



USE OF INTELLIGENT FUZZY IMAGE SEGMENTATION SYSTEMS IN THE PROFESSIONAL TRAINING OF FUTURE SPECIALISTS IN ENGINEERING AND PEDAGOGICAL FIELDS

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Abstract

Relevance: The article addresses the critical issue of integrating intelligent image segmentation systems that utilize fuzzy logic into the training processes for future specialists in engineering and pedagogical fields. This integration is a significant aspect of the digitization of higher education.

Aim: The goal is to implement intelligent vehicle image segmentation systems using fuzzy logic to train specialists in engineering and pedagogical fields.

Methods: The preliminary processing of the images of the studied objects (vehicles) involved digital filtering methods, contour detection, profile analysis, and contrast enhancement. Image segmentation was performed using watershed methods, contour lines, and region growing. After segmentation, the obtained segments were selected based on size. Fuzzy membership functions were then applied to determine the degree of affiliation of the segments to the meaningful parts of the studied objects, ensuring reliable recognition of these parts and stable operation of the intelligent system despite external influences on the acquired images.

Results: A computer system has been developed for the segmentation of vehicle images using fuzzy logic, which has been integrated into the training of specialists in engineering and pedagogical fields. The segmentation methods isolate objects within the images, which are then recognized using fuzzy logic. Thanks to the fuzzy membership functions, elements of vehicle images are reliably recognized even when there is some ambiguity in the shapes of the segments. The practical significance of the developed system is demonstrated through the processing of car images.

Conclusions: The integration of the developed system into the educational process provides students with both theoretical knowledge and practical skills related to intelligent image processing systems.

Keywords: *digitalization of education, higher education institutions, data mining, fuzzy logic, image segmentation, future specialists in engineering and pedagogical fields.*

Introduction. The modern world is characterized by rapid development of digital technologies, which drives global changes in all spheres of human activity, including education. The digitalization of the educational process requires higher education institutions to not only implement the latest technologies into the educational process, but also develop innovative approaches to training professionals capable of working effectively in a digital economy. One important direction of

digitalization in higher education is the integration of intelligent systems into the educational process, specifically image segmentation systems using fuzzy logic, which opens new opportunities for improving the quality and effectiveness of education.

The issue of implementing intelligent image segmentation systems in the professional training of future engineering-pedagogical specialists requires a comprehensive approach. This process is not limited to updating curricula and teaching methods

but also involves the development of material and technical bases, the use of appropriate hardware and software, the preparation of qualified teachers, the creation of conditions for scientific research by students in this field, and the development of effective methods for assessing educational achievements. An important aspect is also collaboration with the IT industry and scientific institutions to update the content of education and enhance the competitiveness of educational programs.

Research sources. The application of the latest digital technologies in education has become the subject of research by scholars such as S. Balovsyak (Balovsyak et al., 2023; Balovsyak et al., 2024), V. Bykov (Bykov et al., 2020; Bykov & Burov, 2020), V. Kovalchuk (Kovalchuk, 2020; Kovalchuk & Soroka, 2021), A. Kocharian, O. Lavrentieva (Pavlenko et al., 2020), S. Litvinova (Kovalchuk et al., 2022), S. Maslich (Kovalchuk et al., 2022), N. Morze (Morze & Strutynska, 2021; Kuzminska et al., 2020), O. Spirin (Spirin, 2021; Spirin & Pinchuk, 2023), S. Semeryakov (Semerikov, S. O. et al., 2022; Papadakis et al., 2023), V. Soroka (Kovalchuk & Soroka, 2020; Kovalchuk et al., 2022), and others.

The use of computer systems for intelligent image processing (Davies, 2012; Kim & Hwang, 2020; Derevyanchuk, 2024) is an important direction of digitalization in professional education, which is closely related to the future professional activity of engineering-pedagogical specialists and can be used to solve applied tasks. Specifically, intelligent image segmentation systems can be effectively used in projects for the automatic processing of vehicle images (Balovsyak et al., 2024; Tereikovskiy et al., 2022). During the implementation of such projects, future professionals enhance their knowledge of data intelligence analysis. Attention is also focused on digital image processing methods: filtering (Balovsyak & Odaiska, 2018), segmentation (Balovsyak et al., 2024; Tereikovskiy et al., 2022), contour detection (Derevyanchuk et al., 2024), contrast enhancement (Balovsyak et al., 2024), and profile analysis (Balovsyak et al., 2019).

