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Central European Researchers Journal

CERES

A WORD OF WELCOME FROM THE EDITORS

Dear Colleagues, Readers and Authors,

The fifth number of the "Central European Researchers Journal (CERES)" is published. This journal has been formed under project Tempus CERES -Centers of Excellence for young RESearchers (544137-TEMPUS-1-2013-1-SK-TEMPUS-JPHES). The project finishes this year. The project members are glad to represent own experience and result in organization and support of investigations of yang researchers that are considered in papers:

- P. Kachurka, S. Parfamuk, V. Kachurka, "Center of Excellence for Young Researchers of Brest State Technical University",
- S.Subbotin, "Work with Young Researchers: Experience of Zaporizhzhya National Technical University".

We hope these publications will allow us to show the main content, subjects and relevance of the project, and to involve new members in the CERES community, as authors and readers of the journal CERES.

Three paper of this number are prepared by young researches from universities involved in the projects:

- R. Luža, F. Orság, M. Drahanský, J. Rozman, "Robot RUDA - Introduction and Current Research",
- K. Kovalčíková, M. Slavík, Verification of Steady State in Blood Flow Experiments,
- M. Ondrušová, "Sensitivity of Red Blood Cell Dynamics in a Shear Flow",
- P. Rusnák, "Transformation of Boolean Expression into Disjunctive or Conjunctive Normal Form".

These publications can illustrate the project successful and excellent potential of our young colleagues.

And we glad to offer you two papers of authors that are not involved in the project, because we are hope to increase of the CERES journal authors and readers. The topics of this number cover different areas and problems in engineering and in information technology in particular. Besides the thematic criterion, all accepted papers can be divided into three groups: regular papers, student's papers and methodological papers. The significant investigations are presented and discussed in the regular papers:

- A. Priyadharisini et al, "Image Fusion for CT AND MRI Scan Images using DWT",
- A.V. Khyzhniak, O.V. Tomchenko, A.Yu.Porushkevych, "Application of the Remote Sensing in Environmental Management as the Interdisciplinary Approach".

With best wishes

Prof. Vyacheslav Kharchenko
Prof. Elena Zaitseva

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Robot RUDA - Introduction and Current Research

Luža R., Orság F., Drahanský M., Rozman J.

***Abstract*—**This paper aims at a robot RUDA designed for detection of survivors in debris and avalanches. After a brief introduction of the robot itself there is the current research of the robot localization in a large outdoor environment described. In the second part there are optional sensor modules described. Available modules mentioned in the paper are a manipulator, bioradar, avalanche transceiver and LIDAR/stereocamera module.

***Keywords*—**Rescue robot, Teleoperated, Bioradar, Thermocamera, Navigation

I. Introduction

Use of robots in search and rescue missions is more and more popular. The reason for this is quite simple - robots can enter dangerous areas inaccessible for people, operate tireless and, in many cases, more efficiently. As the robots get more sophisticated, they can handle more difficult tasks like remote or autonomous exploration of dangerous places. In case the robot was damaged, it would be possible to repair even if it was totally destroyed and, besides, it is better to loose a robot than a human.

In this paper there is a rescue robot RUDA presented with a focus on description of localization of the robot in large open areas with few obstacles and various sensors that the robot is able to carry. RUDA is being developed at our university as a multipurpose robot suitable for various tasks. Based on the task, it can be equipped by a specific module carrying a manipulator, bioradar, avalanche transceiver, camera system with a LIDAR/stereocamera combination and many more. RUDA has a protective painting so it can be easily decontaminated and thus it is suitable even for various army, firefighting, pyrotechnic or rescue operation.

Fig. 1 Photo of the RUDA robot.

RUDA is a middle sized tracked vehicle (fig. 1) designed to be able to maneuver both indoors and outdoors. Its track chassis can overcome some terrain obstacles, but is small enough to go through a common door, at the same time. The robot weighs about 150kg and its outside dimensions are approximately 98x140x70cm. Weight and size vary according to the installed additional modules.

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II. Localization of the robot in an indoor environment

Indoor localization is utilized when the robot operates inside buildings. It relies mostly on the flat ground and walls. If the building is significantly damaged and its walls and ground can not be recognized the robot needs to rely on stereocamera with worse precision.

While working with maps the robot controller is able to operate in two modes: SLAM mode and localization mode. SLAM mode enables robot to build a map of unknown environment and localize itself in this map. Localization mode is used when there is a map of the environment available (usually from the prior SLAM walk through) and the robot needs to localize itself in the map according to its sensor observations.

In mapping and localization tasks we intensively use particle filter based algorithms as they are non-parametric, rather universal and with a decent performance. For indoor SLAM mode we use an existing implementation of the Rao-Blackwellized particle filter SLAM available in ROS called Gmapping [1]. The SLAM process obtains data from the odometry, scans from plane laser scanner (LIDAR usually) and constructs the map according to these data.

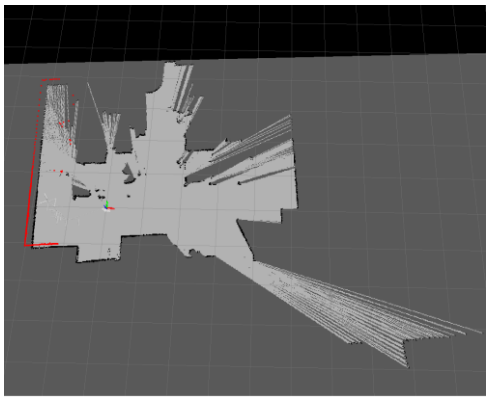

Fig. 2 Map generated by gmapping SLAM.

Localization in the given map uses an adaptive Monte Carlo localization algorithm [2]. The algorithm is based on a universal particle filter algorithm as described in [3]. Each particle represents particular pose of the robot. Enhancement of the universal particle filter algorithm is an adaptive change of amount of particles placed in the environment according to the density of the particles in the state space. We use an existing implementation from ROS called AMCL that uses the Augmented MCL and KLD-MCL algorithms [4].

III. Localization of the robot in a large outdoor environment

As a part of the navigation system of RUDA we are working on a solution of localization of the robot in a large outdoor environment. There is a reliable solution of localization based on a GNSS like GPS, GLONASS or GALILEO. Unfortunately, in some cases, this approach can't be used due to the missing or noisy signal from the satellites. In such cases we have to rely on the sensors of the robot itself.

For the areas with a high density of interesting objects (textures, 3D objects or artificial markers) we can use existing SLAM methods based on 3D LIDAR, stereocamera or some sensor sensitive to the markers. In case the robot operates in an environment with a flat terrain and a very few interesting objects common SLAM approaches fail due to the limited range of sensors. For this purpose we are developing solution of localization based on set of cameras, odometry information and a long-range laser rangefinder.

IV. Principle of the long-range localization

Our approach is based on a FastSLAM algorithm. The main difference is the way of obtaining of observations. In our solution the observation is obtained in two phases. In the first phase interesting objects are detected in the surroundings of the robot. In the second phase the rangefinder is used to obtain an observation in a particular direction. Object detection and obtaining of the observation are independent tasks that can be solved using several approaches.

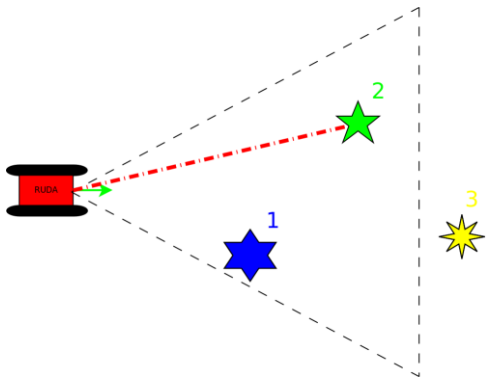

Fig. 3 **Principle of long-range localization.**

V. Considered environment for the localization

As mentioned before there are some assumptions about the environment in which the long-range localization works. It is designed for an environment with only a few of detectable objects. The objects have to be detectable by both camera and laser rangefinder. These requirements satisfy solid objects of a significant volume and texture distinguishable from the surroundings. In the environment there can be only a few objects. The localization approach could, in theory, work also in the environments with a high object density but its performance would be probably worse compared to the existing approaches like ICP library for 3D laser SLAM [5] or RDBG SLAM[6].

Fig. 4 **Example of environment considered for long-range localization.**

VI. Considered environment for the localization

A map for the outdoor localization can be represented in several ways. Considered ways for mostly flat terrain with only a few objects were an occupancy grid [3] and vector representation. The occupancy grid is a grid of cells. Each cell of the grid carries a value of probability that it is occupied by an obstacle. Free space has a small probability of being occupied and obstacles are covered by the cells with a high probability of occupancy. Advantage of the occupancy grid is that it represents the map in a simple deterministic way with constant time complexity of map updates. The occupancy grid with reasonable resolution is inconvenient for large areas due to the quadratic growth of the number of cells with radius of the area.

In a sparse environment the problem with memory used by the occupancy grid can be solved using compression methods. One of them is a tree compression [7] in case the map is represented by a tree of cells. Each level of the tree represents cells with a particular size. If the whole cell is empty or occupied it contains value of probability directly but if the cell is occupied partially it has a subtree of smaller cells describing the occupancy more in detail. This applies on the tree nodes up to given minimum cell size. The compression is visualized in Fig.5.

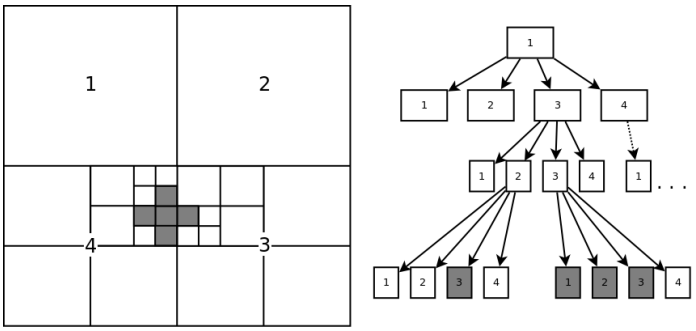

Fig. 5 **Tree compression of occupancy grid.**

Another drawback of the occupancy grid is that it has no implicit semantics of the objects it represents. Basically the occupancy grid has no information about relationship amongst occupied cells and object they represent. Since we need to connect an additional information with an object in the map we decided to use a vector approach of the map representation.
In our approach each object is represented by a Gaussian Mixture Model (GMM). This gives us two important advantages: we can compress the map data and we also have information about particular objects in the map so we can connect additional information to it. It is good to mention that this approach can be effective only for the sparse maps. Each object is described by a set of weighted multidimensional Gaussians (1).

An object in the map is represented by a particular GMM. This way the object can be addressed. Addressing of the object in the map allows us to connect additional information to it: informations for optical recognition of given object and also set of distance vectors obtained by the rangefinder. Set of prior observations of given object are used for the GMM adaptation when new observations of the given object appear.

When a new observation appears it is necessary to connect it with the particular object. If a match probability of given observation overcomes defined threshold it is connected with the object with the highest math probability. If the observation does not overcome the threshold a new object is created.

$$P(x) = \prod_i \omega_i \left(\frac{1}{\sqrt{|\Sigma_i| 2\pi}} e^{\frac{-1}{2}(x-\mu_i)' \Sigma (x-\mu_i)} \right) \quad (1)$$

For adapting of the Gaussian mixture models we use a Maximum Likelihood algorithm [8]. The idea of the ML algorithm is to maximize probability of the matching training vectors of the given class to the Gaussian mixture model.

Process of the map update is described in the detail by the algorithm 1. Input of the algorithm is a map *M* that is a set of GMMs - each of them describes one particular object, set of map object observation *MO* which contains sets of observations of each object in the map, a new observation ***o*** and a threshold *T* that defines minimum match probability for the observation belonging to the particular object.

Data: M_t ,**o**, M O_t , T
Result: M_{t+1}, M O_{t+1}

Pa = CameraMatch(M_t , **o**)
$C = \arg\max_{0<i\leq|Mt|} (\mathbf{Pa}_i\ M_t[i](\mathbf{o}))$
$Pp_C = Pa_C\ M_t[C](\mathbf{o})$
if $Pp_C \geq T$ **then**
  $MO_{t+1} = MO_t$
  $MO_{t+1}[C] = MO_t[C] \cup \mathbf{o}$
  $M_{t+1} = M_t$
  $M_{t+1}[C]$ = TrainGMM($MO_{t+1}[C]$)
else
  $O_{new} = \{\mathbf{o}\}$
  for (j = 0; j < M in Observations; j++) **do**
    $\mathbf{o_j}$ = GenerateObservation(**o**)
    $O_{new} = O_{new} \cup \{\mathbf{o_j}\}$
  end
  $MO_{t+1} = MO_t \cup \{O_{new}\}$
  $M_{t+1} = M_t \cup \{$TrainGMM(O_{new})$\}$
end

Algorithm 1: Map update

VII. Laser aiming

Another part of the problem is choice of the best objects for obtaining observation from the laser rangefinder. At the moment the n closest obstacles are chosen, but this approach has several pitfalls. Quality and usability of the observations is affected by distance to the object, properties of the surface of the given object and also by the position of the object and its relation to other objects. Improvement in the object selection is essential for the precision of the localization.

VIII. Sensor modules

The hull of the robot can carry various sensors as was mentioned in the Introduction. Currently, the modules include a Manipulator, Bioradar, Avalanche transceiver and LIDAR/stereocamera module.

Manipulator

Manipulator module adds a three degrees of freedom manipulator with a two-finger gripper. It can be mounted to the rear module socket on robot hull. The manipulator can carry up to 2kg of payload and it is equipped by an additional camera with thermovision. It helps the operator to recognize living people under debris in cases when the person is not visible by a normal camera. Operator of the robot can switch between the normal camera and thermocamera to see the scene in both modes.

Bioradar

Since RUDA has been designed for help with search of human beings in various situations, it has been set with sensors for such tasks. One of the most important sensor to achieve this is a bioradar. Bioradar is a device used for bioradiolocation [9], which is a method for remote detection of various biological objects by means of radar [10].

The idea of human body detection by radio waves is based on detection of modulation of continuous radio signal in time caused by typical movements of the human body and internal

organs [11]. Movement of the body can be caused by conscious movements (mainly movements of extremities) or unconscious movements (movements of organs). From the human body detection point of view, we aim at subconscious movements because, most likely, the affected person is unconscious.

Organs causing detectable movements are heart and lungs. These organs generate periodic subconscious (automatic) movements of different frequency and amplitude. Heart beating (cardiac movements) causes motion with an amplitude measured in millimeters at frequency ranging from 0.7 Hz to 2.5 Hz [12]. Breathing (respiratory movements), on the other hand, causes motion with the amplitude 3 orders of magnitude greater than those of heart beats at frequency from 0.2 Hz to 0.7 Hz [12]. Hence, detection of breathing is the most viable option for RUDA as its amplitude is much greater than of the other subconscious movements.

Bioradars are usually used in situations where we need to detect persons behind obstacles. It has been successfully used in war missions, police operations or even on various disaster sites. There are various ready-to-use devices available on the market, but none of them was usable for our robot. To be able to use this technology we cooperated with a Czech company RETIA who helped us to modify their ReTWis [13] radar to fulfill our expectations and needs. The radar is originally designed to detect movement of people, but it is able to measure even the micro-movements such as breathing. One of the most important aspect of the successful measurement is frequency and positioning of the antenna [14], placement of which we remotely control by 2 DOF manipulator. Precise alignment with the obstacle is achieved by feedback from infrared distance meters and tactile sensors. The final version of the modified device mounted on RUDA is in action in the Figure 6.

Fig. 6 **Photo of bioradar sensor mounted on robot in action.**

Whereas the bioradar is well known technology for living person detection behind obstacles, we were thinking about different approaches to detection of dead people, too. People who might be dead do not provide movement to be detected by the bioradar. One of the possible solutions to detect them is use of georadar (GPR -- Grounding Penetrating Radar), which is a device using pulses of ultra-wide band of radio waves instead of continuous waves (as in the case of bioradar). There is a wide range of frequencies used in georadars each of them penetrating various materials to different depths (e.g. 25 MHz pulses being used for geologic profiling are able to penetrate ground up to 57 m deep, 200 MHz waves go down to 28 m [15], whereas the modern systems operating at 1.6 GHz are being used for analysis of structural concrete, roadways or bridge decks and can penetrate the material up to 0.3 m [16], whereas in bioradars the typically frequencies are orders of GHz). The main advantage over the bioradar would be the possibility to search in higher depths and even for dead bodies, which would allow for more thorough survey of the disaster site. Use of such device originally designed for a geological

inspection in disaster site inspection scenario has not been tested, yet. We are working on experiments aiming at either confirmation or disapproval of this idea.

Avalanche transceiver

The avalanche transceiver module is a simple module based on a stock avalanche transceiver, which is able either to receive or send signal. The avalanche transceiver was extended by an additional communication interface that allows user to read state of the avalanche transceiver. The device is always switched to the receiver mode so it searches for a signal from other avalanche transceivers that implicitly broadcast radio signal. The transceiver estimates direction and distance of the broadcast signal from the transceiver. It allows the robot to navigate closer to the person under avalanche. Of course avalanche transceiver requires the person to wear other transceiver. This is a limiting factor but usually people, who go to an avalanche field, carry an avalanche transceiver.

