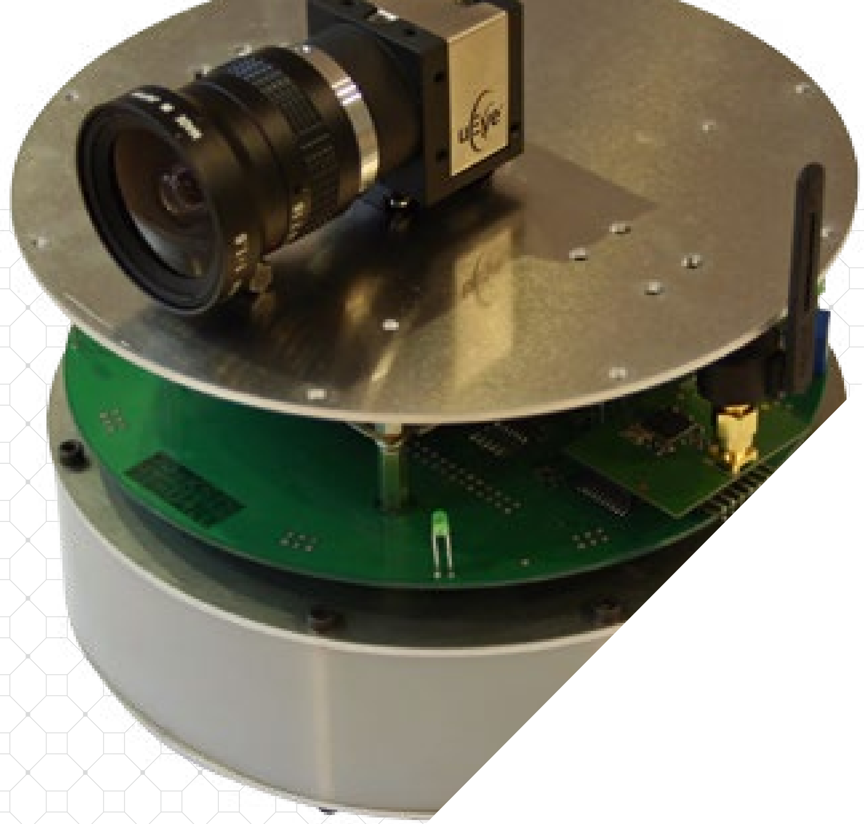
- diameter: 170 mm,
- height (basic version): 65 mm,
- maximal speed 1 m/s,
- drive: two 6 Watt DC motors with gears 14:1,
- encoders on motors' axles 32 CPR,
- powered by rechargeable battery 8–15 V, 2000–4400 mAh,
- proximity sensors with 200 mm maximal range.

The onboard controller is fitted with:

- TMS 320F28335 150 MHz signal processor,
- RAM 256 kB × 16 bit memory,
- FLASH 128 kB × 16 bit memory,
- UART RS-232, USB 2.0 interfaces,
- radio communication: cc2500 256 kb/s module.

The robot optional equipment consists of:

