I.J. Modern Education and Computer Science, **2024, 2, 45-57**
Published Online on April 8, 2024 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijmecs.2024.02.04

STEM Project for Vehicle Image Segmentation Using Fuzzy Logic

Serhiy Balovsyak
Yuriy Fedkovych Chernivtsi National University, Chernivtsi, 58012, Ukraine
E-mail: s.balovsyak@chnu.edu.ua
ORCID iD: https://orcid.org/0000-0002-3253-9006

Oleksandr Derevyanchuk
Yuriy Fedkovych Chernivtsi National University, Chernivtsi, 58012, Ukraine
E-mail: o.v.derevyanchuk@chnu.edu.ua
ORCID iD: https://orcid.org/0000-0002-3749-9998

Vasyl Kovalchuk
Oleksandr Dovzhenko Hlukhiv National Pedagogical University, Hlukhiv, 41400, Ukraine
E-mail: v.i_kovalchuk@ukr.net
ORCID iD: https://orcid.org/0000-0002-5006-573X

Hanna Kravchenko
High State Educational Establishment «Chernivtsi transport college», Chernivtsi, 58000, Ukraine
E-mail: hannakravchenko81@gmail.com
ORCID iD: https://orcid.org/0009-0004-7609-0345

Yuriy Ushenko*
Yuriy Fedkovych Chernivtsi National University, Chernivtsi, 58012, Ukraine
E-mail: y.ushenko@chnu.edu.ua
ORCID iD: https://orcid.org/0000-0003-1767-1882
*Corresponding Author

Zhengbing Hu
School of Computer Science, Hubei University of Technology, Wuhan, China
E-mail: drzbhu@gmail.com
ORCID iD: https://orcid.org/0000-0002-6140-3351

Received: 10 October, 2023; Revised: 12 December, 2023; Accepted: 23 January, 2024; Published: 08 April, 2024

Abstract: A STEM project was implemented, which is intended for students of technical specialties to study the principles of building and using a computer system for segmentation of images of railway transport using fuzzy logic. The project consists of 4 stages, namely stage #1 "Reading images from video cameras using a personal computer or Raspberry Pi microcomputer", stage #2 "Digital image pre-processing (noise removal, contrast enhancement, contour selection)", stage #3 "Segmentation of images", stage #4 "Detection and analysis of objects on segmented images by means of fuzzy logic". Hardware and software tools have been developed for the implementation of the STEM project. A personal computer and a Raspberry Pi 3B+ microcomputer with attached video cameras were used as hardware. Software tools are implemented in the Python language using the Google Colab cloud platform. At each stage of the project, students deepen their knowledge and gain practical skills: they perform hardware and software settings, change program code, and process experimental images of vehicles. It is shown that the processing of experimental images ensures the correct selection of meaningful parts in images of vehicles, for example, windows and number plates in images of locomotives. Assessment of students' educational achievements was carried out by testing them before the start of the STEM project, as well as after the completion of the project. The topics of the test tasks corresponded to the topics of the stages of the STEM project. Improvements in educational achievements were obtained for all stages of the project.

Index Terms: STEM Education, STEM Project, Project-Based Learning (PjBL), Artificial Intelligence in Education, Image Segmentation, Fuzzy Logic.

1. Introduction

In the modern educational process, various STEM projects (S - science, T - technology, E - engineering, M - mathematics) are often implemented, which combine natural sciences, technologies, engineering and mathematics [1, 2, 3]. Such projects, in addition to studying a certain topic, are also designed to solve practical problems. Due to this, the participants of STEM projects are highly motivated to implementation of the project. A feature of STEM projects is the technical orientation and integration with the project of a number of educational subjects and scientific areas. Therefore, to generalize and deepen students' knowledge of technical subjects, it is advisable to implement STEM projects.

When training students of technical specialties at the university, in particular, the specialty "Professional Education (Mechanical Engineering)", it is important to provide students with the necessary competencies for building and using intelligent data analysis systems [4, 5, 6]. The application of intelligent data analysis, in particular, intelligent image analysis [7], allows to automate many tasks in industry, science, transport and other fields. For example, in transport systems, intelligent data analysis is used to recognize vehicles and their details, for technical diagnostics of objects, to control their position and speed of movement, as well as for educational purposes. Currently, there is a need for the development of computer systems for the analysis of the state of rolling stock in railway transport, namely the state of locomotives and wagons. At the same time, in many cases, information about vehicles is obtained using video cameras.

In the images of vehicles, their details and areas in most cases differ in brightness, color, and texture, so it is advisable to use segmentation methods for the analysis of such images [8]. Today, there are a significant number of different segmentation methods, in particular, the region-growing method and the watershed method. The watershed method is particularly effective in segmenting images with clear contours. According to this method, the contours are first highlighted in the image, and then the boundaries of the segments are found taking into account the contours. As a result of segmentation, meaningful areas (segments) are distinguished on the images of locomotives and wagons, for example, windows, headlights, uniform sections of walls, license plates, wheels, etc. are distinguished as segments. Highlighting segments on images greatly simplifies their further computer processing, in particular, determination of turns, sizes and areas of objects, object recognition.

In experimental images, there is not always an unambiguous correspondence of segments to certain objects, for example, the image of a locomotive window may be divided into several segments. Therefore, it is advisable to detect objects in images based on their segments, establish correspondence between objects and their segments using fuzzy functions of segment belonging to a certain object (for example, to a window) [9].

However, a separate study of image segmentation methods and fuzzy logic tools used to build an intelligent vehicle image analysis system does not provide the necessary understanding of the relationships between different parts of the system. Therefore, the goal of the work is to implement an intelligent vehicle image segmentation system using fuzzy logic in the form of a STEM project.

This work is relevant because students' implementation of the STEM project ensures their high motivation and orientation to practical results, deepens students' knowledge and practical skills in the field of digital image processing and artificial intelligence. In the field of digital image processing, students improved their knowledge and skills in practical use of video cameras and software processing of video streams. In the field of artificial intelligence, students improved their knowledge and skills in the practical application of image segmentation methods and fuzzy logic.

2. Related Works

The issue of the huge development of STEM education over the last decade is discussed in the study [2]. The development of STEM is confirmed by the rapid increase in the number of scientific publications on STEM education. A systematic review of publications on the topic of STEM education from 2014 to 2021 showed an increasing trend in the number of quality publications based on citations and substantiated conclusions. Through public engagement, national priority education initiatives, and scientific research, STEM education has become an influential educational movement. An important feature of STEM education is an interdisciplinary approach. Thanks to this, within the framework of one STEM project, students can effectively deepen their knowledge and skills in various scientific areas related, in particular, to the construction and use of computer systems for intelligent image processing.