LIDAR/stereocamera module

The LIDAR/stereocamera module is a module equipped with two cameras, which work in pair together as a stereocamera, and a LIDAR (plane laser rangefinder) made by SICK company. This module has a

driver connected to a HAL (Hardware Abstraction Layer) that uses robot main computer to compute disparity from the stereocamera images. The LIDAR has a driver that only change format of data for higher layers of control system. The LIDAR/stereocamera module can be installed on the front socket on robot hull - it can be installed on top of the bioradar module, too. During usage of the bioradar is this sensor covered by an antenna of the bioradar, which makes the data from cameras and LIDAR invalid. Fortunately, the robot is not allowed to place the antenna of the bioradar while it is moving so this is not limiting - RUDA has to home the bioradar manipulator, activate the LIDAR and stereocamera and then it can move according to the sensors again.

IX. Conclusion

At the moment RUDA is a working prototype. It can be used in real missions but there is still development going on. It has been tested in a testing polygon but not in any real missions, yet. The robot was also awarded by a gold medal on an International Engineering Fair (MSV2015) [17].

Currently the most effort is devoted to the localization system of the robot. It is essential for autonomous operation of the robot and it is also an important supportive system in the remote-controlled mode of operation. Next step will be a fusion of the localization approaches to provide reasonable localization information across various environments. With a robust localization the autonomous behavior of the robot can be significantly extended.

To conclude, RUDA has still space for improvements and further development but in its current state it is an interesting solution for rescue teams in various mission types. Potential of the robot will grow with improvements of the autonomous control and also with additional sensor and effector modules.

Acknowledgment

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Center of Excellence for Young Researchers of Brest State Technical University

Pavel A. Kachurka, Siarhei I. Parfamuk, Volha A. Kachurka

***Abstract*—**The student research work in the Brest state technical university is described. To improve conditions for research work the Centre of excellence for young researchers of the Brest state technical university in the format of a virtual informational resource in the form of a website was created. The website provides information about the research work of undergraduate and graduate students; announcements and reports on scientific activities; project activities, ensuring the dissemination, sustainability and synergies of projects; useful experience and success-stories of young researchers.

***Keywords*—**research, young scientists, support, university.

I. Introduction

At the beginning of 2017 over 8100 students of first and second stages of higher education study at the Brest State Technical University. Each year 30% of full-time students are involved in research work. The main areas of student research are: participation in national and international scientific and practical conferences, publications, the presentation at the exhibitions, participation in student scientific associations.

Since 2009 the Council of Young Researchers operates in university. Its goals include the support and development of scientific-research works of young researchers as one of the most important factors in the preparation of highly qualified specialists and capable of a high theoretical and practical level to independently solve complex scientific problems.

Young researchers often work at a narrow scientific field and do not know tons about the achievements of their colleagues from other faculties and universities. Therefore, the university became necessary to create a contact platform for young researchers. The Center of excellence for young researchers of the Brest State Technical University was established to solve this problem.

II. Student Scientific Research

The main objectives and directions of student research in the Brest state technical university are:

- multidisciplinary training of specialists (engineers, masters, postgraduates and PhDs);
- ensuring a high level of basic and applied knowledge gained by young researchers in the process of scientific works;
- ensuring the participation of young researchers in research and applications, carried out on the basis of state budgetary and contractual works and directed to address specific scientific, technical, socio-economic problems of Brest region and the Republic of Belarus;
- the search for new forms of participation and training of scientific work;
- the development of students' scientific associations, design and technology, research circles, student research laboratories, art studios;

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- ensuring the active participation of students in scientific events;
- promotion of scientific and technical creativity of youth, exchange and dissemination of the university best practices and effective forms of student research development;
- enhancing creativity and efficiency to the students by involving them in research activities;
- promote the implementation and use in the national economy of science and technology advances.

Subjects of research of young researchers are determined within themes of contractual and state budgetary research conducted at the university on the instructions of the National Academy of Sciences of Belarus, ministries, departments, institutions and enterprises, as well as the themes, chosen by the developers.

The main forms of attracting students to the research are:

- research work as part of Student Research Societies, including thematic scientific circles, educational, scientific and industrial complexes, the architectural studio, etc.;
- individual work with talented youth, participation in conferences, exhibitions, contests, competitions, inventive activity of the university, preparation of reports and articles. In particular, in the framework of the annual Student University Conference "Science Week";
- educational and research work, which includes the study of special courses, elective courses, individual lessons on the basics of scientific research (for example, "Fundamentals of research and innovation", "Basics of research, invention and innovation in mechanical engineering");
- conducting of personal and collective creative exhibitions on architecture, design, painting, drawing, participation in international and republican competitions of the best graduation projects on architecture and design (Kazan, Saratov, Samara, Minsk);
- perform tasks on the state of scientific and technical programs, grants, and contracts with the organizations; work as part of the university research groups, created for design and engineering work on the contract;
- implementation of research in the framework of international cooperation with higher educational institutions of the Russian Federation, Ukraine, the Republic of Poland and the Federal Republic of Germany;
- training and internship abroad, training in leading foreign universities. For example, in the department of architectural design and drawing in Poland (Poznan Academy of Arts, Bialystok University of Technology), in Germany (Biberach). Internship students in the framework of the quadripartite cooperation between the University of Lodz University of Technology; study abroad as part of the student exchange program Erasmus Mundus.

The University maintained comprehensive plans for the organization of student research on faculties and specialties for all students studying at the university. A great contribution to the organization and activation of student research make scientific schools of the University, including:

- "Development of high-performance structural foundations", scientific supervisor Prof. Poita P.S.;
- "Neural information processing technology", scientific supervisor Prof. Golovko V.A.;
- "The structural system of prestressed and reinforced concrete (materials, technology, design, safety issues)," scientific adviser Prof. Tur V.V.;
- "Brest hydrological school," scientific supervisor Prof. Volchak A.A.;
- "Non-stationary modes of thermal processes (pulsating combustion)" Pulsar "," scientific supervisor Prof. Severyanin V.S.;
- "Development of new designs and methods of calculation span structural coatings for

civil and industrial construction", scientific supervisor Prof. Dragan V.I.

Student research laboratories are actively working in the university. For example, a student's scientific and architectural workshop "Module", including the section of the Belarusian Association of Architecture Students, "Builder", "Mechanic", "Auto", "ECOM", etc.

Students' Scientific Association "ECOM" was created on the initiative of the Department of Accounting, Analysis and Audit of the Brest state technical university. In 2009 "ECOM" has got financial support of the Special Fund of the President of the Republic of Belarus for the Social Support of Gifted Students "Have won public recognition promising developments" in the amount of 21 million BYR.

"ECOM" is the organizer of the annual International Student Research Forum for the regional universities' "Student Scientific winter in Brest", which participants are student teams from Russia, Ukraine, Kazakhstan and Belarus.

Student research laboratory "Robotics" was created on the initiative of the Department of intelligent information technologies of The Brest state technical university. "Robotics" has got the support from Special Presidential Fund for the Support of Talented Youth in 2012 and 2016 for development activities of 119 million BYR.

Since 2012 student research laboratory "Robotics" is the organizer of the conference of young Researchers and students "Robotics and artificial intelligence. Problems and Prospects".

"Robotics" in 2014 won in the Republican contest of professional skills' first championship WorldSkills Belarus - 2014 in the field "Mobile Robotics", which gave the right The Brest state technical university team to represent our country at the World Championship of working WorldSkills professions, which was held in August 2015 Sao Paulo (Brazil).

Also, the university young researchers conducting research within 4 problem laboratories, 7 student scientific sessions, mugs for preparing students for the International Olympiad in Theoretical Mechanics at the discretion of the Contest tasks on programming, mathematical circle, and others.

III. Centers of Excellence for young Researchers

To improve conditions for scientific-research work of young researchers of the university through aggregation of information from open sources and from direct participants in research and international activities of the University, in the framework of the TEMPUS project 544137-TEMPUS-1-2013-1-SK-TEMPUS-JPHES "Centers of Excellence for young RESearchers (CERES) the Centre of excellence for young researchers of the Brest state technical university (the Centre) was created.

The operation of the Centre is in the format of a virtual informational resource in the form of a website, on which the aggregation of information from the Council of young researchers of the Brest state technical university, from public sources, and from direct participants in research and international activities of the university.

The Centre solves the following tasks:

- formation of positive image of the young scientist and involvement in the research activity of students and undergraduates;
- information support of research and education of undergraduates and postgraduates, including the publication of results of their activities and the facilitation of cooperation with enterprises;
- the stimulation of the academic mobility and participation in international research projects and scholarship programs;
- ensuring the sustainability and dissemination of results of international projects of the University, aimed at young researchers, including the synergy of their results;
- integration of information resources and services of other universities, is intended for

young researchers;
- create a contact platform for young researchers of the university;
- information and contact to support the operation of the Council of young researchers of the Brest state technical university.

The subjects of the Center activities are:
- monitoring and analysis of activities of young researchers of the Brest state technical university;
- the establishment of information exchange among young researchers and specialists of the Brest state technical university: the dissemination and exchange of information on print and electronic sources of professional information about grants, funds, programs of support of young researchers and specialists, conferences, schools, scientific seminars, etc.;
- facilitate the organization of conferences and other scientific events for young researchers of the Brest state technical university;
- integration of information resources and services of other universities, is intended for young researchers;
- create a contact platform for young researchers of the university.

Website development and operational management, interaction with the structural units of the Brest state technical university for information and accommodation provided by the working group of the international technical assistance project "CERES".

In the process of development of the virtual Centre were the main blocks of the site content (see table 1).

To ensure sustainability and relevance of the information provided on the website were analyzed information and control communication on the basis of which formed a working group whose members are responsible for different directions in the work of the Centre (see figure 1).

TABLE 1
THE CONTENT OF THE WEBSITE

Information	Section of the website	Sources
1 Announcements and reports about activities of the Council of young researchers of the Brest state technical University	Science and education	The Council of young researchers of the Brest state technical University
2 Reports (information, photos) about the activities within the framework of international projects of the University, as well as announcements of key ones	Mobility, international cooperation	Web sites of projects, project coordinator, International Department
3 Reports (information, photos) about foreign training of students, undergraduates, graduate	Mobility, education, scholarships, international cooperation	Participants of the internships, International Department
4 Data available for students, undergraduates, postgraduates scholarship programs and grants	Mobility, education, science	The Council of young researchers of the Brest state technical University, web sites, International Department
5 Announcements and calendar of scientific events, conferences, forums	Science, publications	The Council of young researchers of the Brest state technical University, web sites, Research Department
6 Announcement of competitions of scientific works, scholarship, etc., as well as reports of their results	Science, scholarships, international cooperation	Research Department, Postgraduate students Department
7 Data about graduate students' topics, publication activity, participation in conferences, etc.	Science, publications	Research Department, Postgraduate students Department
8 Helpful resources and links for undergraduate and graduate (programs, registration materials, etc.)	Science, education	Web sites, Research Department
9 References and sections related to CERES-portal	International cooperation	The Internet portal of the TEMPUS CERES project

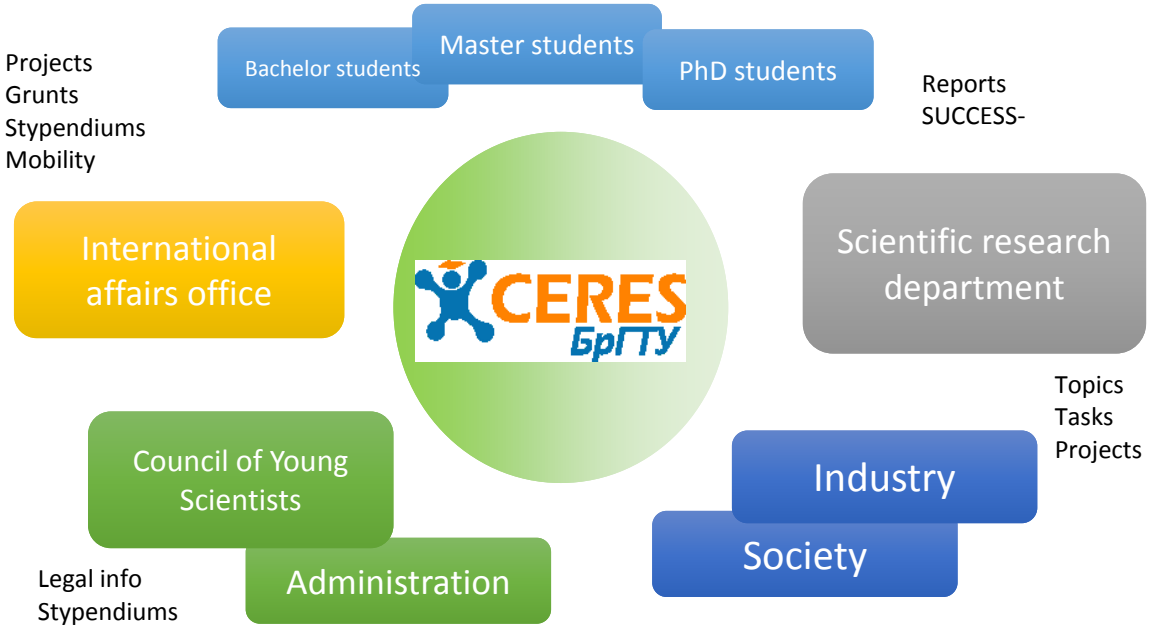

Fig 1 – Direction of obtaining and presenting information Centre

At this stage in the work of the Centre involves technical specialists (programmer, system administrator), editors, representatives of the Scientific Research Department and the International Department of the University, Council of young researchers. The Centre is supported by the university administration (the work is conducted under the leadership of Vice-rector for scientific work), as well as the deans and the Department of graduate studies (being a liaison with students and graduate students respectively).

IV. Conclusion

Created in the Brest state technical university a virtual "Centre of excellence for young researchers of the Brest state technical university" is the Internet site http://ceres.bstu.by in line with modern trends and standards as in design and technical implementation, and the extensibility and functionality.

At this stage, the website also provides information about the research work of undergraduate and graduate students; announcements and reports on scientific activities; project activities, ensuring the dissemination, sustainability and synergies of projects; useful experience and success-stories of young researchers.

The Centre's work is positively received by the audience of the IX Republican scientific conference of young researchers and students "Modern problems of mathematics and computer engineering", which was presented to the plenary a report on the Center.

Long-term tasks in the development of the Center are:

- joining the CERES network: interaction Centers in the partner universities of the project CERES;
- CERES-portal: the occurrence of the website in the single portal project for involving industrial partners and universities outside the project consortium;
- maintaining a database of young researchers, projects, tasks, not only within the University;
- the entry point for young researchers: placing and updating arrays useful information for young researchers – how to study in graduate school, how to make a thesis where to submit jobs, how to choose a theme, who will be the head, etc.

Work with Young Researchers: Experience of Zaporizhzhya National Technical University

Sergey Subbotin

***Abstract*—**The systematic presentation of the main methodological principles, as well as developments of ZNTU in the organization of work with young researchers are considered. Analysis of the needs of young researchers allows us to highlight the key problems of young researchers: the lack of moral motivation to participate in scientific work, the lack of knowledge of research methods, the problem of choosing supervisor, research topic and industrial partner, the difficulty in finding financial support for research.

***Keywords*—**Young researcher, talented youth, research work, students, Zaporizhzhya National Technical University.

I. INTRODUCTION

Zaporizhzhya National Technical University (ZNTU) is the largest and oldest scientific and educational center in the Zaporizhzhya region, Ukraine.

The university has more than 800 scientific-pedagogical workers, including 50 habilitated D.Sc. and 400 Ph.D. The ZNTU provides training of 11000 students at university and it's colleges, 80 post-graduate students, and 7 post-docs. The number of young researchers is 260, including 73 Ph.D. [1]

Annually ZNTU performed 30 scientific projects with total financing over 3,5 million UAH. University publishes 24 textbooks, 10 monographs, 4 scientific journals, and over 2300 scientific articles and 30 patents and copyright certificates each year. University specialists participate every year in 400 conferences and seminars, where published more than 1,000 reports [1].

A significant number of young researchers necessitate organization work with them in ZNTU on a permanent basis. Working with young researchers conducted at the level of teacher, department, and university. The Research Sector and the Council of young scientists and specialists (CYSS) of ZNTU play a special role in the coordination of this work.

The purpose of this article is a systematic presentation of the main methodological principles, as well as developments of ZNTU in the organization of work with young researchers.

II. General Methodological Principles Of Work With Young Researchers

As the main purpose of education is to create conditions for personal development and creative fulfillment the nurturing and development of creative abilities of students is one of the important tasks of higher education.

Talented students and young researchers are characterized by high development thinking, by lasting remembering of educational material, by developed self-control skills in training activities, and by high operability. They have high mental activity, increased susceptibility to mental activity, eccentricity, freedom of self-expression, richness of imagination, formation of different types of memory, reaction time, and the ability to question scientific understanding of certain phenomena, stereotypes and dogmas [2].