To enhance the outcomes in the field of image processing, experts employ a combined approach that incorporates image recognition methods and fuzzy logic (Fayek, 2020; Balovsyak et al., 2023). This enables systems to analyze and interpret visual data with greater accuracy, as fuzzy

logic facilitates the processing of ambiguity and uncertainty often encountered in images.

The goal of this article is to implement intelligent image segmentation systems for vehicles using fuzzy logic for the training of future engineering and pedagogical specialists.

Research methods include theoretical (analysis of scientific studies), digital image filtering methods (median filter and Gaussian filter); edge detection methods (Sobel and Canny methods); profile analysis method (comparative analysis of profiles); contrast enhancement method; image segmentation methods (watersheds, contour lines, and region growing).

The software implementation of the fuzzy image segmentation system is performed using Python, incorporating libraries such as scipy, numpy, matplotlib, and scikit-fuzzy.

Results and discussion. The research revealed that the application of image segmentation and fuzzy logic can significantly enhance the accuracy of analyzing a large volume of images of the studied objects, such as vehicles (Balovsyak et al., 2024). Image segmentation reliably separates different objects in the image, which is critically important for automated object recognition. Fuzzy logic, in turn, aids in handling the ambiguity and uncertainty in the data, allowing systems to make informed decisions even in the case of incomplete or vague information. Such situations occur, for example, when uneven lighting alters the shape of the segment corresponding to the studied object.

Intelligent image processing systems are of particular importance in the context of professional training for future specialists, as the incorporation of such technologies into the educational process helps learners develop critical thinking skills, analytical abilities, and the capacity to solve complex problems. Additionally, the application of these innovative methods promotes a deep understanding of both fundamental and applied aspects of modern technologies, which is extremely important in the rapidly evolving field of technical disciplines.

The integration of image segmentation and fuzzy logic into educational programs may include STEM projects, laboratory works, interactive simulations, and real research projects (Balovsyak et al., 2024). This approach not only deepens theoretical knowledge but also develops practical

skills, which are key for effective professional activity in the future.

Thus, the introduction of image segmentation and fuzzy logic into the professional training of future specialists in engineering and pedagogical fields not only enhances the educational process but also meets the needs of the modern labor market for highly qualified specialists capable of effectively working with cutting-edge technologies.

In preparing future specialists in engineering-pedagogical specialties, particularly in "Professional Education (Mechanical Engineering)," it is crucial to develop the necessary competencies for designing and using intelligent data analysis systems (Lytvyn et al., 2023; Sun Fayou et al., 2022; Prokipchuk et al., 2023). The application of intelligent data analysis, especially intelligent image analysis (Kim & Hwang, 2020), enables the automation of many tasks in transportation, science, education, industry, and other sectors. For example, intelligent image analysis in transportation systems is used for recognizing vehicles and their parts, for technical diagnostics of objects, controlling their position and speed of movement, and also for educational purposes (Balovsyak et al., 2024). In this context, information about vehicles is obtained through digital images from video cameras.

On images of vehicles, their parts and areas mostly differ in brightness, color, and texture; therefore, segmentation methods are appropriately used to analyze vehicle images (Gonzalez & Woods, 2018). As a result of segmentation, meaningful areas (segments) are identified on vehicle images, such as segments identifying headlights, windows, uniform wall sections, wheels, and license plates.

In experimental images, there is not always a clear correspondence between segments and specific objects; therefore, detecting objects on images based on their segments and establishing correspondence between objects and their segments is suitably performed using fuzzy membership functions of a segment to a particular object (Fayek, 2020).