The use of artificial intelligence in STEM education is considered in the work [10]. Artificial Intelligence in Education (AIEd) is a new interdisciplinary field that applies artificial intelligence technologies in education to improve learning and assessment. Applications of Artificial Intelligence in STEM Education (AI-STEM) is a component of AIEd and focuses on the development and implementation of artificial intelligence applications to support STEM education. Automated artificial intelligence technologies such as machine learning, automated assessment, data mining, and learning analytics have been used in STEM education to improve teaching and learning. To obtain a holistic understanding of the application and integration of artificial intelligence in STEM education, artificial intelligence technologies, subject, information, medium and environment in the AI-STEM system were considered. STEM projects are also an effective means of learning artificial intelligence technology, which are based, in particular, on image segmentation methods and fuzzy logic.

Application of projects in vocational education is considered in the study [11]. A bibliometric approach was used, which makes it possible to understand the structure, directions of research and topics of the projects. 60 articles published in Scopus indexed journals between 2010 and 2022 were used for the analysis. Research has shown that the use of computer technology and STEM projects can increase the effectiveness of student learning.

The STEM Project-based Learning (PjBL) approach is considered in the work [12]. This approach encourages students to investigate complex but important problems for practice. The STEM PjBL approach is student-oriented, has a practical orientation, promotes cooperation, team communication, and better assimilation of knowledge. During project-based learning, students are involved in solving real-world projects, working in collaborative groups, which can increase student success in STEM fields.

Modern methods of semantic image segmentation are discussed in the study [13]. The paper proposes a method of semantic segmentation of images using the developed convolutional neural network (CNN), which involves adaptation to the image size, number of color channels, permissible minimum accuracy of segmentation and other parameters. It is shown that a promising direction for improving segmentation methods is the use of artificial neural networks. The developed method was tested experimentally on the example of semantic segmentation of car images. The obtained experimental results show that the built CNN with a sufficiently short training period ensures the achievement of acceptable accuracy of image segmentation. However, artificial neural networks require rather complex training, and their effectiveness is largely determined by the level of adaptability to the conditions of the task. Therefore, when performing a STEM project, it is advisable to use classic methods of segmentation, for example, the method of watersheds, which is relatively easy to study and implement in software.

The work [14] describes the use of fuzzy logic in educational systems. The structure of a Fuzzy Logic System, which contains blocks of Fuzzification, Fuzzy Logic Inference and Defuzzification, is considered. Fuzzy triangular and trapezoidal membership functions are used to describe fuzzy quantities. Fuzzy Logical Inference is performed based on fuzzy rules using developed fuzzy membership functions. In this paper, fuzzy logic is used in the educational system, however, fuzzy membership functions can be used to describe the membership of image segments to a certain object. This is useful if the image of one object (for example, a vehicle door) is divided into several segments (for example, due to uneven illumination of the object). That is, fuzzy logic can be applied to improve the analysis of segmented images.

In work [15], an analysis of the success of students in higher education was carried out by fuzzy logic. Student success is described by fuzzy triangular and trapezoidal membership functions. Fuzzy logical derivation is performed by the Mamdani algorithm. However, the discussed fuzzy logic tools used to analyze student performance can be used to analyze segmented images.

The possibilities of fuzzy logic for controlling complex systems are described in the work [9]. In particular, Fuzzy Machine Learning Techniques and Fuzzy Optimization Techniques are described. Therefore, in order to increase the efficiency of the proposed system of intellectual analysis of images of vehicles, it is advisable to use fuzzy functions of belonging of image segments to certain objects. Based on the analysis of modern research, a conclusion was made about the feasibility of implementing a STEM project for the segmentation of images of vehicles using fuzzy logic. Carrying out a STEM project will allow students to deepen their knowledge and develop practical skills in artificial intelligence technologies that are used in computer systems for intelligent image processing.

3. Methodology

3.1. Stages of STEM project implementation

The STEM project involves students studying the principles of building and using a computer system for intelligent image analysis. The project includes the following stages:

1. Reading images from video cameras using a personal computer or a Raspberry Pi microcomputer (duration 1 week).
2. Digital image pre-processing (noise removal, contrast enhancement, contour selection) (duration 1 week).
3. Image segmentation (duration 1 week).
4. Detection and analysis of objects on segmented images by means of fuzzy logic (duration 1 week).

TOTAL PROJECT TIME – 1 month.

KEY CONCEPTS: STEM education, digital image processing, noise removal, contrast enhancement, contour selection, image segmentation, fuzzy logic, intelligent image processing system.

3.2. Reading images from video cameras (stage #1 of the project)

To read images, USB video cameras are used, the video stream from which is read through the USB ports of a personal computer or a Raspberry Pi microcomputer. Images of objects are received as individual frames of a video stream. The initial color image is read as a three-dimensional array $f_{RGB}(i, k, c)$, where $i = 0, ..., M-1$; $k = 0, ..., N-1$; M – image height in pixels, N – image width in pixels, $c = 0, ..., 2$ – color channel number (Red, Green, Blue) [8]. The f_{RGB} color images are converted to shades of gray (image f), which are processed by software as rectangular matrices $f = (f(i, k))$, where $i = 0,..., M-1$, $k = 0,..., N-1$. The brightness of an image pixel (in grayscale) is described by one byte (8 bits), so the pixel brightness value is in the range 0 to 255.

The task of the students at this stage is to connect a certain model of video camera (for example, Logitech HD Webcam C270) to the computer, programmatically adjust the parameters of the video cameras, and obtain a series of photos for the objects under study using the video cameras. Software setting of video camera parameters consists in setting image resolution, "Brightness" and "Contrast" parameters of video cameras (which are selected from the list of valid values). The parameters of the video cameras are set to ensure the maximum visual quality of the read images.

3.3. Digital image pre-processing (stage #2 of the project)

The digital image pre-processing of images consists in removing noise, increasing contrast, highlighting contours. This makes it possible to increase the accuracy of segmentation, since the experimental images of trains contain a certain level of noise, the images have a non-uniform background and contrast.

The experimental images mainly contain Gaussian and impulse noise. Removal of Gaussian noise is performed by a Gaussian filter, the kernel of which is described by the Standard deviation σ_{NG} [16]. Reduction of the level of impulse noise in the image is performed using a median filter with a window size of d_M.

The students' task is to determine what kind of noise is present in the image by analyzing image profiles [17]. Depending on this, Gaussian or impulse noise (or two types of noise at the same time) is removed. The parameters of the filters are chosen to reduce the noise level without significantly damaging the useful signal.

The developed program increases both global and local contrast. Increasing the contrast allows you to highlight the contours of the image more accurately. Local contrast enhancement is performed as a result of window processing of image f in shades of gray (size $M \times N$ pixels) [18]. Within each window w (size $M_w \times N_w$ pixels) the minimum and maximum brightness values are calculated. The obtained values of local minima are recorded in the rectangular matrix of the lower envelope $f_{min1} = f_{min1}(i, k)$, where $i = 0, ..., M$-1; $k = 0, ..., N$-1. The obtained values of local maxima are recorded in the rectangular matrix of the upper envelope $f_{max1} = f_{max1}(i, k)$, where $i = 0, ..., M$-1; $k = 0, ..., N$-1. In order to avoid brightness distortions when local contrast is increased, filtering of the lower (f_{min1}) and upper (f_{max1}) brightness envelopes of images is performed. Filtering of the envelopes is performed by a Gaussian filter with a Standard Deviation σ_{wG} (for example, σ_{wG} =16).