The university has to identify the level of development of talented students and their potential to help young people to understand themselves, to create conditions for the mobilization of personal resources (psychological mobilization), and to help develop themselves. For this it is important to develop the creative potential of students, educate students interest in knowledge,

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independence in learning, to expand horizons, to form persistence in achieving this goal, to teach them to think critically, to quickly navigate in difficult professional situations and find the right solution.

To realize this the University actively use such forms of work as scientific groups, conferences, seminars, trainings, intellectual competitions, contests and olympiads in which young researchers gain new knowledge and experience, create new research and engineering and projects, cooperate other and with supervisors, learn to write scientific articles and to make public presentations.

One of the most important tasks of training young researchers is to develop their interest in science and research. To do this it is needed to form such student focus on learning activities, which is based on the intellectual and cognitive motivation, creative thinking, the manifestation of willpower, commitment to long-term hard work associated with the independent actions in addressing the goal.

The presence of internal and external reasons of students to intellectual activity is an essential factor for effective research. Internal motivation for research activity can be the satisfaction obtained from the process of finding a solution to the problem of self-selection of topics and methods of solving problems. External motivation can be a variety of incentives: material rewards, scholarships, successful presentation at the conference, the publication of articles, preparation of recommendations for further study in graduate or postgraduate, high evaluation of the results of research [2].

In the development of student research work skills the teacher plays an important role. It consists in the organization and provision of guidance, in the direction of search and research activities of student, providing the ability to effectively overcome the difficulties, the intellectual stimulation of initiative and creativity.

Intelligent self-development contributes to the gradual transition from a joint action with the teacher informative for independence from the unconscious to the conscious and targeted actions. A necessary condition for self-development is the establishment of links between the needs, motives and objectives of the search operation, the complication of the operating aspects of the activity, the allocation of the generalized methods of action, sequence of operations, development of skills of self-regulation on the basis of intellectual reflection [3].

III. Research Work With Students

Scientific research and innovative work of students is an important area of training of future scientists and high qualified specialists and is an inseparable part of the joined process: the educational and scientific-innovative. The research work of students stimulate their intellectual activity, promotes creativity, which consists not only in the ability to generate original ideas in a setting of new challenges, but also be aware of the gaps and contradictions, to abandon the stereotypical ways of thinking [1].

A distinctive feature of the researcher is the desire to understand and explain the phenomenon, identify the laws and patterns that lie at its core. The research work of students meant a special kind of self-learning activities, aimed at solving specific problems related to the lack of existing knowledge and skills, built on the actualization of the individual mental experience of every student, strengthening individual intellectual resources, encouraging self-organized learning activities [3].

In the direction of involvement of students to scientific work in ZNTU the departments and laboratory of pre-doctoral training and working with the talented young people actively and fruitfully cooperate.

Student research activities include competitions in disciplines and specialties. Olympiades provide an opportunity to identify the level of training and give impetus to creative development. Students under the guidance of teachers participate in international, national and regional Olympiads, competitions of scientific works and developments. Participation of students in

student contests of scientific works and scientific conferences it is one of the most pressing forms of involvement of students in research and the ability to find talented young people in research and disclosure of creative potential of university youth.

Recently, ZNTU students received prizes in International open olympiad on programming "KPI-open", International language and literary competition behalf of Taras Shevchenko, International Ukrainian Language Competition behalf of Petro Yatsyk, Ukrainian Student Olympiad on programming ACM, Ukrainian student Olympiads by specialties "Analogue Electronic Devices," "Safety", "Engineering Mechanics", "The Technology and Equipment of Welding", "Electrotechnical Systems", "Foundry of Ferrous and Nonferrous Metals", "Management of Organizations", "Organization of Road Traffc", "Transportation Systems", "Radio electronic Devices", "History of Ukraine", "Computer Science", "Design", Ukrainian competition of student scientific works in the following directions: "Economics of Transport", "Welding", "Electrical Engineering", "Motors", "Marketing", "Metallurgy" [1, 4].

Each year the university held a competition for the best student scientific work in 10 categories. The works, whose authors will be winners of university contest, will be sent to All-Ukrainian competition of student papers.

Competitions LikelT "The future of IT people" held for young IT professionals and programmers in the form of programming marathon (hackathon). Competitions are held in the categories: desktop and web. Continuing to 24 hours of non-stop, in a competitive environment, with minimal time to rest, participants create their own projects. At the end of the marathon team will present its findings and jury evaluates the relevance of ideas, creative approach to problem solving and skills of participants [1].

European BEST Engineering Competition (EBEC) held jointly with ZNTU BEST (Board of European Students of Technology) students of technical universities in Europe [5].

Engineering competition is a project that includes the task of designing and modeling, analytical case studies, debates and negotiations; is an opportunity for students to express themselves and realize their wildest design ideas, share thoughts and ideas, to communicate with partner companies.

The aim of the competition is to promote engineering in Ukraine by creating favorable conditions for its emergence and development. It creates conditions for competition of ideas of participants in the race because it is born and effective creative problem solving. In addition, competition within the engineering students of technical universities the opportunity to develop and realize their ideas through collaboration with companies and communication with the European educational community. Providing contact students, universities and partner companies competition, we create a unique platform for communication, and our project - a new wave of engineering in Ukraine.

Competitions are held in several stages: the local stage at one university level, the national stage at the country level or regional stage among neighboring countries. The winners of the local stages are involved in the national / regional stages, the winners of national / regional stages enter the final stage of European engineering competition. The goal of each stage is to create, to design innovative, creative solution, struggling with a lot of restrictions. The competition involved teams of 4 people.

The categories of competition:

– Team Design is a solving specific technical task by team for a limited period of time. The result of the competition is the availability of a device that performs the functions necessary to solve the problem. A company that provides tasks for this category can cover various areas of engineering disciplines: electrical engineering, electronics, mechanics, hydraulics, radio and so on. Usually the process of solving and presenting the results are quite dynamic and spectacular for its coverage of representatives of the media;

– Case Study is a solving the analytical problems, a detailed study of a particular object, problems, a process that has a clear temporal and spatial boundaries. Typically, as the issue of

administrative or technical field. The company provided all information needed to solve this problem, the problem may be specific nature concerning the problems and development company. The results of research presented by a team as computer presentation. This type of collaboration allows the company, simplifying the selection procedure, to communicate with the best three students of Ukrainian universities.

The development of task involved a group of organizers. In some cases together with providing task. Other organizers do not know the tasks. Organizers do not affect on decision-making results. The only exceptions are those who are members of the jury.

The jury may include as representatives of partner events that provide a specific task, and organizers involved in development tasks, guest lecturers. Decisions are evaluated on criteria such as compliance of solutions (model) to task requirements; creativity and aesthetic performance, teamwork of participants.

IV. Council Of Young Scientists And Specialists Of ZNTU

Council of young scientists and specialists of ZNTU (CYSS) is a voluntary, self-governing public body under the administration ZNTU and has a functional and advisory character [6].

CYSS created to bring together young scientists of Zaporizhzhya National Technical University, expressing their interest in the professional sphere, promoting the solution of scientific problems and protect the social interests. CYSS created on the initiative of young scientists of ZNTU and operates in ZNTU.

As young scientists of ZNTU are considered the Dr.Sc., Ph.D, doctoral and Ph.D students, post-graduate and master students, scientific-pedagogical staff and specialists of ZNTU that up to 35 years old (PhDs and Dr. Sc. students – up to 40 years) who are engaged in research and educational work.

The work of CYSS based on the current legislation of Ukraine, ZNTU Charter and the principles of voluntariness, equality and self-government. The CYSS activities coordinated by administration of ZNTU through vice-rector for scientific work. Head of CYSS of ZNTU is a member of the Academic Council and the Scientific and Technical Council (STC) of ZNTU. The members of the CYSS Presidium included into the councils of institutes and departments, at least one representative in each institute and faculty. The highest collegial body of the CYSS of ZNTU is the general meeting. The executive body of the CYSS of ZNTU is the Presidium of the CYSS.

CYSS operates in the following areas [7].

1) Organizational work: questionning of young researchers and specialists, bringing them to the membership and work of the board, election of the Presidium and the Head of CYSS, the meetings of the Presidium of CYSS, involving members of CYSS to work in the ZNTU Conference of Staff, the Academic Council and the Scientific-Technical Council of ZNTU, department and faculty councils, reporting on the CYSS activities on the ZNTU Academic Council meetings, assembly, installation and maintenance of contacts with the councils of young scientists from other universities, regional councils of young scientists, the Ukrainian Council of Young Scientists and specialists of the Ministry of Education and Science of Ukraine, promoting the consolidation of young professionals in the ZNTU staff.

2) Information support of young researchers: the formation of an electronic database of CYSS members, informing CYSS members via email about conferences, seminars, scientific schools, as well as about competitions for grants with the support of Patent information department and Sector for talented youth of Scientific-research division of ZNTU, support of CYSS web page on ZNTU server, the publication of information on the structure, composition and activity of CYSS and information on grants and conferences, promotional descriptions of ZNTU development of young researchers.

3) Scientific work: holding campaign work among students for their involvement to the scientific work and to the subsequent graduate and postgraduate programs, facilitate the

preparation of dissertations by post-graduate students (providing them with the necessary scientific, methodological and organizational assistance, including organizing and conducting individual consultations and group seminars for post-graduates on the writing, formatting and defense of theses, measures to improve the effectiveness of post-graduate school, including the organization of public control of post-graduate students), support in the university for the conferences and seminars, attract young researchers to work in the organizing committees, promote the publication of works of young researchers in scientific journals and proceedings, involvement CYSS members with scientific degrees to the editorial boards of scientific publications of ZNTU, promote competitions of scientific works and subject Olympiads among young researchers, supporting young researchers to participate in contests and competitions, involvement CYSS members to the organizing committees and competitive commissions of subject Olympiads and contests in ZNTU, the public discussion and recommendations of young researchers to participate in competitions for grants, scholarships, and prizes, admission to Doctoral and Master studies, help young researchers in protecting innovation (consulting in writing and registration of patent applications), facilitation of the participation of young researchers in state budgetary and contractual research projects, assistance in organizing and conducting new scientific research, promotion in increasing access of young researchers to research resources, including scientific electronic libraries, supporting of young researchers for training in leading scientific and educational institutions of Ukraine and other countries, as well as participation in conferences and seminars.

V. Study and Analysis Of The Problems Of Young Researchers

To effectively plan activities on work with young researchers in ZNTU the questioning of young researchers [8] is regularly realized. Survey results are processed and analyzed by CYSS and scientific-research division of ZNTU. Results of the analysis are presented at the scientific-technical council and reported to the vice-rector for scientific work of ZNTU.

In the framework of analysis of the young researchers responses in recent years we select the following problems of young researchers:

– moral motivation to participate in scientific work;

– lack of knowledge and techniques of research principles and standards of scientific publications;

– the problem of choosing of supervisor and of research topic;

– difficulty in finding contact with industry, research detachment from practice;

– low level of foreign language skills of students and graduate students;

– the lack of effective medium for communication and joint implementation of research by young researchers of different universities;

– lack of financial support scientific work of young researchers;

– access to paid young researchers scientific digital libraries and databases of foreign scientific literature;

– low number of foreign publications of universities. Zaporizhzhya;

– payment of foreign publications in scientific journals and participation in conferences.

It is interesting to note that these results are consistent with the results of [3], which states that during the process of research, students face such difficulties: the inability to see the problem, the complexity of the formulation of goals, objectives, study difficulties drawing up a plan of work, allocation of time, the complexity of the information (search, inability to allocate the main thing in selected materials), inability to evaluate the results, the uncertainty and the fear of performance.

To ensure the sustainability and efficiency of research work of young researchers it is proposed to perform such activities.

1. Organization of annual citywide competition of scientific works of students and graduate students of higher educational institutions funded by the Zaporizhzhya City Council with

considerable financial incentives of participants. Promoting competition results in media owned by the City Council.

2. Implementation of grants to talented undergraduate and graduate students on research with financial support of Zaporizhzhya City Council by organizing the annual competition.

3. Conduct engineering competitions (as a means of popularizing science and technical creativity among students in Zaporizhzhya).

4. Development of program project for funding by Zaporizhzhya City Council of students participation in international conferences, payment for publishing articles in international scientific journals.

5. Professional orientation work among school students and college students on choosing a profession. Support of mass media owned by the City Council to popularize university representatives and specialties.

6. Develop an Internet portal for organizing joint execution of research by young researchers from different universities with the support of the international project "Centers of excellence for young researchers" (CERES), funded by the Tempus programme of the European Commission. Providing organizational and informational support for the project from Zaporizhzhya City Council.

7. Continue the practice of setting annual scholarships of mayor of Zaporizhzhya. Increasing the number of scholarships and their scope. Organization of open competition for these scholarships with the participation of students and young researchers.

8. Hold a contest-exhibition of research works of students (for various sections) under the auspices of Zaporizhzhya City Council with the display of the results in the media (television, newspapers, Internet sites) and with participation of businesses, university and college students, and school children.

Formation of research abilities and skills, mastering the methods of scientific work, along with the training and research work of students is carried out by including them in active extracurricular research work in student scientific circles, in the preparation and defense of research work at student conferences, competitions. The effectiveness of this type of work is the possibility of an individualization of training and the construction of individual trajectory of development taking into account the experience of the mental and cognitive stimulation, involving him in different kinds of intellectually-search activity [3].

VI. Conclusion

The article gives a systematic presentation of the main methodological principles, as well as developments of ZNTU in the organization of work with young researchers.

For the training of young researchers should be used such forms of work as scientific groups, conferences, seminars, trainings, intellectual competitions, contests and olympiads in which young researchers gain new knowledge and experience, create new research and engineering projects and cooperate with each other and with supervisors, learn to write scientific articles and public appearances. It is also important to pay attention to motivating young researchers to give them methodical support.

Research and innovative work of students is an important area of training of future scientists. Between the measures of student research work an important place taken by competitions in disciplines and specialties. Olympiads provide an opportunity to identify the level of training and give impetus to creative development. Also the competitions for the best student scientific work plays an important role in this field.

The Council of young scientists and specialists is a form of self-organization of young scientists and allow them to jointly identify and solve existing problems, and to engage in dialogue with the administration of the university.

Analysis of the needs of young researchers allows us to highlight the key problems of young

researchers: the lack of moral motivation to participate in scientific work, the lack of knowledge of research methods, the problem of choosing supervisor, research topic and industrial partner, the difficulty in finding financial support for research.

To ensure the sustainability and efficiency of research work of young researchers we propose to organize competitions and to provide development grants for young researchers, to conduct trainings and conferences for young researchers, to develop an Internet portal for organizing joint execution of research by young researchers from different universities.

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Verification of Steady State in Blood Flow Experiments

Kristína Kovalčíková [1], Martin Slavík [1,2]

***Abstract*—** This work shows a method of examination of the numerical onset of a computer simulation, modeling an experiment with flowing red blood cells in a microfluidic device. The initial onset could have a perturbing impact to the numeric simulation, and so its length is to be determined. A method is based on comparison of the statistical distribution of cell speeds and rotations during simulations, using Kolmogorov – Smirnov test. The speed data show that a behavior of cells gets more stabilized during the simulation. Even though data about rotation do not confirm this finding, a more precise rotation characteristic is suggested.

***Keywords*—**blood flow, steady state, statistical characteristics.

I. Introduction

Recently, specialized microfluidic devices have been developed for sorting, capturing or detecting specific blood cells from blood samples [1], [2]. Design and manufacture of such devices is very time consuming and expansive [3]. Therefore, it is better to use computer simulations for their optimization, where different experimental setup can be relatively easily changed [4], [5]. Such simulation model was developed by Cell-in-fluid research group [6], [7]. The model consists of two main parts: fluid and elastic objects. A fluid is modelled by Lattice-Boltzmann method and can represent plasma or other liquid solution. Objects represent blood cells and their models are based on discretization of their surfaces. An interaction between these two parts is secured by immersed boundary method. The model and its implementation in open source software ESPResSO is in details described in [8].

To evaluate the precision of the software, and so to compare the results of numerical simulations with results of laboratory experiments, we are developing a statistical tool which could be used for such a comparison. This tool does not compare the cells one by one, but it uses a statistical approach to consider a complexity of a multi cellular system [9].

Several aspects of the cell movement are considered: Their position in the microfluidic device, their skew, their speed and their rotation. The statistical tool helps us to process the property of each cell and to determine generalized properties per simulation. The comparison between the two types of experiments (numerical or laboratory one) is done afterward by comparing that generalized information about the ensemble of the cells.

However, the comparison between the numerical and laboratory experiment should be done by comparing a steady state of the cell behavior within the both devices. The initial irregularities in the laboratory experiment can influence the movement of the cells in a manner which is not repeatable in the numerical experiment, and vice-versa. This work is focused on the examination of the numerical onset of the computer simulation. This one influences the course of the simulation at its beginning, however the length of the impacted part of the simulation is to be determined.

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II. Methodology

There are several ways how to determine the effective length of the numerical onset. In [10], the Discrete Fourier Transformation (DFT) was used, although the approach considered only the rotation data from three specific cells. The aim of the article was to get an approximative idea about the influence of the numerical onset, which explain the limited usage of the tool. To get a more founded estimation of the length of the influenced part, this method using the DFT should be applied to the totality of the cells in the simulation, eventually with an extension to the velocity data.