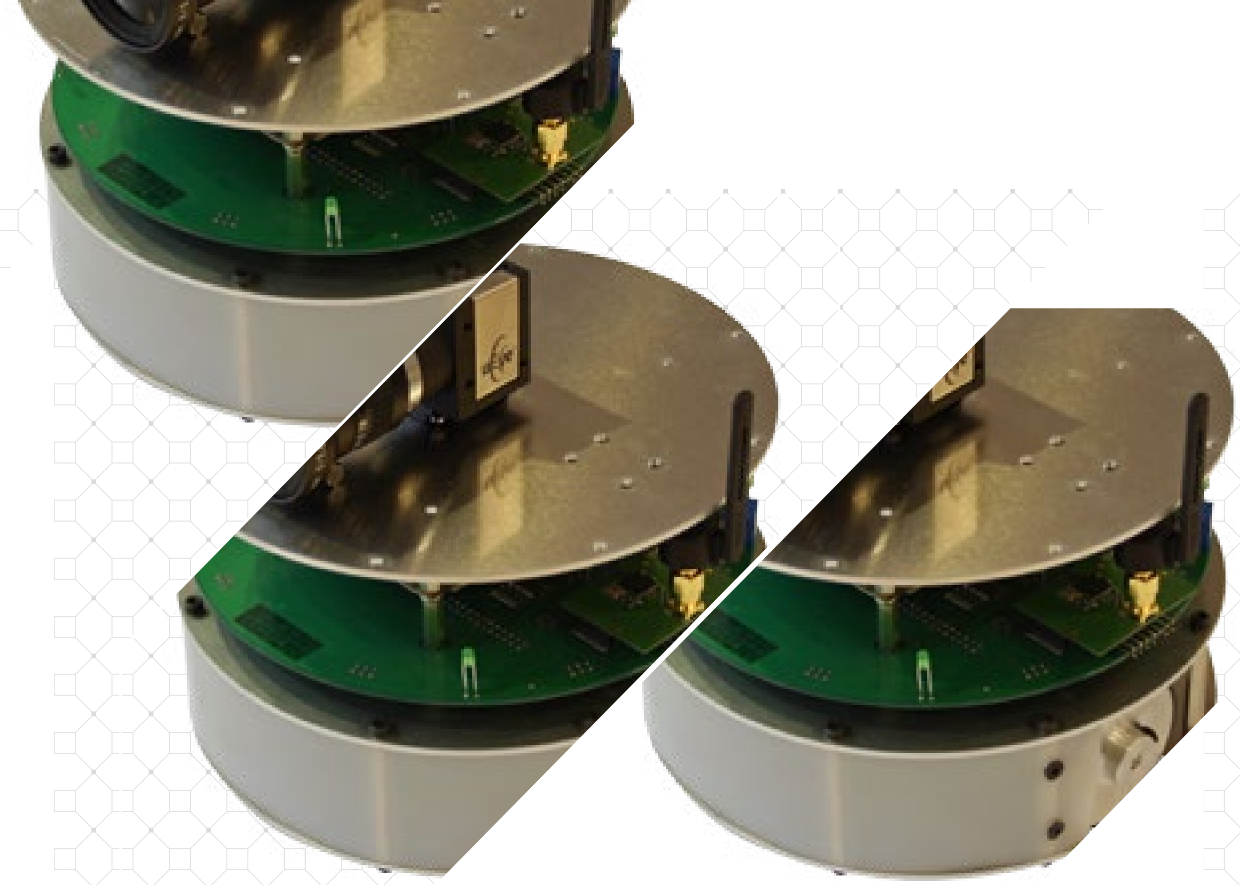
- two dual-axis acceleration sensors,
- gyroscope,
- additional onboard computer with Windows CE or Linux operating systems.



Robots designed at the Department of Control and Systems Engineering, like the MTracker one, are usually fitted with many sensors which may be used in the autonomous operation mode by the built-in controller: IR proximity sensors, gyroscopes, acceleration sensors. Depending on needs, there are used as onboard controllers, built-in PC computers and controllers designed by us and based on signal processors. For communications among the scattered elements of the system popular the wireless networks Wi-Fi are used, as well as the specialised radio modules (depending on the required throughput capacity, range and capacity of the onboard power sources).
A special stress was put on robustness, reliability, and construction modularity of these devices' design. Methods of virtual structures, leader following, and behavioural approach were used in the experiments carried out.

Directions of research

Theoretical research connected with application of the constructed MTracker robots (Department of Control and Systems Engineering has 50 such robots) focuses especially on analytical methods, based on geometrical relationships, artificial potentials functions with their gradients and navigation function, and – in case of multirobot systems – also on the formation function. For robot control, the approach based on input-output linearization of kinematic model (simulation and experimental research) [1, 2, 4] or of the dynamic robot (simulation research) [3] and linear control in the part responsible for minimisation of position error, are used. During tests, problems were solved of movement to a defined point/area of workspace, as well as problems of following trajectories, individual for separate robots, as well as common ones for the whole formation of robots.



The MTracker robots are used for the educational purposes in classes given within teaching program for automation and robotics in the Laboratory of Multirobot Systems for teaching how to solve problems of joint navigation of robots in the environment with static and dynamic obstacles, grouping the robots in the predefined arrays, as well as for the inspection tasks in laboratory environment.