On the basis of the envelopes (f_{min1s}, f_{max1s}) and the initial image f, the resulting image f_C with increased local contrast and removed inhomogeneous background is calculated by the formula

$$f_C(i,k) = \frac{f(i,k) - f_{min\,1c}(i,k)}{f_{max\,1c}(i,k) - f_{min\,1c}(i,k)} = (f(i,k) - f_{min\,1c}(i,k)) \cdot k_C(i,k), \quad (1)$$

where

$i = 0,..., M$-1; $k = 0,..., N$-1;
$f_{min1c} = f_{min1}(i, k)$ – filtered lower envelope of image brightness;
$f_{max1c} = f_{max1}(i, k)$ – filtered upper envelope of image brightness;
$k_C(i, k) = 1/(f_{max1c}(i, k) - f_{min1c}(i, k))$ – local contrast coefficients.

In order to prevent the appearance of artifacts on the reconstructed f_C images, a contrast limiting factor k_{CMax} (for example, $k_{CMax} = 5$) is set for the maximum values of the local contrast coefficients k_C.

When processing color images, the pixel value of a g_{RGB} color image with increased contrast is calculated by the formula

$$g_{RGB}(i,k,c) = \frac{f_C(i,k) \cdot f_{RGB}(i,k,c)}{f(i,k)}, \quad (2)$$

where $i = 0,..., M$-1; $k = 0,..., N$-1; $c = 0, ..., 2$ – color channel number;
f_{RGB} – initial color image.

The students' task is to choose the values of the window height M_w, the window width N_w and the contrast limiting factor k_{CMax}. The selected values should provide an increase in image contrast without the appearance of distortions (artifacts).

Image contours are distinguished by the Sobel method [8]. The students' task is to choose a binarization threshold for image contours. In the case of the presence of too many contours in the image, the binarization threshold increases, and in the other case, it decreases.

3.4. Image segmentation (stage #3 of the project)

Image segmentation is performed by the method of watersheds or the method of contour lines (directly based on image contours). The watershed method is particularly effective in segmenting images with clear contours [8]. According to this method, the contours are first highlighted in the image, and then the boundaries of the segments are found taking into account the contours. The name of the method comes from geography, where a watershed means a conventional line that separates the catchment areas of different river systems. The water separation method uses this principle of separation, but instead of water, the image is divided into segments. In the method of watersheds, a halftone image is represented as a surface of levels, where the brightness values of pixels are interpreted as their heights.

The students' task is to choose a segmentation method (watershed method or contour line method). It is necessary to choose a method that provides higher segmentation accuracy for a set of experimental images. It is also necessary to perform a selection of segments by size, that is, discard segments with too small or too large sizes.

3.5. Detection and analysis of objects (stage #4 of the project)

Detection of objects in images (windshield, headlights, license plates, etc.) based on their segments is performed using fuzzy sets [19]. For example, the detection of headlights and license plates is performed as follows. A set of experimental images is studied; based on the analysis of the parameters of the segments that correspond to the headlights and license plates, the parameters of the fuzzy triangular membership functions are determined. For each segment with the number n_{s1}, its normalized height s_{iw2N} is determined (for an image height of 1000 pixels, and for other image heights, the values of s_{iw2N} change proportionally) and the corresponding value of the segment membership function $\mu_{hLh}(s_{iw2N})$ to headlights and license plates is found, taking into account its height. Similarly, the values of the membership functions $\mu_{hLw}(s_{kw2N})$ taking into account the width of the segment s_{kw2N}, the membership function $\mu_{hLic}(s_{ic2N})$ taking into account the coordinates of the center of the segment by height s_{ic2N}, the membership functions $\mu_{hLkc}(s_{kc2N})$ taking into account the coordinates of the center of the segment by width s_{kc2N} are determined similarly. The values of the resulting membership functions of the segment with the number n_{s1} to headlights and license plates, taking into account all the parameters of the segment (height, width, coordinates of the center by height and width), are determined as the product of the values of the corresponding membership functions:

$$\mu_{hLs}(n_{s1}) = \mu_{hLh}(s_{iw2N}) \cdot \mu_{hLw}(s_{kw2N}) \cdot \mu_{hLic}(s_{ic2N}) \cdot \mu_{hLkc}(s_{kc2N}). \quad (3)$$

From the maximum of the μ_{hLs} membership function, the number of the segment n_{s1_hL}, which most completely belongs to headlights and license plates, is calculated. Other objects in the image are detected similarly.

Object analysis consists in estimating the size, shape, and position of detected objects in the images.

The students' task is to determine the parameters of fuzzy triangular membership functions. For example, when detecting headlights and license plates, the maximum of the membership function $\mu_{wsh}(s_{iw2N})$ should correspond to the average value of the height of the headlights and license plates for the series of investigated images. Parameters of other fuzzy membership functions are defined similarly.

4. Hardware and software implementation of the project

To implement the STEM project, a computer system with the following structure was developed (Fig. 1).

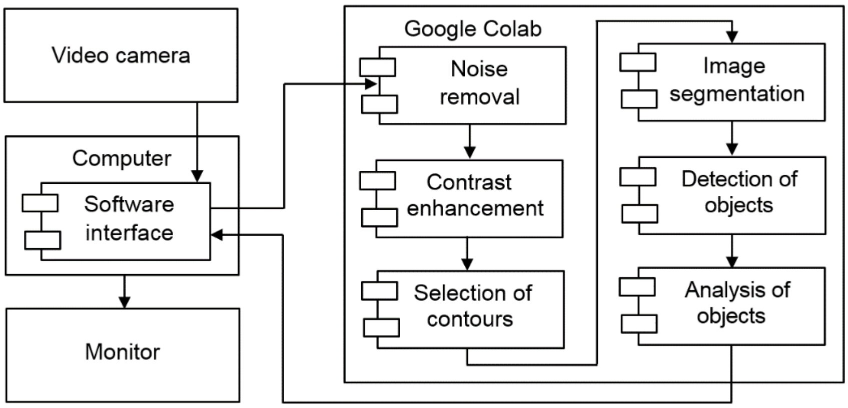


Fig. 1. Deployment diagram of a computer system for vehicle image segmentation using fuzzy logic.

During the implementation of the STEM project, the developed hardware and software tools of the computer system are used. A personal computer or a Raspberry Pi 3B+ microcomputer [20] with attached video cameras was used as hardware. Software tools of the computer system for the segmentation of images of trains are implemented in the Python language using the Google Colab cloud platform (in the Jupyter Notebook) [21].