In this article, a different approach is used, in order to take into account a totality of the cells in the simulation, using a simpler approach which do not require the using of the DFT. Instead of it, the evolution of the speeds and rotation magnitudes of the cells was tracked, to identify whether they get stabilized during the simulation. The rotation in this concept means angular speed of the cell in respect of the center of the cell.

A simplified approach was chosen to quantify the rotation magnitude of the cells – it consists only on the simple difference between the X-velocity of two points with extremal Y-coordinate (more details in [10]). This approach appears to generate very comparable courses of the cell rotation during the simulation as the rigorous method, which is however more data-demanding.

To identify the stabilization of the cell behavior, instantaneous speeds (and rotations) of each cell were recorded regularly during the simulation. Each measurement represents a set of 50 values. The values in such a measurement were than sorted in ascending order. The recording of the speeds and of the rotation magnitudes was executed every 5000 numerical steps, which correspond to 1 ms. In such a time, a cell makes a shift of approximately one length (~4μm).

Examples of recorded speeds and rotation magnitudes are shown in Fig. 1 and Fig. 2.

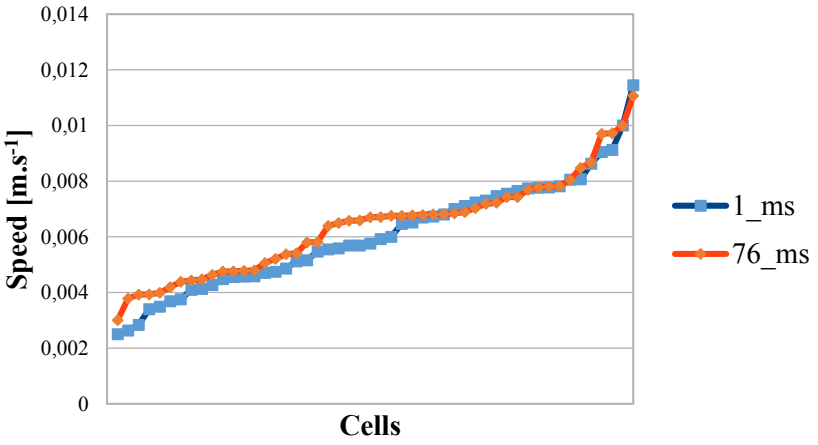

Fig. 1: Example of measured velocity magnitudes of all the cells after 1 ms of the simulation, and in the end of the simulation, after 76 ms. Values are sorted in ascending order.

The statistical distribution of those speeds (or rotations) in one moment is an object of comparison between the various moments of the simulation. This helps us to determine whether the distribution of the speeds (or rotations) get stabilized during the simulation.

The distribution of the speeds (and rotations) are compared using Kolmogorov-Smirnov (KS) test. It is a test which determines whether two compared samples come from the same

distribution, even if the distributions are not common or well-known in the statistics. The smaller is the result of the KS test comparing the samples, the bigger is the probability that the two samples came from the same distribution.

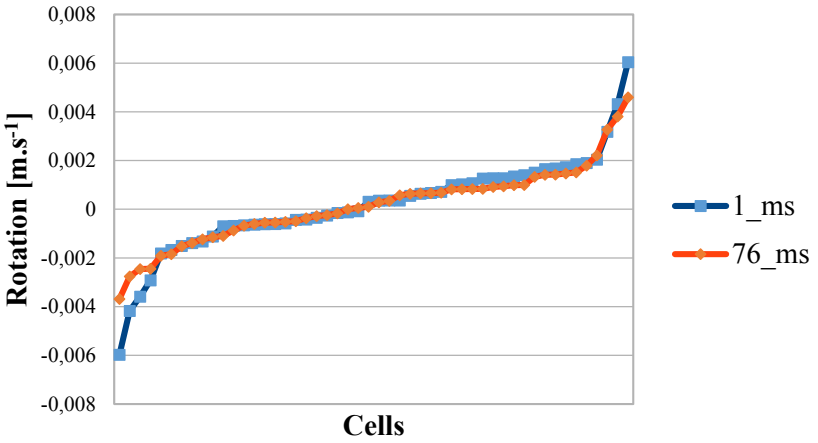

Fig. 2: Example of measured rotation magnitudes of all the cells after 1 ms of the simulation, and in the end of the simulation, after 76 ms. Values are sorted in ascending order.

During the simulation, with a total number 380 000 steps, 77 recordings of the instant speeds and rotation magnitudes were done. In order to monitor the evolution of the stability of the speed (or rotation) distribution in time, the KS test was at first done for each couple of subsequent measurements. So, the difference of the speed (or rotation) distribution was checked every 1 ms. After that, a similar comparison was done by skipping 4 measurements. It means that the difference of the speed (or rotation) distribution was checked for intervals of 5 ms. Then, the comparison between the distributions was done with skipping 9 measurements, so for the intervals of 10 ms. Finally, for each simulation, we obtained three series of the comparisons. An example of such a series is shown in Fig. 3.

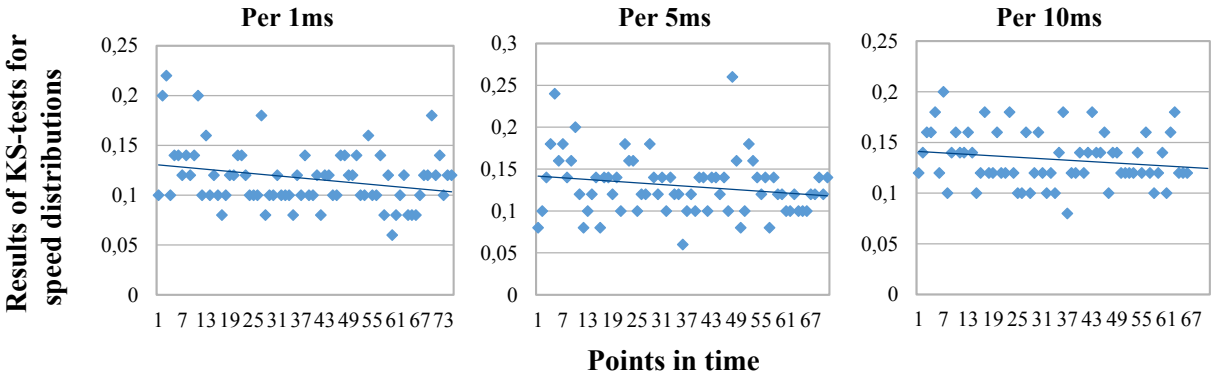

Fig. 3: Example of a comparison between different speed distributions recorded during the simulation.

Each series was than divided into two equal parts, from 0 to 38 ms and from 39 to 76 ms. After that, the average fit was evaluated for the first part and for the second part. Those two numbers signify the average resemblance of the speed (or rotation) immediate distributions in the first half and in the second half of the simulation. The improvement in the steadiness of the speed distribution is than checked by comparing the two numbers. The example is shown in the Fig. 4.

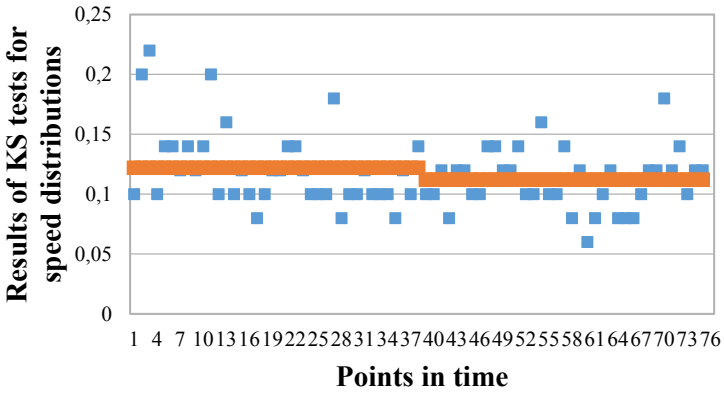

Fig. 4: Example of comparison of steadiness of the speed distribution in the first and the second half of the simulation. The average value of the results of the KS test is bigger in the first half of the simulation. It means that speed distributions in various moments are less similar to each other than in second half of the simulation.

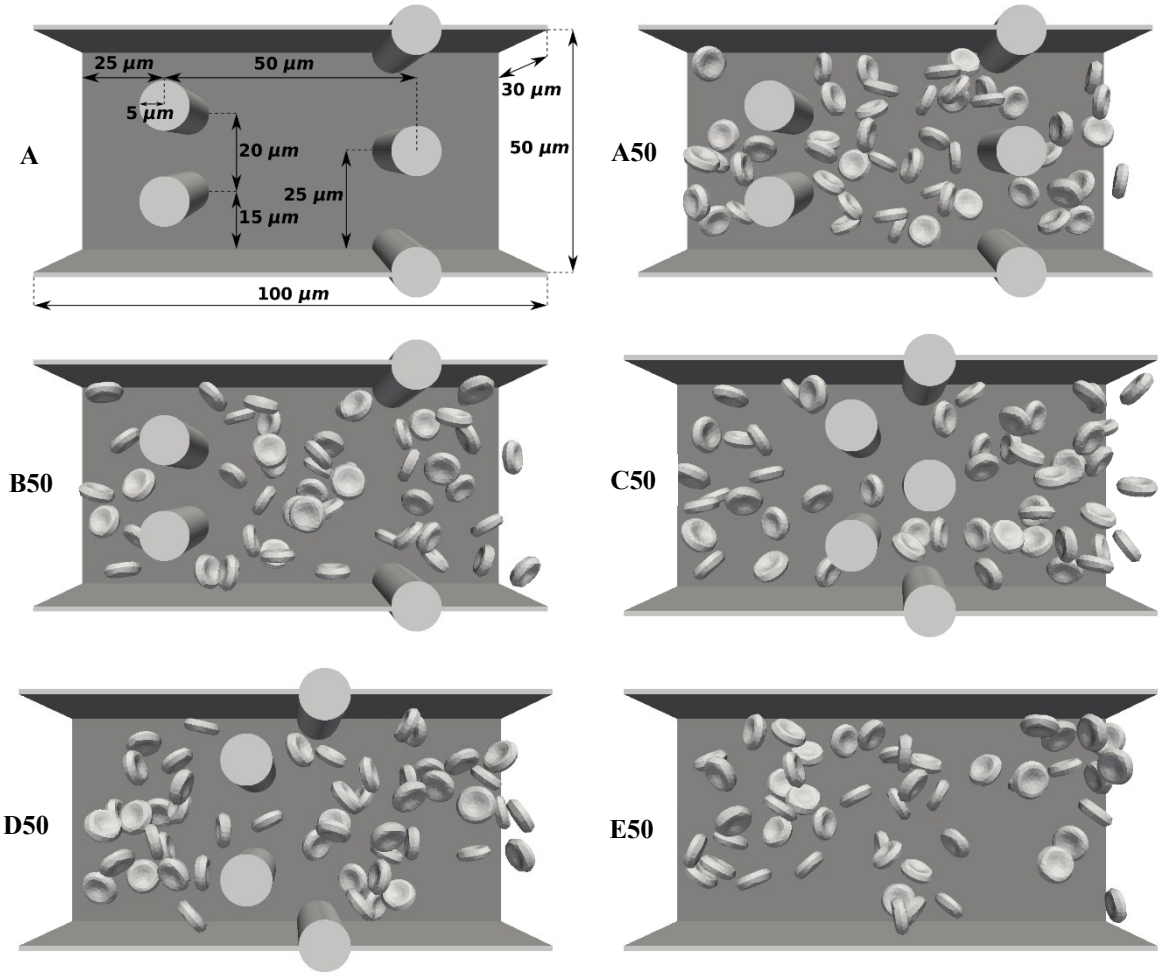

Figure 5: Five different geometries (A, B, C, D, E) used for evaluation of the numerical onset impact length. On the top left picture are sizes of the channel A, other pictures show different RBCs seedings.

Moreover, we examined the evolution of the minimal, maximal and average speed (or rotation) of the cells during the simulation. Those values should, as well, get stabilized in the time, within a range of acceptable oscillations.

III. Examined simulations

All of the examined simulations contain 50 cells, they differ only by an initial position of those cells and by a geometry of the obstacles inside of the channel. The Fig. 5 represents five different geometries of the simulation box. Each geometry was used twice to run an experiment, with two different initial seedings of the cells. Hence, ten simulations (A50a, A50b, B50a, B50b, C50a, C50b, D50a, D50b, E50a, E50b) were used to determine the length of the numerical onset impact.

IV. Results

In the Table 1, we can see the results of the comparison for velocities and in the Table 2 the results for the rotations.

Table 1: The evolution of the average fit between the velocity distributions - comparisons of the velocity distributions in first and second half of the simulation ("imp." means improvement), with an offset of 1ms, 5ms and 10ms. The fit is evaluated by using Kolmogorov-Smirnov test.

	offset 1 ms			offset 5 ms			offset 10 ms		
	0-39 ms	**38-76 ms**	**imp.**	**0-41 ms**	**36-76 ms**	**imp.**	**0-44 ms**	**35-76 ms**	**imp.**
A50a	0.122	0.112	8.20%	0.134	0.124	7.46%	0.135	0.132	2.22%
A50b	0.129	0.115	10.85%	0.152	0.130	14.47%	0.144	0.127	11.81%
B50a	0.115	0.106	7.83%	0.130	0.116	10.77%	0.138	0.119	13.77%
B50b	0.113	0.107	5.31%	0.133	0.123	7.52%	0.124	0.117	5.65%
C50a	0.090	0.090	0.00%	0.133	0.116	12.78%	0.146	0.120	17.81%
C50b	0.104	0.097	6.73%	0.142	0.130	8.45%	0.148	0.139	6.08%
D50a	0.092	0.088	4.35%	0.102	0.102	0.00%	0.097	0.098	-1.03%
D50b	0.092	0.094	-2.17%	0.129	0.132	-2.33%	0.125	0.114	8.80%
E50a	0.054	0.051	5.56%	0.064	0.066	-3.13%	0.071	0.071	0.00%
E50b	0.057	0.047	17.54%	0.070	0.061	12.86%	0.081	0.066	18.52%
avg.	**0.097**	**0.091**	**6.42%**	**0.119**	**0.110**	**6.89%**	**0.121**	**0.110**	**8.36%**
avg A-D	**0.107**	**0.101**	**5.14%**	**0.132**	**0.122**	**7.39%**	**0.132**	**0.121**	**8.14%**

Table 2: The evolution of the average fit between the rotation distributions – comparison of the rotation distributions in first and second half of the simulation ("imp." means improvement), with an offset of 1ms, 5ms and 10ms. The fit is evaluated by using Kolmogorov-Smirnov test.

	offset 1 ms			offset 5 ms			offset 10 ms		
	0-39 ms	**38-76 ms**	**imp.**	**0-41 ms**	**36-76 ms**	**imp.**	**0-44 ms**	**35-76 ms**	**imp.**
A50a	0.113	0.110	2.65%	0.146	0.144	1.37%	0.138	0.144	-4.35%
A50b	0.124	0.115	7.26%	0.155	0.141	9.03%	0.155	0.146	5.81%
B50a	0.115	0.117	-1.74%	0.144	0.148	-2.78%	0.154	0.149	3.25%
B50b	0.112	0.119	-6.25%	0.149	0.158	-6.04%	0.143	0.164	-14.69%
C50a	0.108	0.114	-5.56%	0.148	0.153	-3.38%	0.155	0.161	-3.87%
C50b	0.112	0.121	-8.04%	0.144	0.150	-4.17%	0.137	0.159	-16.06%
D50a	0.113	0.120	-6.19%	0.144	0.146	-1.39%	0.139	0.149	-7.19%
D50b	0.126	0.117	7.14%	0.184	0.149	19.02%	0.162	0.142	12.35%
E50a	0.114	0.118	-3.51%	0.132	0.145	-9.85%	0.128	0.149	-16.41%
E50b	0.116	0.109	6.03%	0.161	0.132	18.01%	0.152	0.138	9.21%
avg.	**0.115**	**0.116**	**-0.82%**	**0.151**	**0.147**	**1.98%**	**0.146**	**0.150**	**-3.20%**
avg. A-D	**0.115**	**0.117**	**-1.34%**	**0.152**	**0.149**	**1.46%**	**0.148**	**0.152**	**-3.09%**

We can observe that there is a systematic improvement of the similarity of the velocity distributions along the course of the simulation. Its value is about 5% - 8%. We can note also that the absolute values of the similarity are smaller for the geometry without obstacles.

The same conclusion cannot be stated regarding the evolution of the rotation distribution similarity. The similarity of the rotation distributions is randomly improving or getting worse during the simulation, with an average improvement comparable to zero. It does not mean that the rotations are already in a steady state from the early beginning. As we can see in [10], it is not the case, the rotation is as well perturbed at the beginning of the simulation, but this method of comparing its distribution is probably not pertinent enough to show it.