1 K. R. Kozłowski, W. Kowalczyk, B.Krysiak, M. Kiełczewski and T. Jedwabny, Modular Architecture of the Multirobot System for Teleoperation and Formation Control Purposes, 9th International Workshop on Robot Motion and Control, str. 19-24, 3-5 czerwiec 2013, Wąsowo, Polska.
2 W. Kowalczyk, M. Michałek, K. Kozłowski, Trajectory Tracking Control and Obstacle Avoidance for Differentially Driven Mobile Robot, Preprints of the 18th IFAC World Congress, Mediolan, Włochy, str. 1058-1063, sierpień 28 - wrzesień 2, 2011.
3 W. Kowalczyk, K. R. Kozłowski, J. K. Tar, Trajectory tracking for Multiple Unicycles in the Environment with Obstacles, International Workshop on Robotics in Alpe-Adria-Danube Region (RAAD), 2010 IEEE 19th, str. 451-456, 24-26 Czerwiec 2010, Budapeszt Węgry.
4 W. Kowalczyk, M. Michałek, K. Kozłowski, Trajectory tracking control with obstacle avoidance capability for unicycle-like mobile robot, Bulletin of the Polish Academy of Sciences, Technical Sciences, wolumen 60, numer 3, 2012, str. 537-546.

Vision-based KUKA KR3 robot motion control

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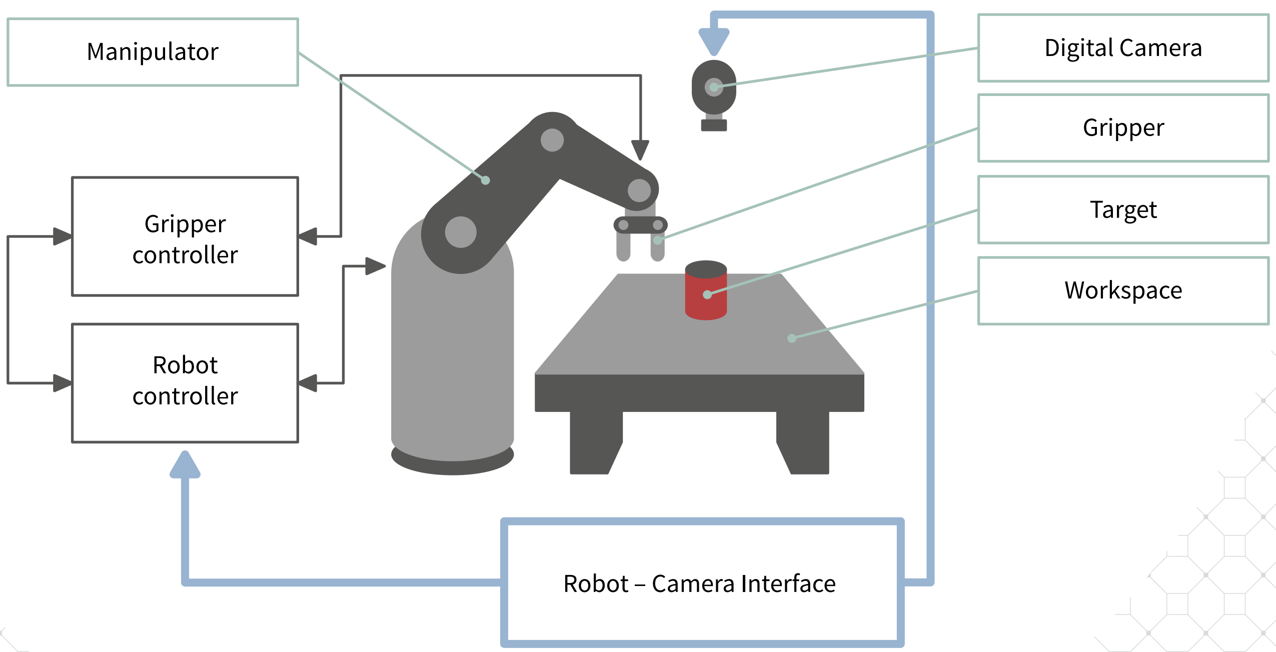
Project realised at the Institute of Automatics Control, Silesian University of Technology tackles the problem of integration of the KUKA KR3 robot with a NI Smart Camera 1742 vision system. Project includes subjects such as communication interfaces between robot and digital camera, building a library for LabVIEW, image acquisition and transformation of visual information into robot's movements.

Description of robotic stand and its peripherals

Project is based on workstation composed of industrial robot equipped with a gripper and a digital camera mounted above the workspace. The robot vision based control interface can be implemented directly in robot controller or in the intermediary device.



KUKA KR3 robot and its specification

KUKA KR3 is a robotic platform with our system onboard. Our system is composed of the following elements: manipulator (KR3), controller (KR C3) and Control Panel (KCP). This set of components is chosen, as it is representative for many of branches of the Polish light industry.