The software uses several libraries:

- Scipy (import of the ndimage class) is a library for processing digital images.
- NumPy (imported as np) is a library for processing multidimensional arrays, contains a set of basic mathematical functions.

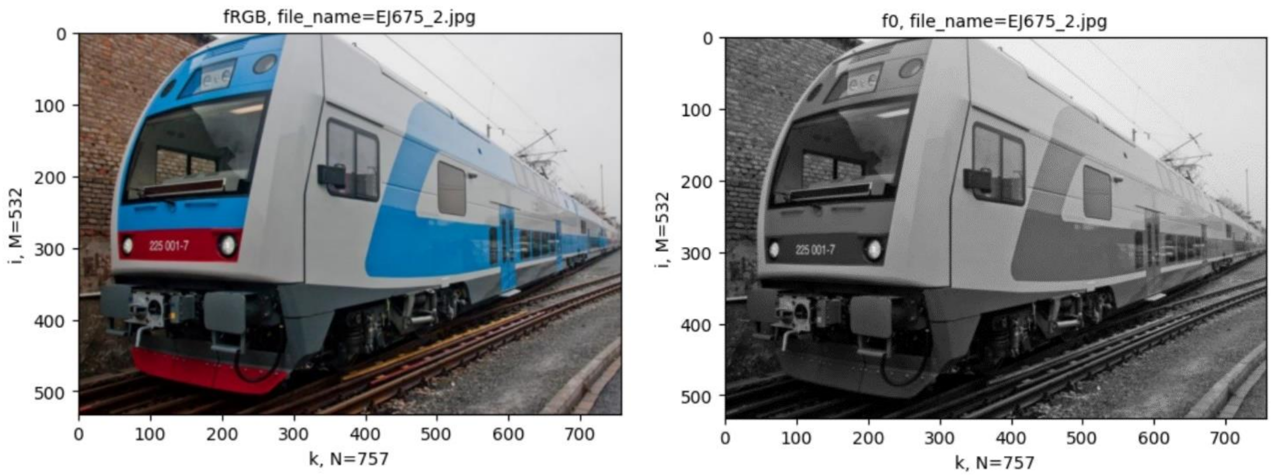
- MatPlotLib (imported as plt) is a library for plotting and rendering images.
- Scikit-fuzzy (imported as fuzz) is a library for working with fuzzy logic (Fuzzy Logic).

Software image processing consists in reading initial images from digital video cameras, removing noise, increasing contrast, highlighting contours, segmenting images, detecting objects on segmented images by means of fuzzy logic, analyzing the shape and size of detected objects.

The initial (input) data for the developed program are digital images read from a video camera or from graphic files (images of trains, locomotives, wagons) (Fig. 2). The program supports reading images of basic graphic formats (.bmp, .jpg, .tiff); processing of the following types of images is provided: grayscale, color, indexed.

Output data (results) of the program are image segments and coordinates of rectangles that correspond to meaningful areas of objects (for example, windows, license plates).

In Python, image filtering with a Gaussian filter kernel (with standard deviation σ_{NG}) is performed by the "gaussian_filter" function of the Scipy library. Median filtering (with window size d_M) is performed by the "median_filter" function of the Scipy library (Fig. 3).



a) b)

Fig. 2. Initial f_{RGB} color image (a) and initial f_0 grayscale image (b)

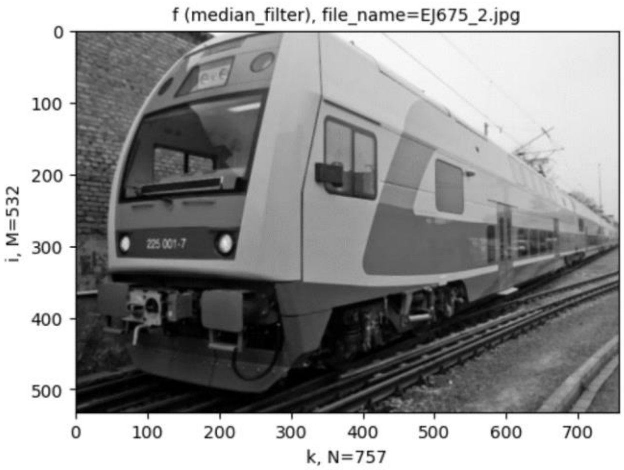


Fig. 3. Image f after median filtering, filter window size $d_M = 3$

On the basis of image brightness envelopes (f_{min1c}, f_{max1c}) (Fig. 4) and the initial image f according to formula (1), the image f_C with increased contrast is calculated (Fig. 5a). The g_{RGB} color image (Fig. 5b) with increased contrast is calculated according to formula (2).

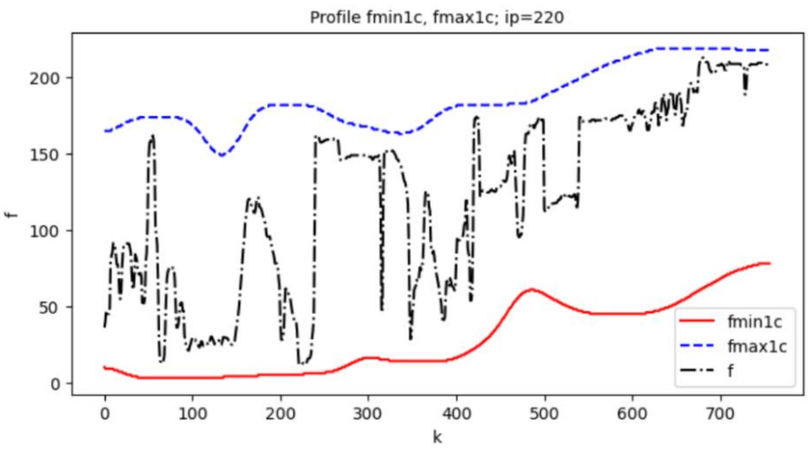


Fig. 4. Profiles of filtered lower f_{min1c} and upper f_{max1c} brightness envelopes of image f, as well as image f (Fig. 3) for pixel row i =220