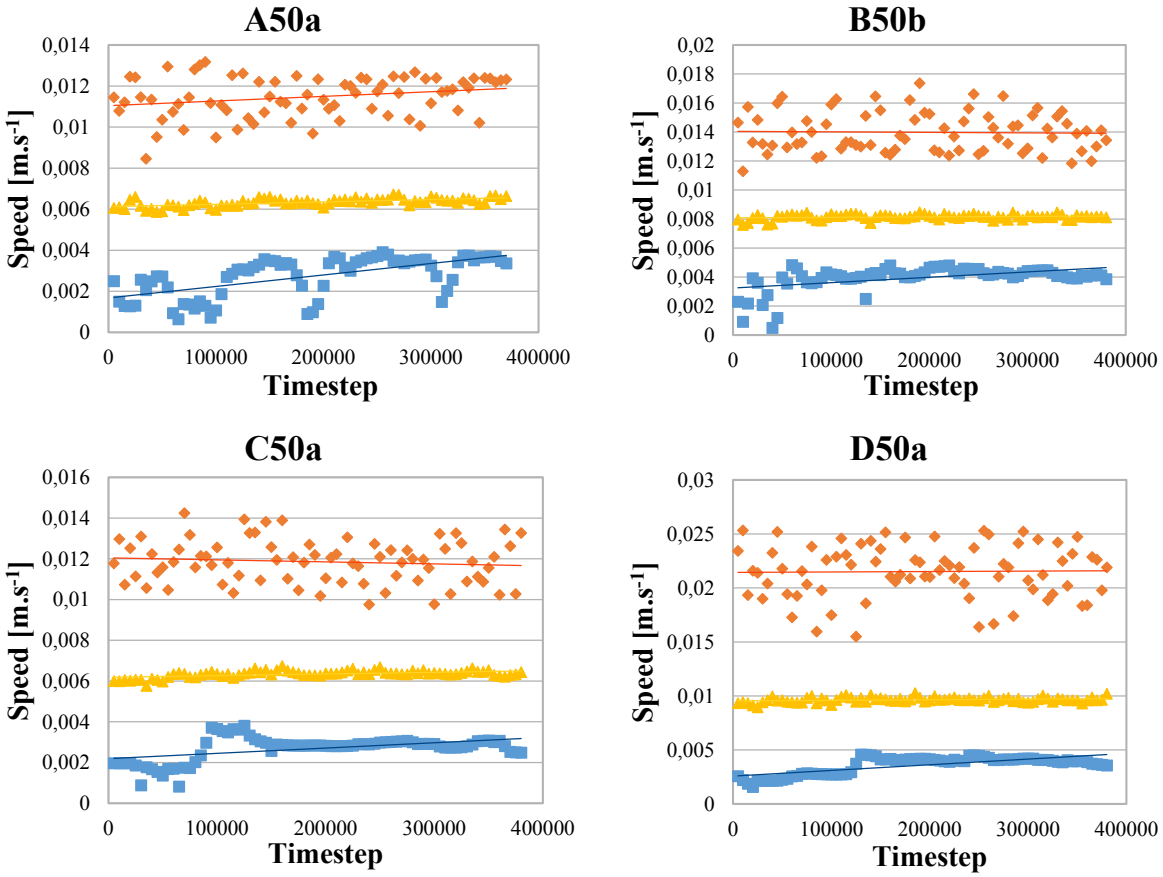

Fig. 6: Examples of evolution of the minimal (blue rectangles), maximal (red diamonds) and the average (yellow triangles) speed during the simulation.

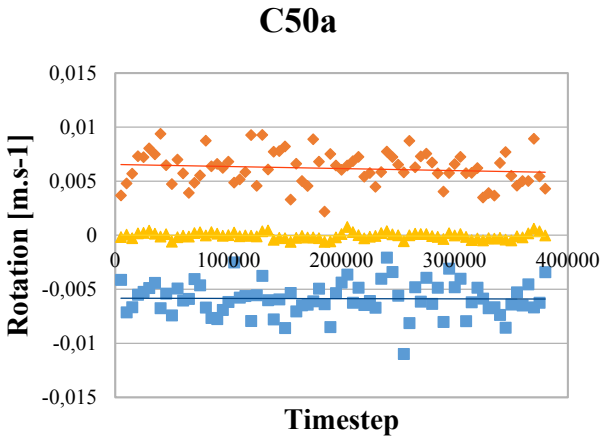

Fig. 7: Example of evolution of the minimal (blue rectangles), maximal (red diamonds) and the average (yellow triangles) rotation during the simulation.

Another point of view can be obtained by observing evolution of the extremal and average velocities. The Fig. 6 shows examples of such a graph. While the average and the maximal speed do not seem to be perturbed in the beginning of the simulation, the minimal speed is slightly different in the beginning. It takes approximately one fourth to one half of the simulation (20-40 ms) to get stabilized.

The Fig. 7 represents an example of such a graph for rotation magnitudes. The disadvantage of this approach applied to the rotations is that while the values of the speed are always positive and relatively far from zero, the values of the rotation are as negative as positive. Even if we consider only the absolute value of the rotation, we obtain a lot of values close to zero. There is not any tendency in the evolution of the minimal, maximal and average rotation, which confirms the conclusion from the observations from the Tab. 2.

V. Conclusion

In this article, we study the possibility to determine the numerical onset impact length in numerical models of cells in microfluidic devices. We compare the statistical distribution of the cell velocities and rotations during the simulation, using Kolmogorov-Smirnov test. The results of the comparisons of the speed distribution show that the behavior of the cells gets more stabilized in the second half of the simulation. The evolution of the value of the minimal cell speed during the simulation show that the length of the numerical onset impact is approximately 20-40 ms. However, these results are issued only from the data relative to the speed of the cells. The rotation of the cells does not manifest a stabilization of its distribution. This could mean that the applied approach is not appropriate, and another one should be used to evaluate the steadiness of the cell rotation. The Discrete Fourier Transformation is a tool which was used briefly to determine the presence of impact of the numerical onset in our previous work, and it appears that it could be more sensible to detect the evolution of the steadiness of cell rotations during simulation.

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Sensitivity of Red Blood Cell Dynamics in a Shear Flow

Mariana Ondrušová

***Abstract*—** The computational models of cells have specific parameters that affect their properties in the shear flow. We want to analyze influence of individual parameters on cell behavior when setting simulations. We select the parameters that affect in particular the bending and the frequency of rotation of the cell in the shear flow. For each parameter change, we perform several simulations to improve the visibility of the results. The results indicate that the viscosity of the membrane is the key parameter influencing the rotation frequency of the cells in a shear flow.

***Keywords*—** computational modelling, red blood cell, shear flow, simulations, elastic parameters.

I. Introduction

Behavior of red blood cell (RBC) is closely related to the elastic properties of cell membranes and their interactions. Dynamical properties and morphology of RBC were studied in experimental studies [1, 2].

Nowadays, simulation models are important that help in designing microfluidic devices.[3] A well-designed simulation model helps to verify experimental results. An example of such scenario is the stretching experiment, used in [2]. Here, the RBC is stretched on the opposed sides with optical tweezers. Dependence of deformation index on applied stretching force is used to determine elastic parameters of the model.

Our spring-network based model was described in [4,5]. Here, spring-network based model is defined by triangulation of the membrane of RBC. The static validation of elastic properties was described [8] and the software implementation of the model in [9].

In our article, we focused on analyzing elastic parameters and the sensitivity of RBC behavior during their change. First, we changed the coefficient in the bending modulus. Since this modulus is responsible for the bending of the membrane by prescribing preffered angles between the triangles in discretization of the model, we expect, that changing this parameter will affect the rotation of the cell during simulation. In the next simulation, we changed the set of elastic parameters. We want to verify that a different set of elastic parameters can be suitable for simulation. Finally, we changed the viscoelasticity of the cell membrane. We chose it for its ability to relieve fast changes shape from the original to the stretched and, on the contrary, to remind RBC in the blood.

In Section II we describe our red blood cell model, parameters of RBC and fluid and their interaction. Section III is devoted to basic simulation setup. Sections IV and V describe results with different elastic parameters and visco-elasticity. Finally, in Section VI we summarize the findings and draw conclusions.

II. Model of red blood cell

A detailed description of the model was presented in [6,7]. The red blood cell model is based on membrane deformation and fluid dynamics. Both components are interconnected.

The fluid dynamics: The description of fluid dynamics is based on the lattice-Boltzmann method. It is assumed that the fluid is divided into discrete points evenly located in the cubic lattice (three dimensions with 19 different directions). More details we can found in [10].

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The cell deformation: RBC is elastic objects whose surface is covered by a spectrin (protein) membrane. Spectrin forms a network of springs that can be stretched and bended to change the shape of the membrane. RBC may significantly deform during the experiments.

Cells are described through points and a triangular network of springs through which these points are linked. By moving the cell, the individual points also move and interact with one another by stretching the springs. The cell model elasticity preserves five basic moduli - the elastic modulus, stretching, bending, local and global area conservation and volume conservation. The following equations for are described in [11].

Stretching - this module affects the stiffness of the object's membrane. It acts on each neighboring pair of points that are interconnected. At higher stretching, the RBC model is stiffer and less flexible. The force between two mesh points is given by

$$F_s = k_s \kappa(L)(L - L_0). \tag{1}$$

Here, k_s is the stretching coefficient denoting the stiffness of the springs, L is the current length of the edge between two points, L_0 is the length of the edge in the relaxed state and a function $\kappa(L)$ represents the neo-Hookean nonlinearity of the stretching force.

Bending - this module keeps the angles between each pair of adjacent triangles having a common edge and angle θ. Bending is given by

$$F_b = \kappa_b \frac{\theta - \theta_0}{\theta_0} n \tag{2}$$

where κ_b is the bending coefficient modifing modulus, when returning to a relaxed state , θ is the angle between two triangles having a common edge, θ_0 is their relaxed angle, and n is the normal vector to the corresponding triangle.

Fluid-Cell Coupling: The individual forces of fluid and the forces of the cell interact. The fluid develops force on every single particular mesh point of membrane. This force F_d is proportional to the difference between point velocity and fluid velocity at the same location. The magnitude of the force is given

$$F_d = \xi(u - v) \tag{3}$$

The friction coefficient ξ provides the distribution of the resistive force of the object to its individual discrete points. v is the velocity of the mesh point and u is the velocity of the fluid at the position of the mesh point.

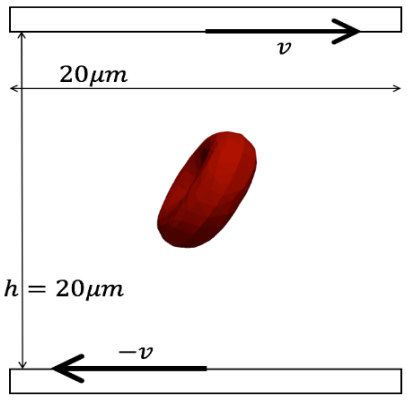

Fig. 1 Simulation setting with velocities of the fluid at the boundaries

III. Simulation setup

Simulations were conducted in cubic box with dimensions $20\ x\ 20\ x\ 20\mu m$. The shear flow is generated by setting the constant velocity v and $-v$ at the top and bottom boundaries of the channel, see Figure 1. In this setting for an empty channel, the velocity field has zero y and z components and the horizontal x component linearly decreases from the value v at the top boundary to value −v at the bottom boundary. This means that the shear rate is constant over the whole channel.

In our simulation, we used one cell in the center of the channel with shear flow. Together we made 3 different sets of simulations, in each set we changed one parameter and we kept other constant. This way we can see how the whole system reacts on the change of one parameter.

To compare the results, we choose 10 different times at the beginning - from 0.0002 μs to 0.002 μs. The following parameters were common in all simulations: density of fluid - 1050 kg. m^{-3} and viscosity 5 mPa. s. These values correspond to biological solutions of dextran that is typically used in experiments as in [4,5]. From a recent study [12], the friction coefficient was taken $\xi = 5.0$. For discretization of time we use the time step equaling to 0.1μs. To monitor the rotation frequency, we marked a particular point. So we could see a point in Figure 2, which rotated in x-direction around the cell.

During simulations we changed the visco-elasticity and the elastic parameters. Specific values are in the other sections.

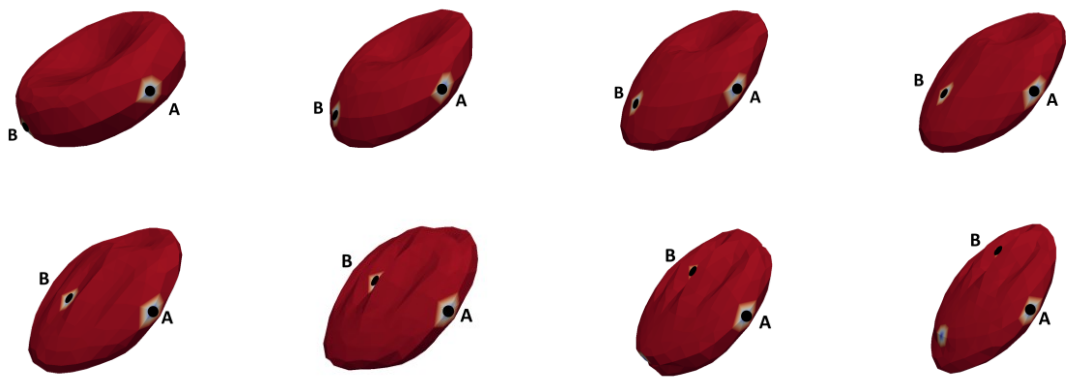

Fig. 2 Two specific mesh points are highlighted. Point A is on the y-axes of rotation. Point B rotates around the cell.

IV. Parameters of the membrane

The biological membrane of a RBC exhibits visco-elastic properties [13]. Viscoelasticity is a property of cells that help to mitigate rapid shape changes. It also influences the rotation frequency. The force is given

$$F_{vis} = k_{visc}\frac{dL}{dt} \tag{4}$$

Here, k_{visc} is the viscosity coefficient, which complements the visco-elastic properties, dL is the change of the edge length and dt denotes time derivative.

In our previous study [14] we verified the viscoelasticity than closely corresponds to the properties of red blood cells. We also valued k_{visc}, which also correlates with experimental data. [4,5].

By simulations, we find out how different k_{visc} values affect the cell rotation frequency. Results we compared with verified study [14]. We have selected the following values for elastic parameters

$$k_s = 0.008,\ k_b = 0.0003,\ k_{al} = 0.006,\ k_{ag} = 0.9,\ k_v = 0.5,\ k_{visc} = 1.5$$

We started simulations with 5 different values for k_{visc} = 0.0, 0.5, 1.0, 1.5, 2.0. Figure 3 represents the rotation frequency of a point in time for different values of k_{visc}. Results confirmed our assumption, that even a small change in visco-elasticity values affects the rate of rotation. The marked dots indicate the speeds for computation of frequency described in [14].

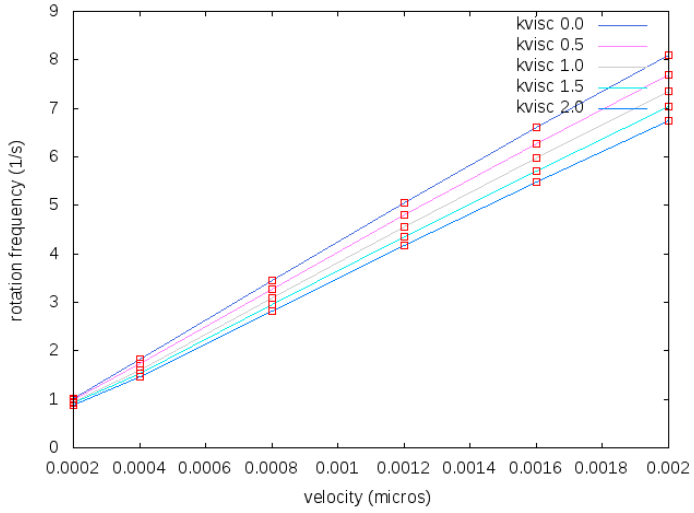

Fig. 3 Frequency of rotation of the cell in shear flow with change of visoelasticity.

V. Elastic parameters

Elastic parameters are an essential part of the model of cell and have an important role in changing shape. We compared results from [14] for which we have elastic parameters like in Section IV.

$$k_s = 0.008,\ k_b = 0.0003,\ k_{al} = 0.006,\ k_{ag} = 0.9,\ k_v = 0.5,\ k_{visc} = 1.5$$

In first part with elastic parameters we focused on change k_b. Bending is main parameter that regulates the cell membrane's flexibility. We chose values - 0.0003, 0.0012, 0.0048. Higher values cause too high resistance to bending, which is atypical behavior of RBC. Simulations were evaluated in the same way as in IV – graph with rotation frequency. We also used the same speeds. In Figure 4 we can see small divergences in line. However, these are negligible and we can conclude that the bending in the range of 0 to 0.0048 does not influence the rotation frequency.

In other simulations, we wanted to find out the rotation behaviour for another set of elastic parameters. From our preliminary simulations we know that elastic behaviour of cell in static case is reproduces also for other value of k_{al}. We have preserved other elastic parameters from (5), but we changed value of k_{al}.

$$k_s = 0.008,\ k_b = 0.0003,\ k_{al} = 0.003,\ k_{ag} = 0.9,\ k_v = 0.5$$

We started simulations with different values for k_{visc} = 1.0, 1.5, 2.0. The results are again reported over the frequency. We can see in Figure 5, that these elastic parameters are very similar to the original results in Figure 3. So they are also suitable for later simulations and we confirmend that k_{visc} influences the dynamical behaviour of cell in the same way as in Figure 3.