KUKA KR 3 manipulator datasheet

Parametr	Value	
Nominal payload	1.5 kg	
Number of axes	6	
H-Range	635 mm	
Repeatability	±0,05 mm	
Weight	53 kg	
Parameters of axes	Motion range	Motion speed
Axis 1 (A1)	±180°	240°/s
Axis 2 (A2)	–45°/+135°	210°/s
Axis 3 (A3)	–225°/+45°	240°/s
Axis 4 (A4)	±180°	375°/s
Axis 5 (A5)	±135°	300°/s
Axis 6 (A6)	unlimited*	375°/s

Manipulator KR3

KR3 Manipulator

The kinematic structure has six rotary axes which enable the manipulator to access every point in the workspace with a given gripper orientation.

Manipulator software

KSS software (KUKA System Software) with a user friendly interface has been designed for program development and edition. The programming process is done using the dedicated KRL language (KUKA Robot Language), with which the operator receives an access to:

- operations on variables,
- conditional functions and loops,
- handling of timers and exceptions,
- control of robot inputs/outputs,
- linear/axial/circular motion to a predefined point.

NI 1742 Smart Camera and its specification

The 1742 series devices by National Instruments are the so-called smart cameras. They can process and analyse the data gathered Apart from image acquisition. The dedicated processor and a memory unit enable the user to implement his own program. The real time operating system, ensures the deterministic execution of every program installed.

The programming possibilities are dependent on the device manufacturer. The National Instruments Company, due to camera integration with the LabVIEW environment, enables implementation of very intricate vision applications, as well as management of multiple functions. We have used in our project, among others, functions like:

- image acquisition in singular and continuous mode,
- sensor configuration and light control,
- image processing,
- external communication.

Kamera National Instruments 1742 Smart Camera

NI 1742 Smart Camera datasheet

Parameter	Value
Processor	533 MHz
Operating system	VxWorks
Image sensor type	1/3 inch Sony ICX424AL CCD
Image colour	Monochromatic
Resolution	640 × 480 px (VGA)
Frame rate	60 (FPS)
Interface	2 × Ethernet 1 Gb/s DE-15 socket (+I/O

Camera software

NI 1742 SC can be programmed in one of the two environments, depending on the user requirements:

- NI Vision Builder
- LabVIEW.

NI Vision Builder is a program dedicated to development of visual inspection applications for the intelligent Smart Cameras family. Simple interface and intuitive method of algorithms design enables rapid application development, make this software easy to use and adapt to the requirements of the particular enterprise. The user can use many image processing functions, which to be run sequentially as consecutive actions. The final shape of given application is then reduced to image acquisition, processing by given number of functions and resulting data transfer. However, this environment encounters many problems when implementing more complex algorithms including e.g. parallel loops.

LabVIEW package, the National Instruments flagship, enables implementation of much more complex image processing and increases the autonomy of the camera device. This environment, however, requires considerably higher programming skill than Vision Builder.

The robot-camera interface concept and its realisation

The proposed solution necessitated development of three applications supporting communication with external devices and internal robot data exchange. The applications developed are:

- CamServer (LabVIEW) – TCP/IP server supporting acquisition and configuration commands,
- KUKAServer (C++) – TCP/IP server and the application of direct data exchange program for KUKA robot,
- RoboSlave (KRL) – program in the standard robot language, controlling robot moves.

Test stand

The test application used in this project was based on two types of objects, namely Donald Duck and Mickey Mouse tokens. Objects were identical in size and shape, the difference was only in the pattern painted on them. The tokens were equipped with a pin, so as to be suitably handled by the gripper.