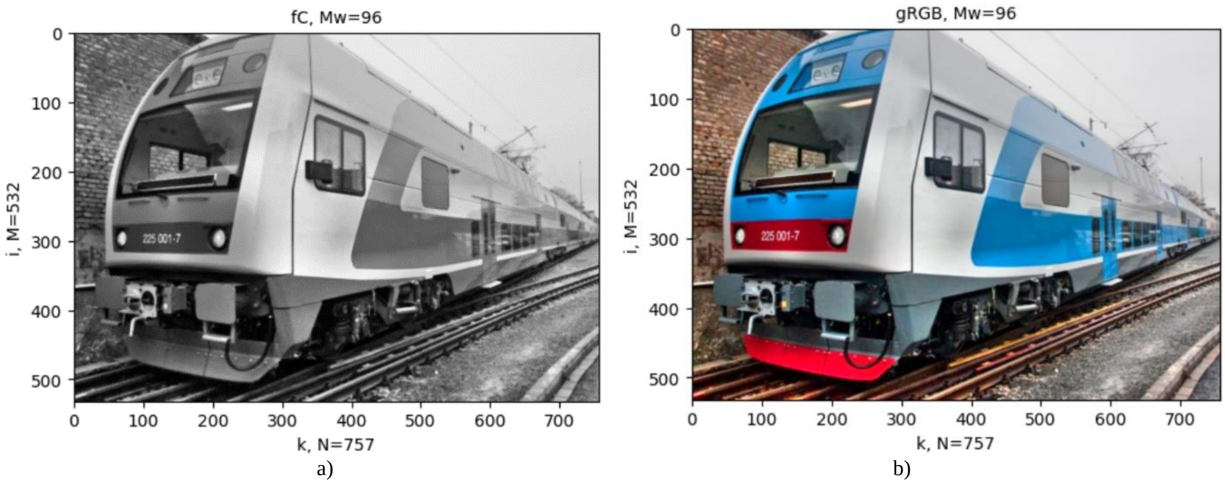


Fig. 5. Images with removed heterogeneous background and increased local contrast, obtained on the basis of image f (Fig. 3): a) image f_C in shades of gray; b) g_{RGB} color image

Calculation of g_{CS} contours (Fig. 6) on the f_C image is performed by the "sobel" function of the Scipy library. The binarization threshold for the contour image is calculated by multiplying the given coefficient by the Th_otsu threshold, which is calculated according to the Otsu method.

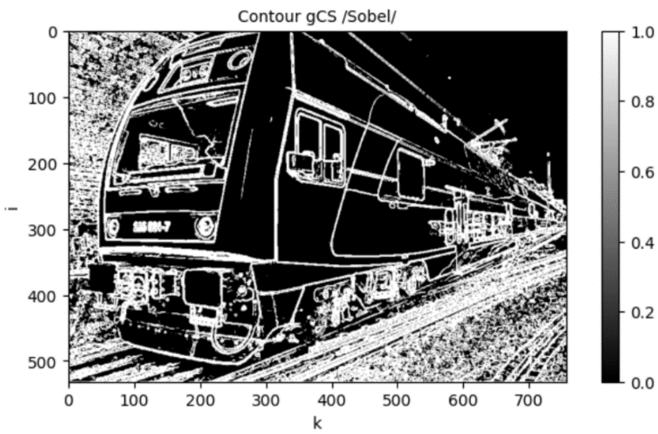


Fig. 6. Contours of the g_{CS} image obtained on the basis of the f_C image (Fig. 5) by the Sobel method

Segmentation of images in Python is performed by the watershed method (the "watershed" function of the Scipy library) or the contour line method (the "label" function of the Scipy library) based on g_{CS} contours that highlight segment boundaries. As a result of image segmentation, a g_{sL} array is obtained, in which segment numbers are recorded. For the received image segments, their selection is performed by size, as a result of which segments of a certain height (greater than s_{iw_min}; for example, s_{iw_min} = 30) and width (greater than s_{kw_min}; for example, s_{kw_min} = 30) are selected (Fig. 7).

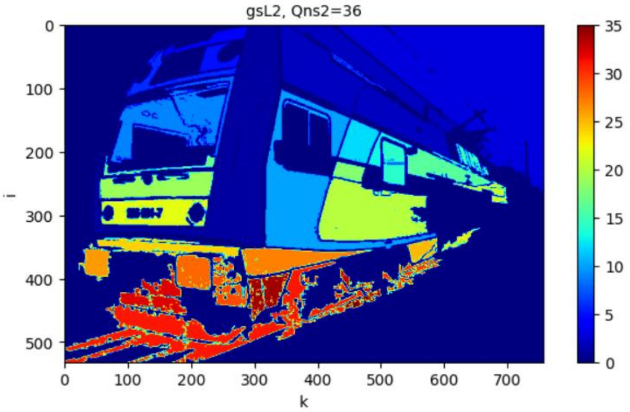


Fig. 7. Segmented g_{sL2} image after segment selection, segments with small sizes are discarded; Q_{ns2} is the number of segments

Detection of objects in the image is performed using fuzzy sets. Calculation of fuzzy triangular membership functions is performed by the "trimf" function of the Scikit-fuzzy library. Let's consider the detection of objects using the example of detecting headlights and number plates on the image of a locomotive. Based on the analysis of the parameters of the segments that correspond to headlights and license plates, the parameters of fuzzy triangular membership functions are determined (Fig. 8). For each segment with the number n_{s1}, its normalized height s_{iw2N} is determined (for an image height of 1000 pixels) and the corresponding value of the segment membership function $\mu_{hLh}(s_{iw2N})$ to the area of headlights and license plates is found, taking into account its height (Fig. 8a).