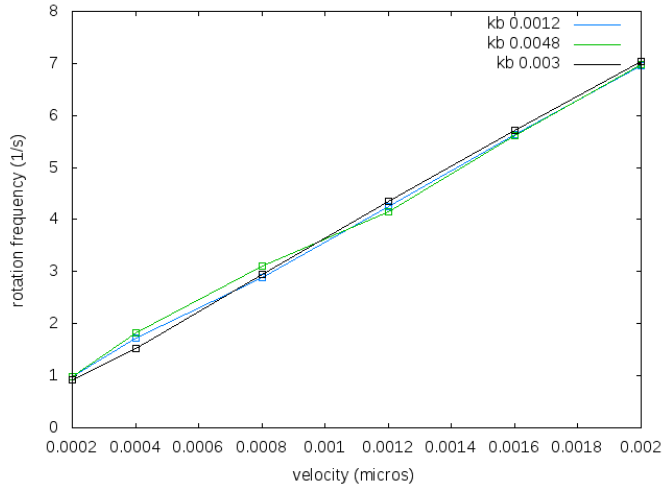

Fig. 4 Frequency with different values of bending. Correct value, which coresponds with RBC is 0.0003.

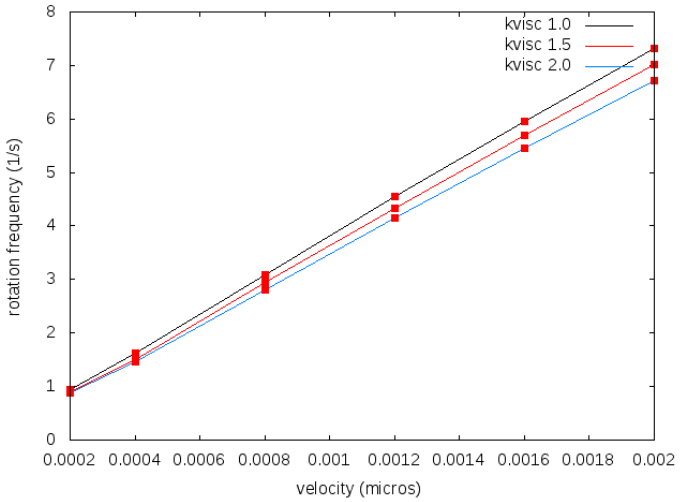

Fig. 5 Frequency using other set of elastic parameters.

VI. Conclusion

The RBC model that has been used, has numerous parameters. The aim of this article was to study the effect of some of these parameters on the behaviour of a red blood cell in a shear flow.

Typically, the RBC starts to rotate in such flow. The speed of rotation, or, the rotation frequency is an important feature of the cells and we decided to analyze how the rotation frequency is influenced by the change in model parameters. In Section 1 we identified two elastic parameters that are likely to affect the rotation frequency: the bending resistance of the membrane, represented by bending coefficient k_b and the membrane viscous coefficient represented by k_{visc}.

A serie of simulations were performed where we tracked how fast the cell rotates for different shear rates. This serie was run numerous times with different k_b and with different k_{visc}. Each

of Figures 3-5 shows the results. When k_b was changing (see lines in Figure 4 with different colors), we see no significant changes. When the viscosity coefficient changes, we do see the changes in frequencies in Figures 3 and 5.

Our simulations indicate that the viscous coefficient significantly influences the rotation of the RBC whereas the bending coefficient has only small influence.

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Application of the Remote Sensing in Environmental Management as the Interdisciplinary Approach

Anna V. Khyzhniak, Olha V. Tomchenko, Anatolii Yu. Porushkevych

***Abstract*—**The purpose of this study is to show the interdisciplinary integration of the remotely sensed data and in-situ measurements of different physical and biological nature and various dimensions. The set of methods for monitoring of the environment based on methods and models of the system analysis and their modification which were used in solving the number of problems is proposed. Also the description of the numerical methods of system analysis and their application is given. Approbation of the above methods were done on the variety facilities of Ukraine such as Kyiv city, Dnieper River, Kyiv reservoir, Ukrainian part of Danube River.

***Keywords*—**remotely sensed data, system approach, environmental management, monitoring, Kyiv, Kyiv reservoir, Ukraine

I. Introduction

The use of remote sensing (RS) makes it possible to provide reliable information on environmental conditions, properties of the spatial structure of natural-territorial complexes, their dynamics and helps in accumulation of data for the development of the system natural resources monitoring [1]. The solution of these problems only through remote sensing is usually impossible without using data from related disciplines. The interdisciplinary approach is moving to the foreground in studying the problems of nature management. Open and self-improvement complex systems become the objects of the interdisciplinary research. Notable place among complex systems occupy a system, which included the man as one of its elements. Solving the problems of the environmental management based on information retrieved from space is a good example of the interdisciplinary scientific approach, the relevance of the use of which is particularly evident when it is necessary to consider many interrelated factors of different physical nature integrating data obtained from various disciplines.

The interdisciplinary research based on the system analysis methods is proposed for the remote aerospace researches in environmental management and defined as the integration of theory, methods and models, information and experimental results from different scientific disciplines.

The most rational mathematical models of the use of remote sensing in solving various thematic problems of natural-territorial complexes assessment, modeling and predicting development of the studied processes are proven by the means of the system analysis.

II. Concept and methods

The methods for monitoring the environmental management are developed due to the use of remote sensing and geographic information (GIS) technology which provide comprehensive monitoring of large areas. The main advantages of using satellite images are: simultaneous coverage of a large area of water area / territory, continuous information content of the image for each image point, high frequency data acquisition for analysis.

The experience of research shows that the main prerequisite for efficient decoding of satellite

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images is the integrated use of in-situ measurements and remotely sensed data. Therefore, the development of integrated methods for assessing the environmental properties is the most urgent task.

Figure 1 represents steps for monitoring the environmental management based on interdisciplinary scientific approach with regard to integration of in-situ measurements and remotely sensed data.

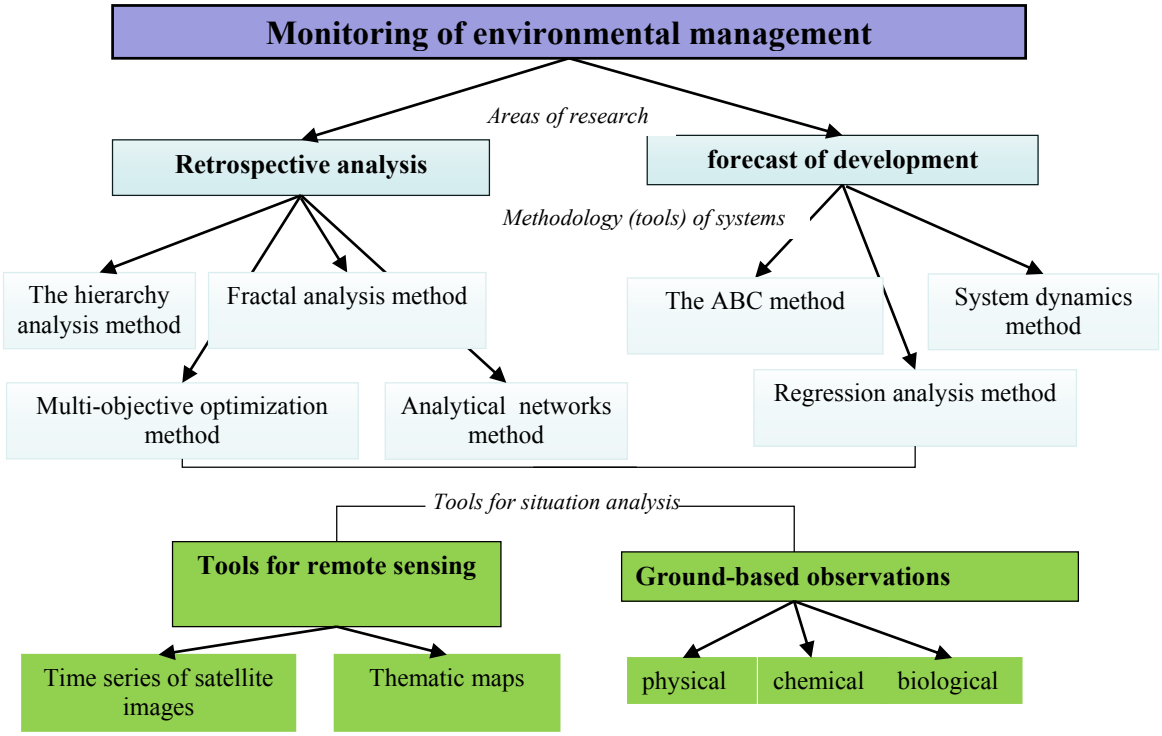
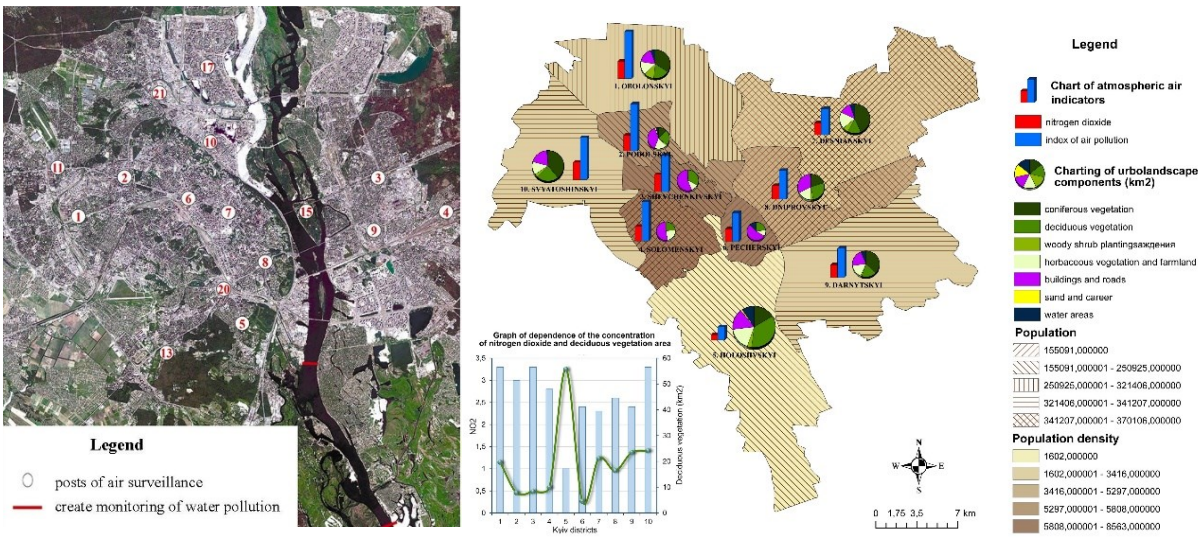


Fig. 1. Schematic representation of the stages of monitoring natural resources.

A. Pre-processing

The interdisciplinary approach to the study of nature management is presented by two different examples: urban landscapes of Kyiv as anthropogenically altered object and the top of the Kyiv reservoir, as natural water bodies of Dnieper River, which has undergone radical changes as a result of human activities. Block "tools for situation analysis" in both cases is the same material of remote sensing and ground data, but in each case it has its own features. Satellite images are chosen for the season when the selected features are better represented. For example, urban landscapes are better represented at the beginning of summer when trees are covered with leaves, but aquatic landscapes are better presented late summer, when the aquatic vegetation is at the peak of the growing season. Ground-based measurement are differ in the same way. For example, for urban landscapes - the concentration of harmful substances in the air, or the state of water pollution within the city, and for the water bodies - indicators of water quality, such as stability indices of hydrobiological organisms to organic pollution (saprobic index) or hydrophysical, such as flow rate, and water exchange rate.

Ground-based observations appear as the coherent set of characteristics. Therefore, the first stage is the examination, classification and processing of all possible ground statistics. Figure 2 shows the location of the observation points of the ecological state. Kyiv (*a*) and the scheme of ground structured data (*b*).



a *b*

Fig. 2. Ground-based statistics for environmental assessment of Kyiv.

The next step is systematization of satellite images and their decoding for changes in the territory, such as the assessment of vegetation, areas under buildings, geological structures, surface temperature, etc. (Fig. 3, 4).

Results from decoding of satellite images and maps (topographic maps and depth maps) are used for retrospective analysis. The procedure for thematic processing of the remotely sensed data and ground-based data that are built on isolating certain combinations of objects with similar spectral characteristics related to common structural nature and uniformity of propagation conditions is developed. Maps of natural-territorial complexes are the results of such procedure. Next two ways of decoding and classification of satellite images for the following studies are developed:

- Pixel-oriented classification using neural networks to highlight biotopes on satellite images of medium spatial resolution (Landsat).
- Object-oriented classification of remotely sensed data (feature extraction) to highlight biotopes on satellite images of high spatial resolution (QuickBird).

The results of processing and interpretation of satellite images are:

- The set of thematic maps of the environment state (biotopes, vegetation and water indexes, surface temperature, parameters of landscape diversity) high and medium spatial fragmentation.
- Statistical tables with values of components from ground-based observations.

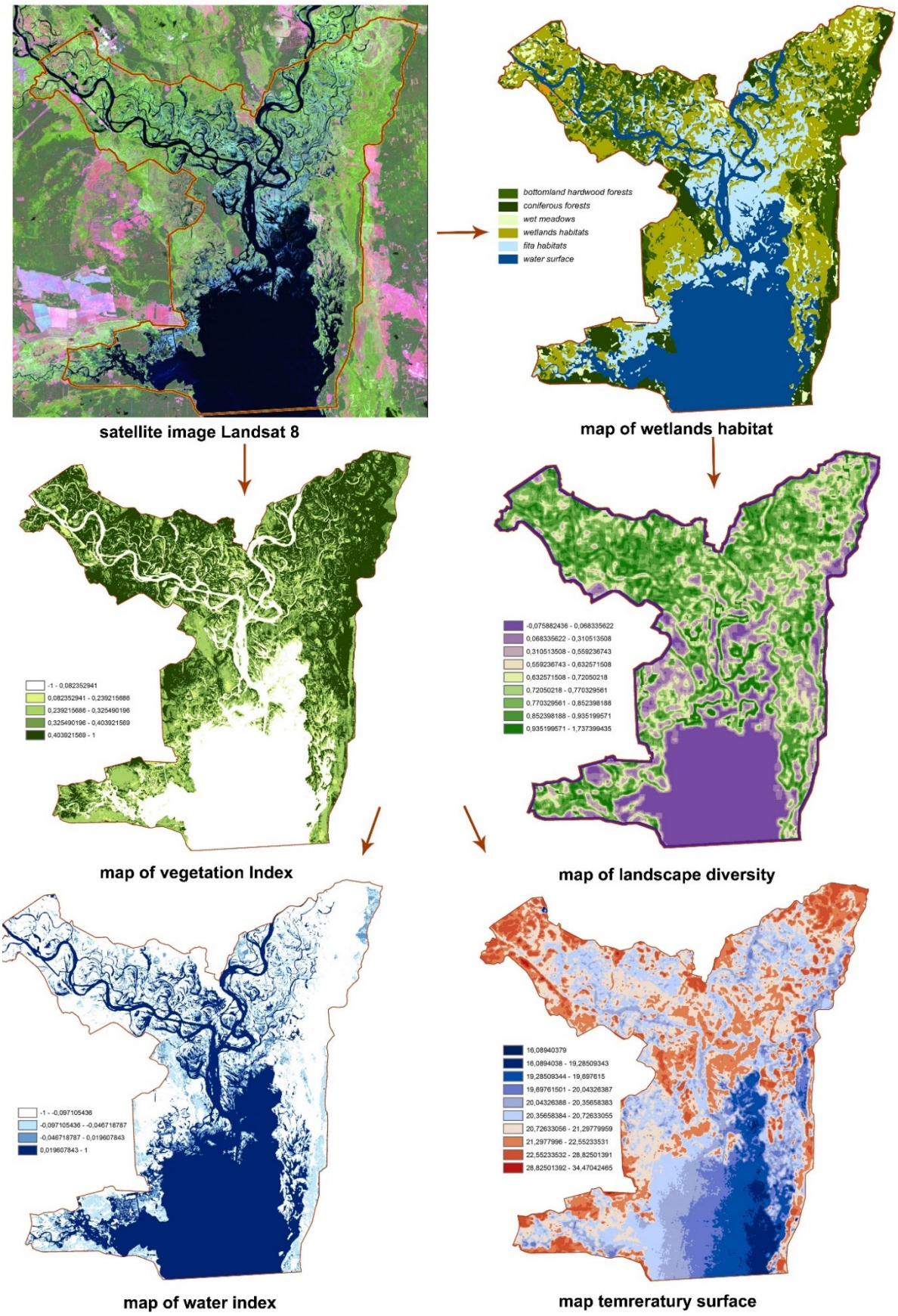


Fig. 3. Decoding of satellite images and mapping biotopes of the top of Kyiv reservoir.