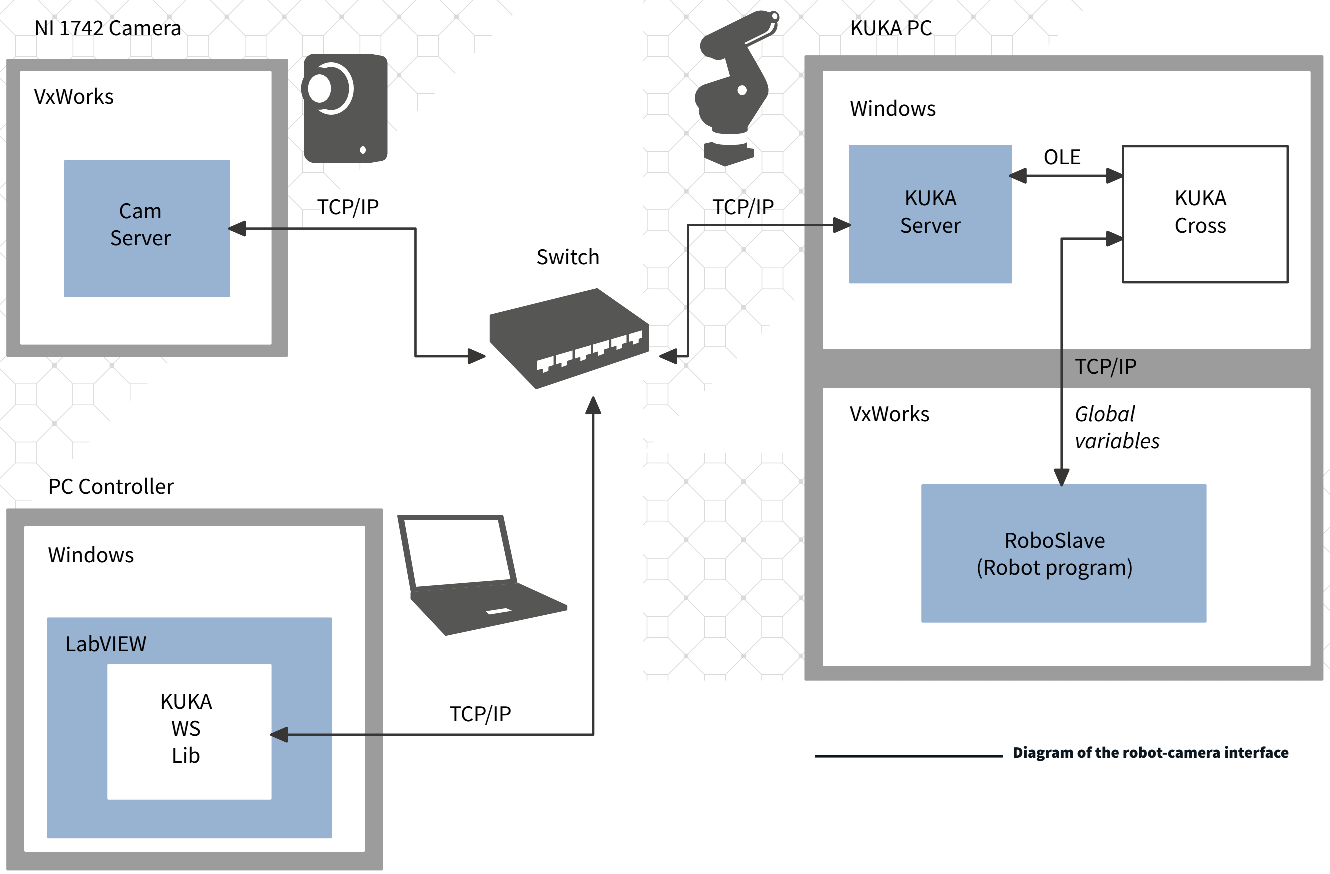
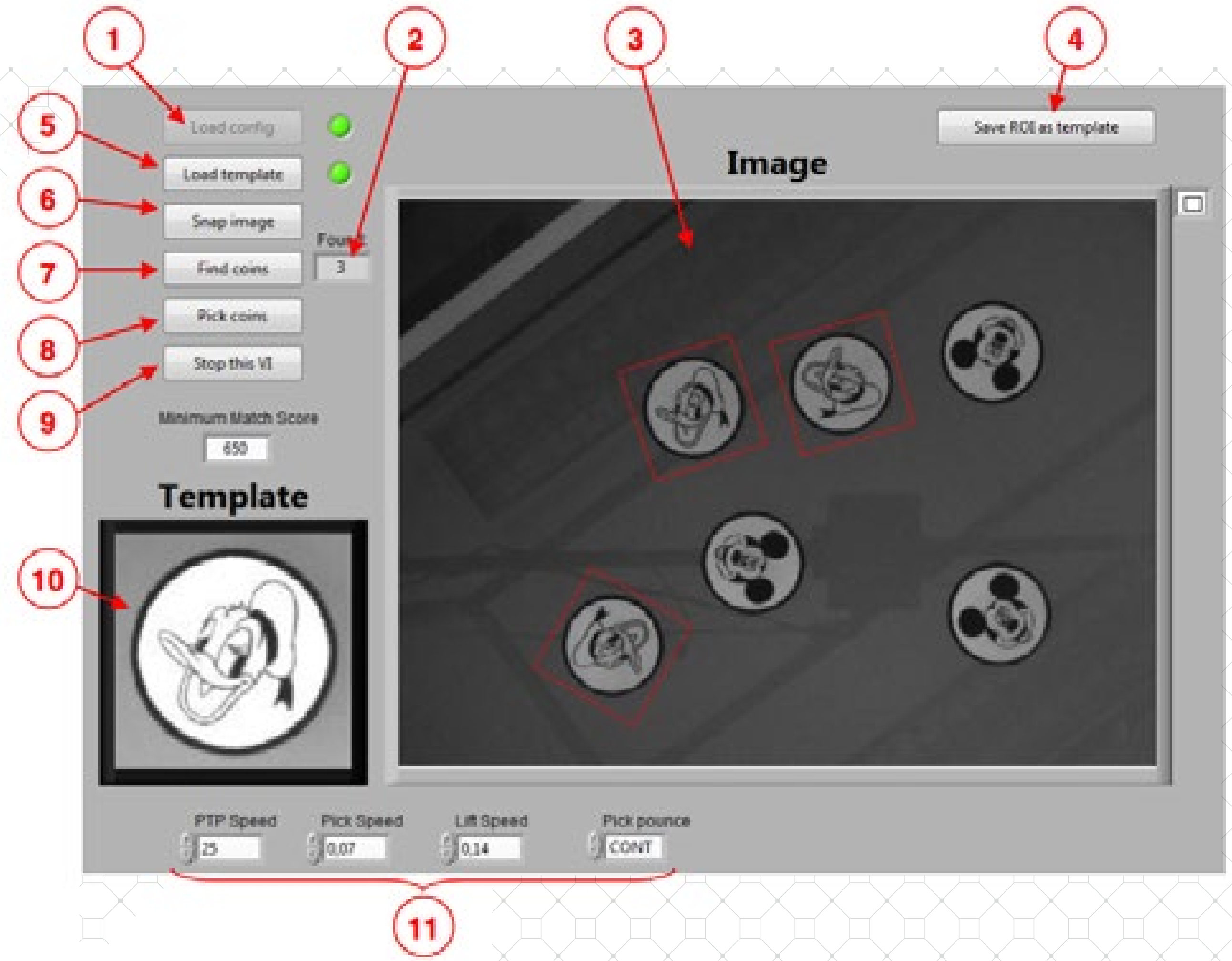