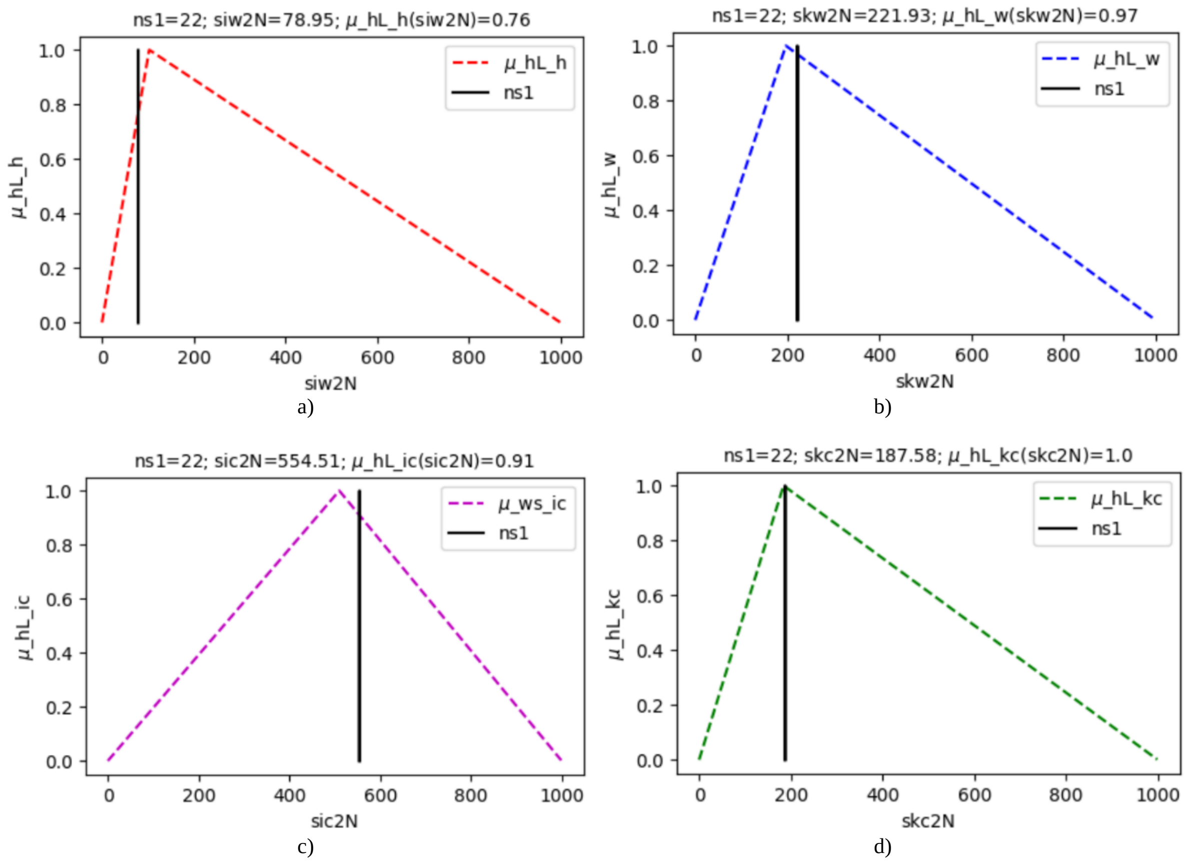


Fig. 8. Membership functions of fuzzy sets that describe the membership of the segment numbered n_{s1} to headlights and license plates depending on: a) normalized segment height s_{iw2N} (for an image height of 1000 pixels); b) normalized segment width s_{kw2N} (for an image width of 1000 pixels); c) normalized coordinate of the segment center by height s_{ic2N} (for an image height of 1000 pixels); d) normalized coordinates of the segment center by width s_{kc2N} (for an image width of 1000 pixels).

Similarly, the values of the membership functions $\mu_{hLw}(s_{kw2N})$ are determined taking into account the width of the segment (Fig. 8b) and the membership functions $\mu_{hLic}(s_{ic2N})$, $\mu_{hLkc}(s_{kc2N})$ taking into account the position of segment center (Fig. 8c, Fig. 8d). The value of the resulting membership functions μ_{hLs} of the segment with the number n_{s1} to headlights and license plates, taking into account all parameters of the segment (height, width, coordinates of the center by height and width), is determined as the product of the values of the corresponding membership functions according to formula (3) (Fig. 9).

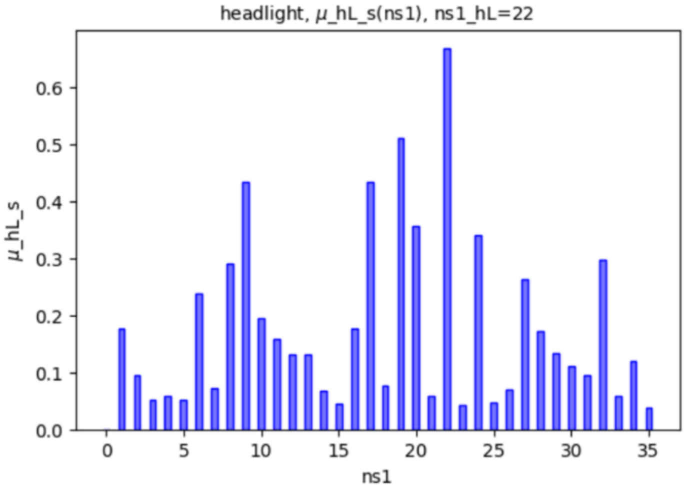


Fig. 9. The value of the resulting functions of belonging $\mu_{hLs}(n_{s1})$ of segments with numbers n_{s1} to headlights and license plates, taking into account all the parameters of the segments (height, width, coordinates of the center); n_{s1_ws} - the number of the segment that most fully belongs to headlights and license plates

From the maximum of the membership function $\mu_{hLs}(n_{s1})$, the number of the segment n_{s1_hL}, which most fully belongs to headlights and license plates, is calculated (Fig. 10). The obtained result is correct.

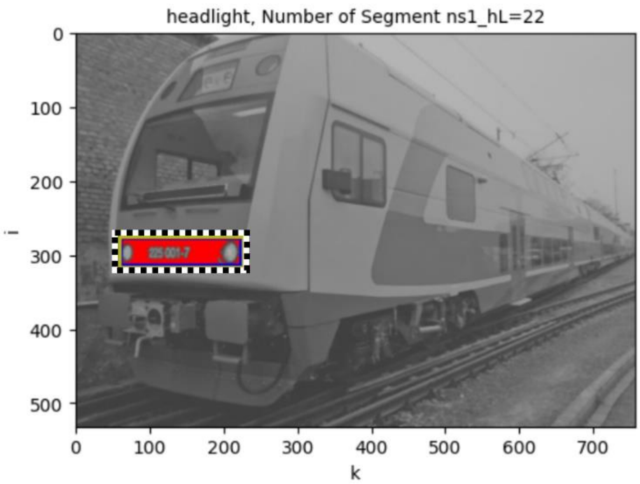
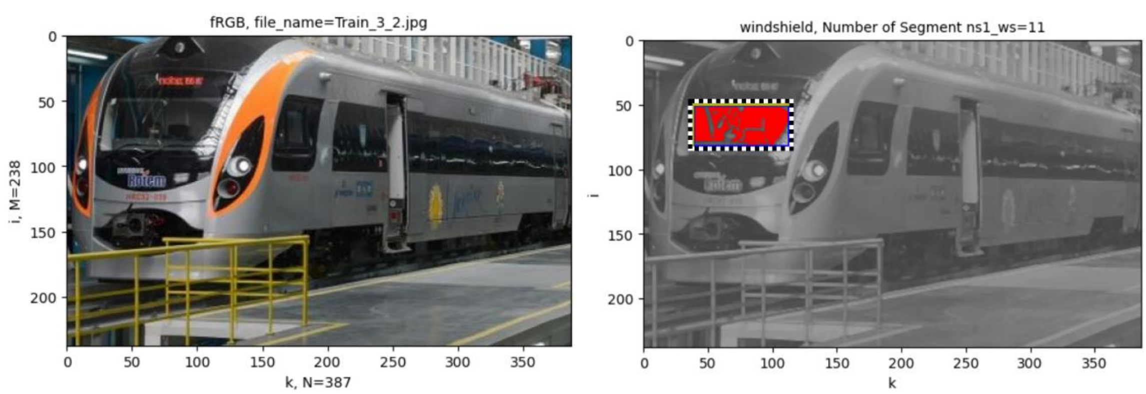


Fig. 10. The result of detecting headlights and license plates

Similarly, the windshield is detected in the image (Fig. 11).



a) b)

Fig. 11. Windshield detection result: a) initial image; b) detection result

The developed STEM project is implemented in stages. At each stage, students configure hardware and software, change program code, and process experimental images of vehicles. As a result of such stages of the project, students deepen their knowledge and acquire practical skills.