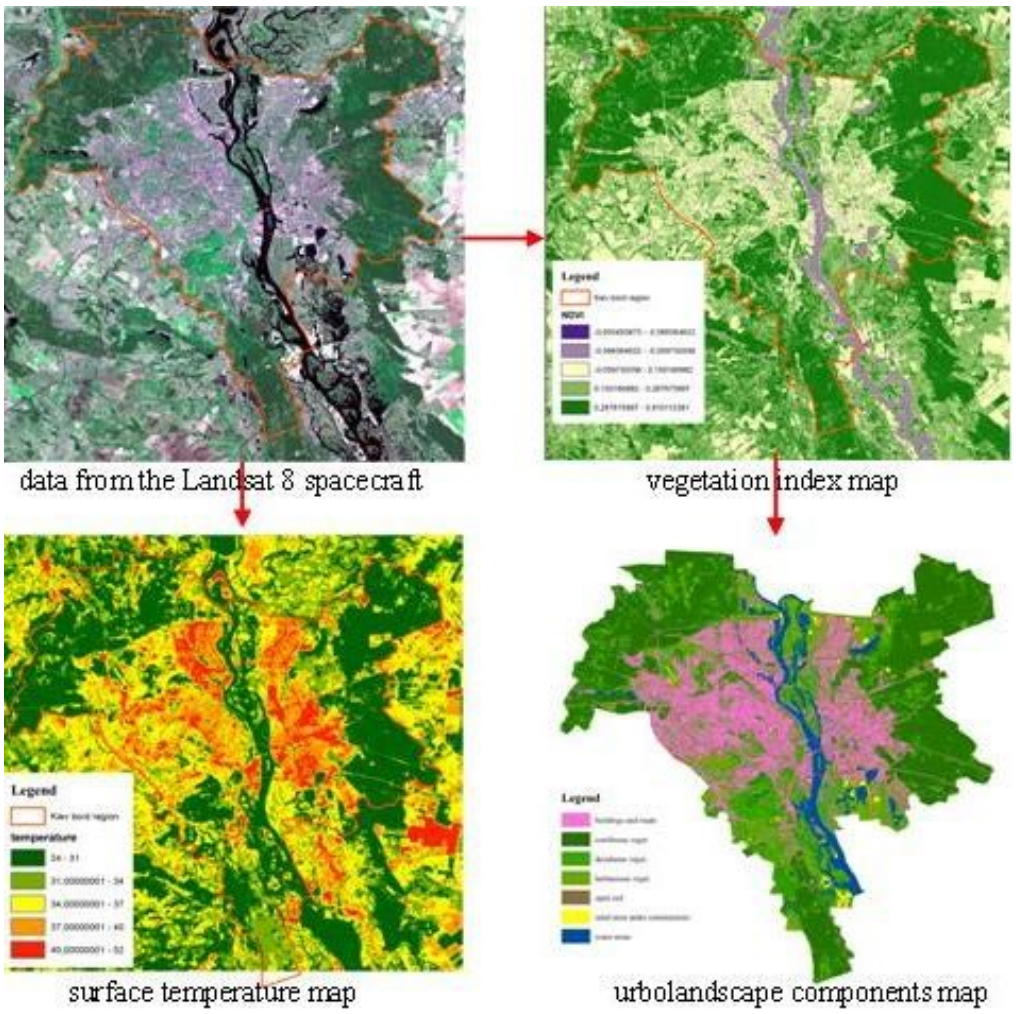


Fig. 4. Decoding of satellite images and mapping components of urban landscapes of Kyiv.

B. Methods of system analysis

The methods of system analysis is used on the next step for the obtained arrays of the statistical and remotely sensed data.

The system approach is the set of methods for decision-making system based on the comprehensive analysis and modeling of the relationships between components of processes in complex systems, including the technological, environmental, economic, and social conditions subsystems under the conditions of a large amount of information of different physical nature [2].

Different thematic environmental and ecological problems were solved in the Scientific Centre for Aerospace Research of the Earth using satellite imagery and the systems analysis methods.The theoretical basis of the system analysis methods that have been modified and adapted for monitoring and assessment of the anthropogenic facilities (for example, Kyiv city) and natural facilities (for example Svitjaz Lake, Pripyat River, Dnieper River, Danube River, Kyiv reservoir, etc.) are presented in this section.

When solving problems that need to simultaneously take into account values of many individual criteria, each of which describes one side of the problem, the *method of multi-objective optimization (MOO)* is used [3,4]. It is often necessary to find a compromise version of the studied system, when the process of selecting is done with a single generalized criterion. The MOO method consists of the following stages: introduction of proximity functions for the values and being compared, calculating values for the proximity function - *S*, and the membership function *F* (generalized criterion). The method is adapted for the specific purpose

of environmental protection by forming the corresponding generalized criterion *F* and choosing the functions: proximity – *S* and the trade off function *f*, which are determined by the nature of the problem.

For obtaining regularized, uniformly distributed data with a specified step in a predetermined coordinate system, the *Kolmogorov spatial interpolation technique* is used [5]. This complex of these methods is called downscaling or "reducing dimensions." Using them one can transform unevenly distributed low-resolution data into regularized datasets that fit the simulation requirements and allow minimizing errors present in monitoring systems.

Fractal analysis [6,7,8] gives the possibilities for obtaining objective geodynamic information based on real data, provides an estimation of the structure and configuration of the test process or object, the frequency of distribution of geometrical, physical and other characteristics. Introducing multifractal parameters allows evaluating the system's degree of order and resistance to external influences, which is impossible to determine by other regular statistical methods.

The fractal dimension of Renyi - D_q, which shows how tight and uniform set of items fill Euclidean space is used as a quantitative measure that describes the structure of the composite objects. The value D_q - invariant to the size of the sample area, scale.

The ability to use fractal analysis for comparison purposes of the variability of the components of the studied object establishes verification of two conditions: first, the power dependence of the growth components of the partition Z_q of the sample size N and, secondly, not growing range of features views of the generalized dimensions D_q, dynamics changes which characterize the patterns of growth and evolution process.

$$Z_q(N,q) = \sum_{i=1}^{n} p_i^q, p_i = \frac{N_i}{N}, \sum_{i=1}^{n} p_i = 1 \tag{1}$$

$$D_q = \frac{\tau(q)}{1-q}\bigg|_{q\neq 1}, \tau(q) = \frac{\log \sum_{i=1}^{n} p_i^q}{\log N} \tag{2}$$

For simulating integrated ecosystem processes and evaluating potential resources I.Timchenko and Y.Igumnova proposed the *method of adaptive balance of causes (ABC)*, which by using basic principles of the system dynamics method is free from these limitations [9]. The ABC method allows to model and predict the development of complex systems and perform computing functions, taking into account the interaction of all the modules, each of which is in a state of dynamic balance. The balance is maintained by influence functions that relate the module with other modules of the system. The mode of dynamic balance is maintained inside the system under control of external influences on the system.

The *System dynamics method* was proposed by J. Forrestor for quantitative analysis of complex systems with multiple internal connections between the elements (modules) of the system [10]. With this method, a conceptual model was elaborated and a mathematical model was formed that consists of mathematical equations describing the balance of influence in the system, based on the cause-and-effect relationships in the system. Four types of tasks are resolved by this: analysis and assimilation of information, forecasting, and planning. With the help of these models state functions are calculated, which characterize the behavior of the system in space and time. Formally, the system's levels are mathematically described by a coupled system of nonlinear first order differential equations of the following form:

$$d\mathbf{x} / dt = F(\mathbf{x}(\mathrm{t}), \mathbf{p}(t), t), \rightarrow \mathbf{x}(t_0) = \mathbf{x}_0 \tag{3}$$

where: $\mathbf{x}(t)$ - vector – equation function (shifting states);

$\mathbf{p}(t)$ - vector – function of the system parameter;

$F(\mathbf{x}(t),\mathbf{p}(t),t)$ - nonlinear, in general time-dependent vector function, which in most cases is the difference between the rates (flow, velocity) of the positive and negative feedbacks

$$F(\mathbf{x}(t),\mathbf{p}(t),t) = f^{+}(\mathbf{x}(t),\mathbf{p}(t),t) - f^{-}\left(\mathbf{x}(t),\mathbf{p}(t),t\right) \quad (4)$$

where: $f^{+}(\mathbf{x}(t),\mathbf{p}(t),t)$ - rate of positive feedbacks, which include all the factors that cause the growth of the variable x; $f^{-}\left(\mathbf{x}(t),\mathbf{p}(t),t\right)$ - rate of negative feedbacks, which includes all the factors that cause a decrease in the variable x.

Multiple regression method [11]. Its general purpose (the term was first used by Pearson in 1908) to analyze the relationship between several independent variables (also called covariates or predictors) and the dependent variable. The term "multiple" refers to the presence of several covariates or predictors, which are used in the model.

The *method of spectral autocorrelation* [12] is based on the statistical relationship between the values of the spectral intervals of the same spectrogram taken with a shift along the wavelength. If one consider the spectrogram as an implementation of a process with unknown characteristics along the wavelength axis of the emission spectrum, then it is advisable to use the autocorrelation function, which is the second-order correlation moment of one process, to determine the informativity of the spectral ranges.

When the evaluation of a particular process is associated with such concepts as a practical necessity, technological opportunity, economic feasibility, which are not possible to measure by direct measurements and calculations, the *Analytic Hierarchy Process* is used, proposed by T. Saaty (USA) on the basis of the linguistic approach and expert data [13]. It allows to form the desired objective function and hold rating alternatives based on expert judgments. The main problem of the method consists in a sequential decomposition of the objective function into simpler criterial components - indicators that are combined in appropriate hierarchical levels. The most important stage is the construction of a hierarchy of judgments between the first and last levels.

$$F = \sum K_l^1 \sum K_m^2 \sum K_r^3 \sum K_p^4 \cdot x_p^s \quad (5)$$

Where the top index of the criteria priority *Kj* notes the hierarchy level; x_p^s - coefficient of the advantage of option s by the indicator p, *F*- generalized criterion.

$$K_1 = a_1 \Big/ \sum_i a_i ; ... ; K_n = a_n \Big/ \sum_i a_i , a_1 = \left(\prod_{j=1}^{n} a_{1j} \right)^{1/n} ; ... ; a_n = \left(\prod_{j=1}^{n} a_{nj} \right)^{1/n} \quad (6)$$

During this, the objective function is decomposed into simpler indicators, which are combined in appropriate levels of a hierarchical scheme. To formalize the expert procedure we construct a set of matrices of pairwise comparisons for each level and for each component of the hierarchical level. Their normalization is held and priority vectors *Kj* are rated in terms of their effect on the components of the previous level. The matrix processing, for example, of four equations makes it possible to calculate the priority vectors of the respective equations K^1, K^2, K^3 and K^4 - components determining their priorities from the expert viewpoint. The meanings *F* allow establishing the advantage of one or the other alternative states of the system along the totality of the factors considered.

III. Results and discussion

In CASRE IGS NAS of Ukraine next thematic problems in nature management have been solved on the basis of satellite imagery and system methods:

- evaluation and improvement of water quality Dnieper River estuary and analysis of anthropogenic impact on water resources and aquatic vegetation classification of areas

and the quality of water in the Pripyat River mouth area [14];

- comprehensive assessment of the ecological state of water bodies (for example Lake Svitiaz) [15];
- study of wetlands (for example, the top of the Kyiv reservoir) [16].
- assessment and forecast of urban areas on the example of Kyiv [17];
- the study of changes in coastal marine areas; [18];
- monitoring of aquatic landscapes Kiliya delta of the Danube River [19].

The following conclusions were made using a multidisciplinary approach on Kyiv reservoir:

- Creation of integrated criterion for evaluation of water quality based on remote sensing data including indicators that have positive and negative effects set the change of state of the Kyiv reservoir towards a slight deterioration in the quality of water for consumption purposes.
- The developed hierarchical model of expert assessment of the ecological functions of Upper Kyiv reservoir proved that the analysis of ecosystem value of waters should be based on an assessment of the capacity of the operation of two of its main components: the maintenance and production and implementation of three directions of reservoir purpose such as: maintaining biotic diversity, water supply and electricity.
- The distinct relationship have been found between the dynamics of changes in the structure and condition of wetlands reservoir. This relation is the priority for operational control of the reservoir ecosystem. The developed ABC model confirmed the direct relation between water quality and the degree of the overgrown shallow biotopes.
- Predictive estimation of wetland of the top of the Kyiv reservoir up to 2023 is done based on various factors. This showed a clear tendency for further transformation of major biotope types in the direction of growth that will further improve water quality and enhance the potential of biological resources reservoir.

The following conclusions were made during assessing and forecasting of the ecological state of the environment in Kyiv:

- The relationship between the dynamics of changes in the structure of components of the urban landscape and environmental condition of the city was established. This confirmed the feasibility of space monitoring for operational control of the environment of the urban area.
- The complex criteria for environmental assessment of urban areas based on remote monitoring was developed. This also includes indicators that have positive and negative effects on the ecological state of the city. The change of state toward deterioration by reducing the amount of green space and increased density in the central built-up area boroughs was found.
- A multifractal model of the city was made. It allowed describing components of urban landscapes using fractal analysis and conducting a study of variability of components of the urban area.
- Modification of Graham-Forrester dynamics system model of city, allowed to conduct integrated environmental assessment of urban areas based on information obtained from remotely sensed data and ground-based environmental and socio-economic statistics and get the estimation of the environment of Kyiv up to 2025. This showed clear trends in further deterioration of the ecological state of the city by increasing the density of the built-up part of town and destruction of adjacent green plantations.

IV. Conclusion

The suggested approaches make it possible to monitor the condition of the explored territory

at a qualitatively new level, to predict the change in the environmental situation with minor errors and to develop a balanced management and action plan for public services.

Further development is seen in increasing the efficiency of remote research in environmental management by extending functionality through the development of methodological base such as interdisciplinary scientific direction: integration of knowledge from different disciplines and areas of information and different physical parameters of various dimensions.

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Transformation of Boolean Expression into Disjunctive or Conjunctive Normal Form

Patrik Rusnak

***Abstract*—**Reliability is an important characteristic of many systems. One of the current issues of reliability analysis is investigation of systems that are composed of many components. Structure of such systems can be defined in the form of a Boolean function. A Boolean function can be expressed in several ways. One of them is a symbolic expression. Several types of symbolic representations of Boolean functions exist. The most commonly known are disjunctive and conjunctive normal forms. These forms are often used not only in reliability analysis but also in other fields, such as game theory or logic design. Therefore, it is very important to have software that is able to transform any kind of Boolean expression into one of these normal forms. In this paper, an algorithm that allows such transformation is presented.

***Keywords*—**reliability, Boolean function, normal forms.

I. Introduction

Investigation of system reliability is a complex problem consisting of many steps. One of them is creation of a model of the system. Since the system is usually composed of several components, a special map defining the dependency between operation of the components and operation of the system has to be known. This map is known as structure function and, for a system consisting of n components, it has the following form [1]:

$$\phi(x_1, x_2, \dots, x_n) = \phi(\boldsymbol{x}): \ \{0,1\}^n \rightarrow \{0,1\}, \tag{1}$$

where set $\{0,1\}$ is a set of possible states at which the components and the system can operate (state 1 means that the component/system is functioning while state 0 agrees with a failure of the component/system), x_i is a variable defining state of the i-th system component, for $i = 1,2, \dots, n$, and $\boldsymbol{x} = (x_1, x_2, \dots, x_n)$ is a vector of components states (state vector).

Based on the properties of the structure function, two classes of systems can be recognized – coherent and noncoherent. A system is coherent if its structure function is monotonic, i.e. there are no circumstances under which a failure of any system component can result in a repair of the system. If this condition is not met, the system is noncoherent.

Most of the systems studied by reliability engineers are coherent and, therefore, a lot of methods of reliability analysis are based on the assumption that the structure function is monotonic. Typical examples are methods of importance analysis [2], which focuses on ranking the components with respect to their influence on the system operation. However, real noncoherent systems also exist. Some of them are k-to-l-out-of-n systems that are working if at least k but not more than l components are working [3, 4] or logic circuits [5]. Reliability analysis, especially importance analysis, of such systems requires development of new methods that will take the incoherencies into account. One of the possible ways is to use tools related to the analysis of Boolean function. One of such tools is logical differential calculus.

Logical differential calculus allows investigating dynamic properties of Boolean functions [6]. Boolean derivative is the central term of this tool. Several types of Boolean derivatives exist but, for the purpose of reliability analysis, the most important one is Direct Partial Boolean Derivative (DPBD) [7]. For a Boolean function $\phi(\boldsymbol{x})$, it is defined as follows [6, 7]:

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$$\partial\phi(j \to \bar{j})/\partial x_i(s \to \bar{s}) = \begin{cases} 1, & \text{if } \phi(s_i, \boldsymbol{x}) = j \text{ AND } \phi(\bar{s}_i, \boldsymbol{x}) = \bar{j} \\ 0, & \text{otherwise} \end{cases}, \quad \text{for } s, j \in \{0,1\}, \tag{2}$$

where $(s_i, \boldsymbol{x}) = (x_1, x_2, \dots, x_{i-1}, s, x_{i+1}, \dots, x_n)$. In reliability analysis, this derivative can be used to find situations in which a failure/repair of a given system component results in the failure/repair of the system. Quantification of such situations can be performed to rank importance of the system components [7].