Diagram of the robot-camera interface



View of GUI:
1 – loading of station configuration,
2 – indicator of objects in agreement with set pattern,
3 – camera image preview, 4 – image crop selection save to file,
5 – pattern load from file,
6 – single stage acquisition (step 1),
7 – image object search (step 2)
8 – robot motion to objects found (step 3),
9 – application stop,
10 – pattern preview,
11 – setting robot speed

Implementation and operation

The object recognition application was developed in LabVIEW environment based on two libraries and modules:

- KUKA WS Lib – image acquisition from the NI 1742 camera, visual information conversion to manipulator space coordinates and robot control,
- NI Vision Development Module – pattern recognition and learning, objects detection in the camera image.

Search and selection of objects are performed in a three step process. Each stage of this process is initiated separately: still image acquisition, object search and motion execution.

Test of the final version of the visual robot control system showed that proposed solution results in all tokens being detected and placed in a designated spot in the workspace. Consecutive tests resulted in the same outcome, but each time it required reloading of the pattern to be found and repetition of above three steps.

Robotic stand with tokens to take

Summary

This work describes the problem of integration of robot manipulator and digital camera to create a functional workstation, easily implementable in industry. The resources used for that purpose – KUKA KR3 robot manipulator and NI 1742 Smart Camera are all off-the-shelf components, hence minimise the costs connected with that solution. Additionally, the software presented makes development possible of vision algorithms in-house with the following advantages:

- autonomous robot operation,
- possibility of integration with other LabVIEW compatible devices,
- fast diagnostics and problem removal thanks to embedded error handling,
- simple system use due to configurators and creators.

The system was developed and installed in the Institute of Automatic Control, Faculty of Automatic Control, Electronics and Computer Science of the Silesian University of Technology.