5. Results and Discussion

To evaluate the effectiveness of the STEM project, the educational achievements of a group of 12 students (specialty "Professional Education (Mechanical Engineering)") were evaluated before the start of the project, as well as after the completion of the project. Evaluation of educational achievements was carried out by performing 4 tests, the maximum possible number of points for each test is equal to 100. The topics of the test tasks corresponded to the topics of the STEM project stages. Test questions were both theoretical and practical.

The results of the testing of the students in all subjects were analyzed, for each test the Mean score for the group and the Standard Deviation of the students' scores relative to the mean score were calculated [22] (Fig. 12, Table 1).

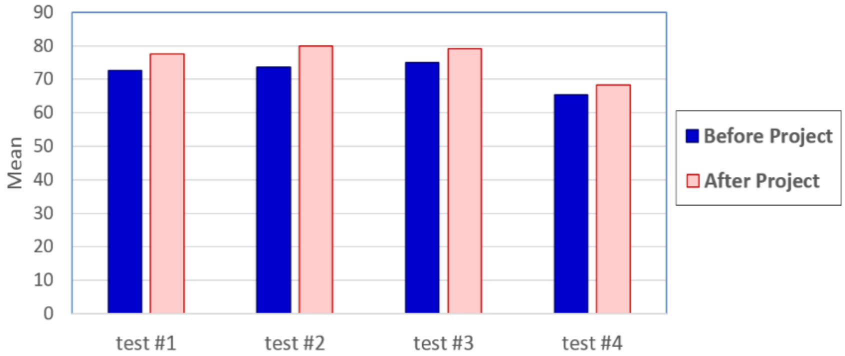


Fig. 12. Mean values of student test results

Table 1. Student test results

Tests	Mean		Standard Deviation	
	Before Project	After Project	Before Project	After Project
test #1	72.667	77.583	12.153	11.966
test #2	73.583	79.833	12.810	12.037
test #3	75.000	79.167	12.828	11.831
test #4	65.417	68.250	10.431	9.937

For tests #1-#4 the mean score for the students' group after the STEM project increased by 4.917, 6.250, 4.167 and 2.833 points, respectively (Table 1). The Standard Deviation of students' grades after the implementation of the project slightly decreased (from 12.055 to 11.443 for all tests). As a result of the project, students' academic achievement improved the most for test 2, which corresponds to the topic of stage #2 of the project "Digital Image Preprocessing". This can be explained by the fact that the issues of image noise removal, contrast enhancement, and contour selection are relatively easy to understand and implement in software.

The mean improvement in student achievement was obtained for Test #1 (Stage #1 “Reading images from video cameras using a PC or Raspberry Pi microcomputer”) and Test #3 (Stage #3 “Image segmentation”). The lowest improvement in students' academic achievements was obtained for test #4 (stage #4 "Detection and analysis of objects on segmented images by means of fuzzy logic"). This is explained by certain difficulties in learning the principles of fuzzy logic.

6. Conclusions

As a result of the work, a STEM project was developed, which is designed for students to learn the principles of building and using a computer system for segmenting images of vehicles using fuzzy logic. The project includes the following 4 stages:

1. Reading images from video cameras using a personal computer or a Raspberry Pi microcomputer.
2. Digital image pre-processing (noise removal, contrast enhancement, contour selection).
3. Image segmentation.
4. Detection and analysis of objects on segmented images using fuzzy logic.

During the implementation of the STEM project, hardware and software tools of a computer system for intelligent image analysis were developed. A personal computer or Raspberry Pi 3B+ microcomputer with attached video cameras was used as hardware. Software tools for train image segmentation are implemented in Python using the Google Colab cloud platform. At each stage of the project, students configure hardware and software, change program code, and process experimental images of vehicles. The processing of experimental images showed the correct result of segmentation of images and selection of meaningful parts of vehicles, for example, windows and license plates on images of locomotives.

The scientific novelty of the work is the use of fuzzy membership functions, which made it possible to correctly determine the membership of image segments to component parts of vehicles.

Assessment of educational achievements of students of the "Professional Education (Mechanical Engineering)" specialty was carried out by testing them before the start of the STEM project, as well as after the completion of the project. The topics of the test tasks corresponded to the topics of the stages of the STEM project. The average score for the group after the STEM project increased for all tests #1-#4 by 4,917, 5,667, 3,250, and 2,833 points, respectively. As a result of the project, students' educational achievements improved the most for test 2, which corresponds to the topic of stage 2 of the "Digital Image Pre-processing" project. Since the improvement of educational achievements was obtained for all stages of the project, therefore, the implementation of the project can be considered successful.

References

[1] Y. Li, Y. Xiao, K. Wang, et al., “A systematic review of high impact empirical studies in STEM education”, *International Journal of STEM Education (IJSTEM)*, vol. 9, no. 72, pp. 1-18, 2022. doi: 10.1186/s40594-022-00389-1.

[2] Y. Li, Y. Xiao, “Authorship and topic trends in STEM education research”, *International Journal of STEM Education (IJSTEM)*, vol. 9, no. 62, pp. 1-7, 2022. doi: 10.1186/s40594-022-00378-4.

[3] V. Kovalchuk, A. Androsenko, A. Boiko, V. Tomash, O. Derevyanchuk, “Development of Pedagogical Skills of Future Teachers of Labor Education and Technology by means of Digital Technologies”, *International Journal of Computer Science and Information Security*, vol. 22, no. 9, pp. 551-560, 2022. doi: 10.22937/IJCSNS.2022.22.9.71.

[4] Thiago Nascimento Rodrigues, "A Fast Topological Parallel Algorithm for Traversing Large Datasets", International Journal of Information Technology and Computer Science, Vol.15, No.1, pp.1-8, 2023.

[5] Nikita Taneja, Hardeo Kumar Thakur, "Evaluating the Scalability of Matrix Factorization and Neighborhood Based Recommender Systems", *International Journal of Information Technology and Computer Science*, Vol.15, No.1, pp.21-29, 2023.

[6] Sun Fayou, Hea Choon Ngo, Yong Wee Sek, “Combining Multi-Feature Regions for Fine-Grained Image Recognition”, *International Journal of Image, Graphics and Signal Processing*, vol. 14, no. 1, pp. 15-25, 2022.

[7] DaeEun Kim, Dosik Hwang, *Intelligent Imaging and Analysis*. Switzerland, Basel: MDPI, 2020.

[8] R. Gonzalez, R. Woods, *Digital image processing*. 4th edidion, Pearson/ Prentice Hall, NY, 2018.

[9] A. R. Fayek, “Fuzzy Logic and Fuzzy Hybrid Techniques for Construction Engineering and Management”, *Journal of Construction Engineering and Management*, vol. 146, no. 7, pp. 1-12, 2020. doi: 10.1061/(ASCE)CO.1943-7862.0001854.