Definition (2) implies four different DPBDs with respect to variable x_i exist. For coherent systems, only DPBDs $\partial\phi(1 \to 0)/\partial x_i(1 \to 0)$ and $\partial\phi(0 \to 1)/\partial x_i(0 \to 1)$ are relevant since there exist no situation in which a failure (repair) of a component can result in system repair (failure). However, this is not true for noncoherent systems and, therefore, DPBDs $\partial\phi(1 \to 0)/\partial x_i(0 \to 1)$ and $\partial\phi(0 \to 1)/\partial x_i(1 \to 0)$ have to be taken into account too [8].

DPBDs can be computed numerically (if the analyzed function is defined by the truth table) or symbolically (if the function is defined by a symbolic expression). Numerical calculation can be implemented using the computer easily. However, it can be applied only to functions of few variables since defining a big Boolean function using the truth table requires a huge amount of memory. This problem can be solved using the symbolic representation. This solution requires creation of complex software that is able to manipulate with different forms of symbolic expressions. Development of such tool has been considered in [9].

The software described in [9] will implement methods needed for reliability analysis. The methods should be based primarily on symbolic manipulation with Boolean (and also with multiple-valued logic) functions. The principal part of the software is a parser that is able to transform a symbolic expression into the form of a multi way tree that can be processed on the computer much more easily than the original string representing the symbolic expression. Normal forms [10] are one of the most commonly used Boolean expressions. In order to work with them, the software has to be able to transform various kinds of Boolean expressions into a specific normal form. In this paper, an algorithm for such transformation is presented. The algorithm assumes that a Boolean expression is represented in the form of a multi way tree. After applying the algorithm, we obtain a new tree that will agree with one of the normal forms that are used in Boolean algebra.

II. Boolean Normal forms

Boolean function can be represented in many forms, and one of them is a symbolic form. A Boolean function can be expressed in a number of symbolic forms, some of which have a specially defined format and are called normal forms [10]. One of the normal forms is a disjunctive normal form or a sum of products. This form consists of elementary conjunctions. An elementary conjunction of n Boolean variables $x_1, x_2, \dots, x_n$ has the following form [11]:

$$P = \bigwedge_{i \in \mathbb{A}} x_i \wedge \bigwedge_{j \in \mathbb{B}} \bar{x}_j \text{, where } \mathbb{A} \cup \mathbb{B} \subseteq \{1,2,\dots,n\} \text{ and } \mathbb{A} \cap \mathbb{B} = \emptyset. \tag{3}$$

Examples of elementary conjunctions are expressions such as $1, \bar{x}_1, x_2, x_1 \wedge \bar{x}_2, \bar{x}_1 \wedge x_2 \wedge x_3$.

Logical expression $\phi(x_1, x_2, \dots, x_n)$ that has the following form [11]:

$$\phi(x_1, x_2, \dots, x_n) = \bigvee_{k=1}^{l} P_k = \bigvee_{k=1}^{l} \left(\bigwedge_{i \in \mathbb{A}_k} x_i \wedge \bigwedge_{j \in \mathbb{B}_k} \bar{x}_j \right), \tag{4}$$

is then known as Disjunctive Normal Form (DNF) composed of l elementary conjunctions denoted as P_k for $k = 1,2,\dots,l$. Examples of logical expressions in DNF are expressions such as $\phi(x_1,x_2,x_3) = x_1 \vee x_2 \wedge \bar{x}_3, \phi(x_1,x_2) = \bar{x}_1 \wedge x_2 \vee x_1 \wedge \bar{x}_2, \phi(x_1,x_2,x_3) = x_1 \wedge x_2 \vee \bar{x}_1 \wedge \bar{x}_2 \vee x_1 \wedge x_2 \wedge \bar{x}_3$.

Another commonly used form is a conjunctive normal form also called product of sums. This form consists of elementary disjunctions (they are known as clauses). For n Boolean variables $x_1, x_2, \dots, x_n$, an elementary disjunction is defined as follows [11]:

$$S = \bigvee_{i\in\mathbb{A}} x_i \wedge \bigvee_{j\in\mathbb{B}} \bar{x}_j \text{, where } \mathbb{A} \cup \mathbb{B} \subseteq \{1,2,\dots,n\} \text{ and } \mathbb{A} \cap \mathbb{B} = \emptyset. \quad (5)$$

Examples of elementary disjunctions are expressions such as $0, \bar{x}_1, x_2, x_1 \vee \bar{x}_2, \bar{x}_1 \vee x_2 \vee \bar{x}_3$.

Logical expression $\phi(x_1, x_2, \dots, x_n)$ that has the following form [11]:

$$\phi(x_1,x_2,\dots,x_n) = \bigwedge_{k=1}^{l} S_k = \bigwedge_{k=1}^{l} \left(\bigvee_{i\in\mathbb{A}} x_i \wedge \bigvee_{j\in\mathbb{B}} \bar{x}_j \right), \quad (6)$$

is Conjunctive Normal Form (CNF), where S_k is the k-th elementary disjunction for $k = 1,2,\dots,l$. Examples of logical expressions in CNF are expressions such as $\phi(x_1,x_2,x_3) = (x_1 \vee x_2) \wedge (x_1 \vee \bar{x}_3), \phi(x_1,x_2) = (x_1 \vee x_2) \wedge (x_1 \vee \bar{x}_2), \phi(x_1,x_2,x_3) = x_1 \vee \bar{x}_2 \vee x_3$.

These normal forms find their usage in a number of fields, such as game theory, artificial intelligence, logic programming, logic design, and reliability analysis. For example, a special DNF, called the Horn clause (condition), is used in proposition logic and logic programming [11], DNF and CNF are used in the area of logic circuits to layout the logic gates from the logic function of circuit [12], or DNF is used in the reliability analysis, specifically in symbolic fault-tree analysis [13].

III. TRANSFORMATION TO NORMAL FORMS

The previous text indicates that normal forms are important in a number of fields. Therefore, it is necessary for the software tool introduced in [9] to transform the expressions of Boolean functions into these basic forms.

Before the transformation of the stored Boolean function into DNF or CNF is performed, it is firstly necessary to ensure that Bool's negation operation (NOT) is only in front of variables or constants. For this purpose, it is necessary to transform the Bool operation that is the operand of the NOT operation. This will transform the operation into its equivalent that is not preceded by operation NOT [14]. The specific transformations of the Boolean operations used in the software tool can be seen in Table I, where a and b represent operands of the Boolean operations.

It is also necessary to ensure that Boolean operations such as exclusive or (XOR), equivalence (EQV), Sheffer stroke (NAND) and Peirce's arrow (NOR) will be replaced with equivalent expressions containing only basic Bool operations, thus AND, OR and NOT [15]. All transformations can be seen in Table II, where a and b represent the operands of Boolean operations.

TABLE I TRANSFORMATION OF NOT OPERATION

Before transformation	After transformation
NOT(NOT a)	a
NOT(a OR b)	a NOR b
NOT(a AND b)	a NAND b
NOT(a NOR b)	a OR b
NOT(a NAND b)	a AND b
NOT(a EQV b)	a XOR b
NOT(a XOR b)	a EQV b

TABLE II TRANSFORMATION OF BOOLEAN OPERATIONS

Before transformation	After transformation
a NAND b	NOT a OR NOT b
a NOR b	NOT a AND NOT b
a EQV b	(a AND b) OR (NOT a AND NOT b)
a XOR b	(a AND NOT b) OR (NOT a AND b)

After performing all of the previous transformations, we get a logical expression that characterizes a function and contains only basic Boolean algebra operations AND, OR and NOT. Also, NOT operation is located just above variables and constants, becuase the transformation are performed in top-down manner. An example of the transformation process for logical expression $(1 \text{ NAND } x_1) \text{ XOR } (0 \text{ NOR } x_2)$ can bee seen on Fig. 1, where red circles depict unwanted nodes for DNF or CNF.

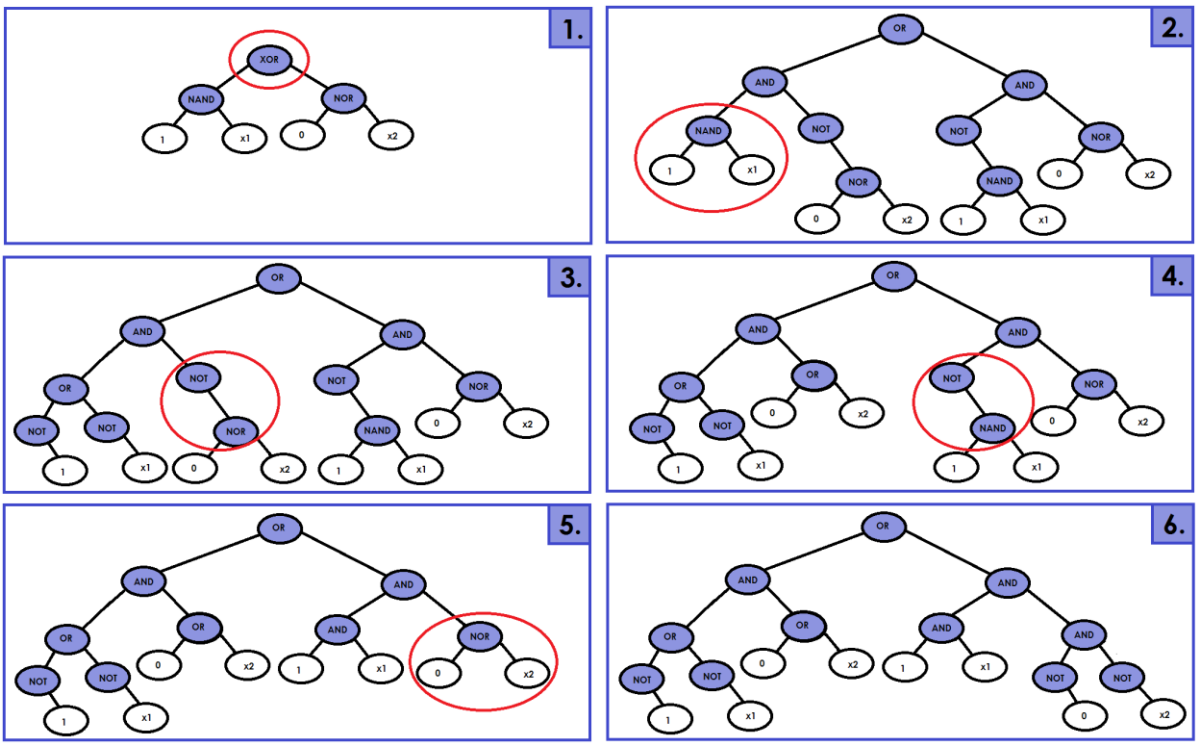

Fig. 1 Illustration of the transformation process

In order to ensure that the expression will be in DNF (i.e. disjunctions of elementary conjunctions) or CNF (i.e. conjunctions of elementary disjunctions), it is necessary to perform the transformation of the arrangement of AND and OR operations [14]. In total, there are three cases needed to be addressed by the relevant transformation. It is also needed to point out that all cases are for DNF, but if the AND operation is changed to OR operation and vice versa, these cases are also usable for CNF.

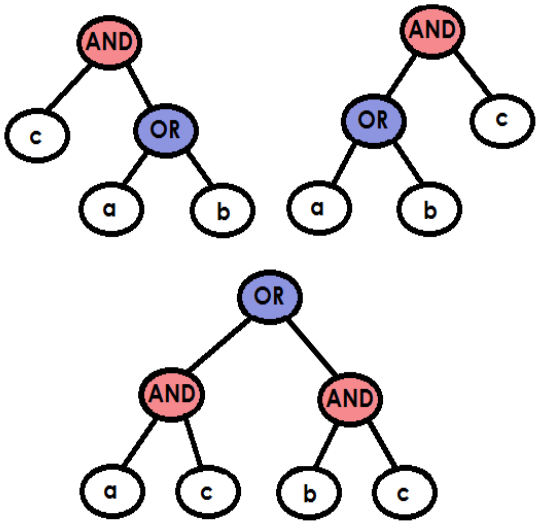

Fig. 2 Case one and its transformation

The first case corresponds to situation c AND (a OR b), or through the commutativity of the operation AND also to the situation(a OR b) AND c. In this case, it is necessary to multiply the operands a and b of the OR operation with another operand c of the AND operation based on the distribution law of the Boolean algebra. This means that the resulting expression (a AND c) OR (b AND c) will be correct for DNF [14].

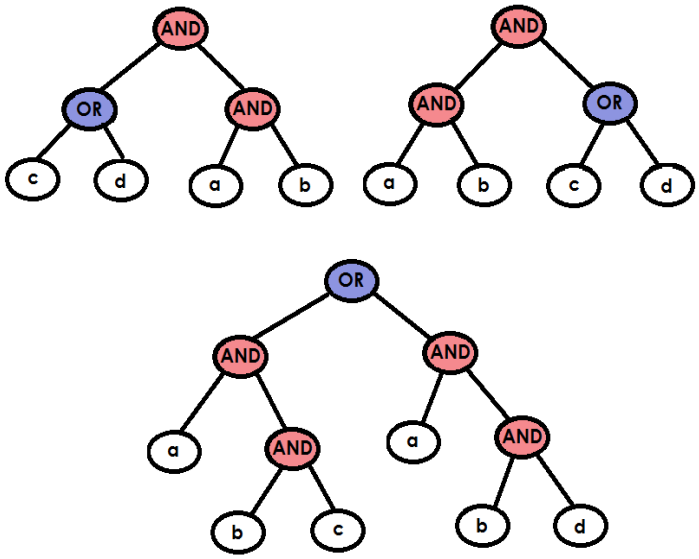

Fig. 3 Case two and its transformation

The second case corresponds to the occurrence of situation (c OR d) AND a AND b, possibly due to the commutativity of the AND operation also the occurrence of situation

a AND b AND(c OR d) . In this case, it is necessary to multiply the operands c and d of the OR operation with operands a and b of the AND operation based on the distribution law. This means that the obtained expression (a AND b AND c) OR (a AND b AND d) will already be correct for DNF [14].

Finally, the third case corresponds to situation (a OR b) AND (c OR d). In this case, it is necessary, on the basis of the distribution law, to multiply the individual operands of OR operations between themselves. After multiplication, the created expression (a AND c) OR (a AND d) OR (b AND c) OR (b AND d) will already be correct for DNF.

After performing all the transformations for the symbolic expression of the Boolean function, the result expression is in DNF or CNF. This transformation process is very intuitive and easy to implement, so it was chosen for a software tool.

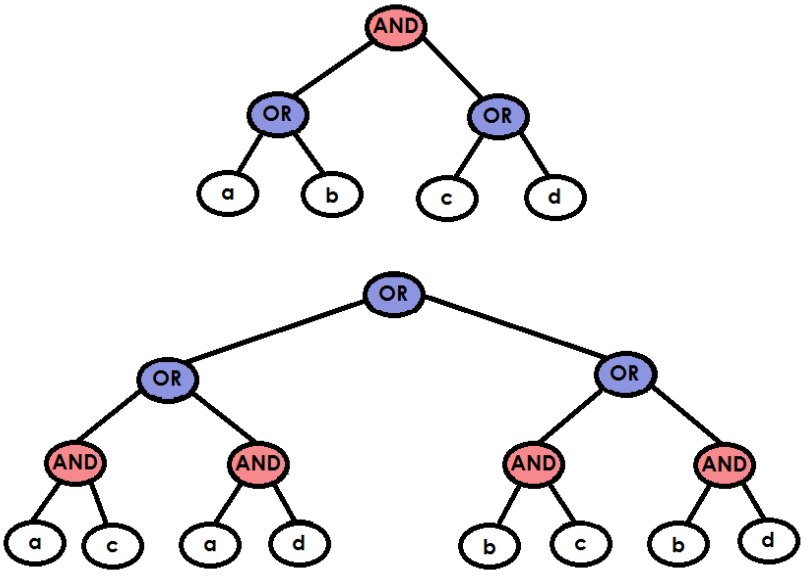

Fig. 4 Case three and its transformation

IV. Conclusion

Boolean functions are very powerful tool, which can be used in many fields, such as game theory, propositional theory, logic programming and reliability analysis. They can be represented by many forms. One of them is symbolic expression, which can be easily read by humans but not computers. The special symbolic expressions, called normal forms, consist only of specific Boolean operations and are used in a number of fields. However, retrieving these forms from a symbolic expression of Boolean function may be hard and time consuming. Because of that, the software introduced in [9] was extended by other functionalities that allow obtain normal forms, specifically DNF and CNF, from any symbolic representation of Boolean function.

In order to receive Boolean normal forms, a transformation process is needed. In this paper, we presented the transformation of symbolic expressions of a Boolean function by replacing Boolean operation into a form that contains only basic Boolean algebra operations AND, OR, and NOT, which is located just in front of variables or constants, and by transforming three specific cases described above that are not valid for DNF or CNF. This transformation process is intuitive and also effective for tree structure in which the symbolic expression is stored in the software.

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