[10] W. Xu, F. Ouyang, “The application of AI technologies in STEM education: a systematic review from 2011 to 2021”, *International Journal of STEM Education (IJSTEM)*, vol. 9, no. 59, pp. 1-20, 2022. doi: 10.1186/s40594-022-00377-5.

[11] Selamat Triono Ahmad, Ronal Watrianthos, Agariadne Dwinggo Samala, Mukhlidi Muskhir, Gimba Dogara, “Project-based Learning in Vocational Education: A Bibliometric Approach”, *International Journal of Modern Education and Computer Science*, vol. 15, no. 4, pp. 43-56, 2023.

[12] M.A. Samsudin, S.M. Jamali, A.N. Md Zain, N. Ale Ebrahim, “The Effect of STEM Project Based Learning on Self-Efficacy among High-School Physics Students”, *Journal of Turkish Science Education*, vol. 17, no. 1, pp. 94-108, 2020. doi: 10.36681/tused.2020.15.

[13] Ihor Tereikovskyi, Zhengbing Hu, Denys Chernyshev, Liudmyla Tereikovska, Oleksandr Korystin, Oleh Tereikovskyi, “The Method of Semantic Image Segmentation Using Neural Networks”, *International Journal of Image, Graphics and Signal Processing*, vol. 14, no. 6, pp. 1-14, 2022.

[14] Tarik Bourahi, Azouazi Mohamed, Abdessamad Belangour. “The application of fuzzy logic to improve orientation in system education in Morocco”, *Journal of Theoretical and Applied Information Technology*, vol. 99, no. 13, pp. 3292-3305, 2021.

[15] Tengku Zatul Hidayah Tengku Petra, Mohd Juzaiddin Ab Aziz, “Analysing Student Performance in Higher Education Using Fuzzy Logic Evaluation”, *International journal of scientific & technology research*, vol. 10, no. 01, pp. 322-327, 2021.

[16] S.V. Balovsyak, Kh. S. Odaiska, “Automatic Determination of the Gaussian Noise Level on Digital Images by High-Pass Filtering for Regions of Interest”, *Cybernetics and Systems Analysis*, vol. 54, no. 4, pp. 662-670, 2018. doi: 10.1007/s10559-018-0067-3.

[17] S.V. Balovsyak, O.V. Derevyanchuk, I.M. Fodchuk, “Method of calculation of averaged digital image profiles by envelopes as the conic sections”, *Advances in Intelligent Systems and Computing*, Hu Z., Petoukhov S., Dychka I., He M. (Eds.), Springer International Publishing, vol. 754, pp. 204–212, 2019. doi: 10.1007/978-3-319-91008-6_21.

[18] S.V. Balovsyak, O.V. Derevyanchuk, H.O. Kravchenko, O.P. Kroitor, V.V. Tomash, “Computer system for increasing the local contrast of railway transport images”, *Proc. SPIE, Fifteenth International Conference on Correlation Optics*, vol. 12126, pp. 121261E1-7, 2021. doi: 10.1117/12.2615761.

[19] S.V. Balovsyak, O.V. Derevyanchuk, Ya.V. Derevianchuk, V.V. Tomash, S.V. Yarema, “Segmentation of railway transport images using fuzzy logic”, *Trans Motauto World*, vol. 7, no. 3, pp. 122-125, 2022.

[20] Raspberry Pi 3 Model B+. URL: https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/.

[21] Google Colab. URL: https://colab.research.google.com.

[22] F. Taşdemir, “Examination of the Effect of STEM Education on Academic Achievement: A Meta-Analysis Study”, *Education Quarterly Reviews*, vol. 5, no. 2, pp. 282-298, 2022. doi: 10.31014/aior.1993.05.02.489.

Authors' Profiles

Serhiy Balovsyak, Graduated from Chernivtsi State University (1995). In 2018, he defended his doctoral dissertation in the specialty "Computer systems and components".

Currently position – associate professor at the Department of Computer Systems and Networks of Yuriy Fedkovych Chernivtsi National University, Ukraine.

Research Interests: digital processing of signals and images, programming, pattern recognition, artificial neural networks.

Oleksandr Derevyanchuk, Received the master of engineering degree (1999) and Ph.D. of Physics and Mathematics (2014) at the Yuriy Fedkovych Chernivtsi National University. He is a Candidate of Physical and Mathematical Sciences, Associate Professor of the Department of Professional and Technological Education and General Physics, Yuriy Fedkovych Chernivtsi National University, Chernivtsi, Ukraine.

Research Interests: digital processing of signals and images, programming, pattern recognition, artificial neural networks.

Vasyl Kovalchuk, Studied at Yuri Fedkovych Chernivtsi State University and got specialist degree in Professional education (1993-1998). In 2014 defended doctoral dissertation "Theoretical and methodological principles of developing pedagogical skills of vocational schools professional training masters in postgraduate education" and became Doctor of Pedagogical Sciences. Professor, head of the department of professional education and technologies of agricultural production, Oleksandr Dovzhenko Hlukhiv National Pedagogical University, Hlukhiv, Ukraine.

Research Interests: include professional and higher education development, introducing innovative teaching technologies in the educational process, teachers' pedagogical skills development, introducing digital technologies in the educational process, emotional intelligence development, leadership.

Hanna Kravchenko: PhD student at the of the Department of Professional and Technological Education and General Physics, Physical, Technical and Computer Sciences Institute of Yuriy Fedkovych Chernivtsi National University, Chernivtsi, Ukraine.

Research Interests: digital processing of signals and images, programming, pattern recognition, artificial neural networks.

Yuriy Ushenko, M.Sc. in Telecommunications (2003). PhD in Optics and Laser Physics (2006). D.Sc. in Optics and Laser Physics, Taras Shevchenko National University of Kyiv (2015). Current position – Professor, Head of Computer Science Department, Yuriy Fedkovych Chernivtsi National University, Ukraine.

Research Interests: Data Mining and Analysis, Computer Vision and Pattern Recognition, Optics & Photonics, Biophysics.

Zhengbing Hu, Prof., Deputy Director, International Center of Informatics and Computer Science, Faculty of Applied Mathematics, National Technical University of Ukraine "Kyiv Polytechnic Institute", Ukraine. Adjunct Professor, School of Computer Science, Hubei University of Technology, China. Visiting Prof., DSc Candidate in National Aviation University (Ukraine) from 2019. Major research interests: Computer Science and Technology Applications, Artificial Intelligence, Network Security, Communications, Data Processing, Cloud Computing, Education Technology.

How to cite this paper: Serhiy Balovsyak, Oleksandr Derevyanchuk, Vasyl Kovalchuk, Hanna Kravchenko, Yuriy Ushenko, Zhengbing Hu, "STEM Project for Vehicle Image Segmentation Using Fuzzy Logic", International Journal of Modern Education and Computer Science(IJMECS), Vol.16, No.2, pp. 45-57, 2024. DOI:10.5815/ijmecs.2024.02.04