The separate study of image segmentation methods and fuzzy logic, which are used to construct an intelligent fuzzy segmentation system for vehicle images, does not provide an adequate understanding of the interrelationships between different parts of the system. Therefore, a comprehensive study of image segmentation methods and fuzzy logic significantly improves the efficiency of learning image segmentation systems in training future engineering-pedagogical specialists. The intelligent fuzzy segmentation system for vehicle images is implemented using Python as the "SegmentFuzzyAuto24" program.

Image segmentation is performed using region-growing, watershed, and contour line methods (the latter two methods are effective when the objects under study are bounded by clear contours). In implementing watershed and contour line methods, image contours are highlighted using the Sobel or Canny methods.

Consider an example of processing a test image of cars (image_0193 from the database: Computational Vision Group. Car dataset) using the developed system ("SegmentFuzzyAuto24" program). The program performs preliminary processing and segmentation of the image, after which, using fuzzy logic, the image of the left rear car light (Rear car lights) is recognized. Recognition involves identifying the image segments that belong to the studied object.

The initial color image $fRGB$ with dimensions $M \times N$ pixels (Fig. 1) is read from a graphical file, although it is also possible to read images from video cameras. The initial color image is processed as a three-dimensional array $fRGB(i, k, c)$, where $i = 0, \dots, M-1$; $k = 0, \dots, N-1$; $c = 0, \dots, 2$ – the color channel number (Red, Green, Blue).

In this case, image segmentation is performed using a region growing method, and the preliminary processing of the $fRGB$ image involves enhancing its contrast.



Fig. 1. Initial fRGB color image

Subsequently, the system determines the average RGB components of the color of the objects being studied (Res_RGB) based on a fragment of the image resembling the object (Fig. 2). After this, based on the initial image, an image fP (Fig. 3) is calculated with pixel membership values to the studied object, which is determined based on the color similarity of the pixels in the initial image and

the average RGB components of the objects' color Res_RGB (Fig. 2). To reduce the number of non-informative small segments, the image fP is smoothed using a Gaussian filter (or median filter), resulting in the image fPG (Fig. 4). The degree of smoothing of the fPG image is controlled by analyzing the image contours (as needed).

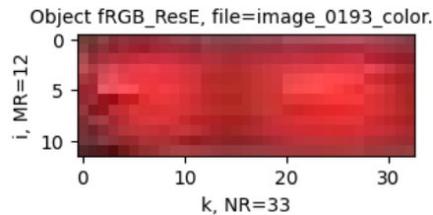


Fig. 2. Image fragment with a characteristic area of the studied object (lantern); average RGB components of the objects' color Res_RGB = $[[185.7, 51.3, 57.7]]$

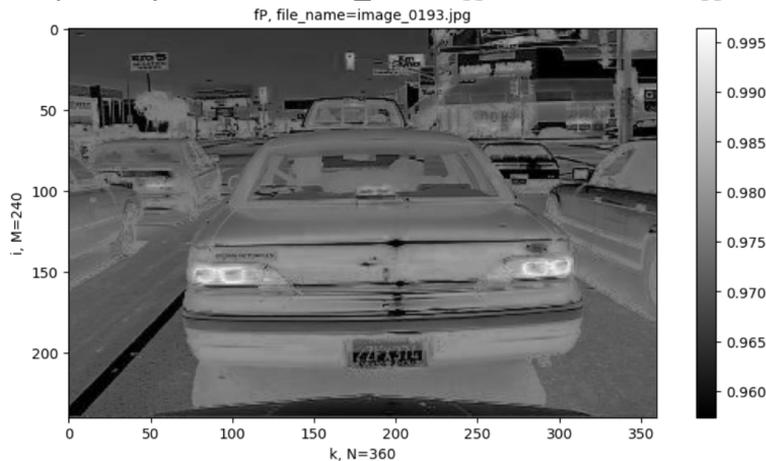


Fig. 3. Image fP with pixel membership values to the studied object (calculated based on the color similarity of the pixels and the average RGB components of the objects' color Res_RGB (Fig. 2))

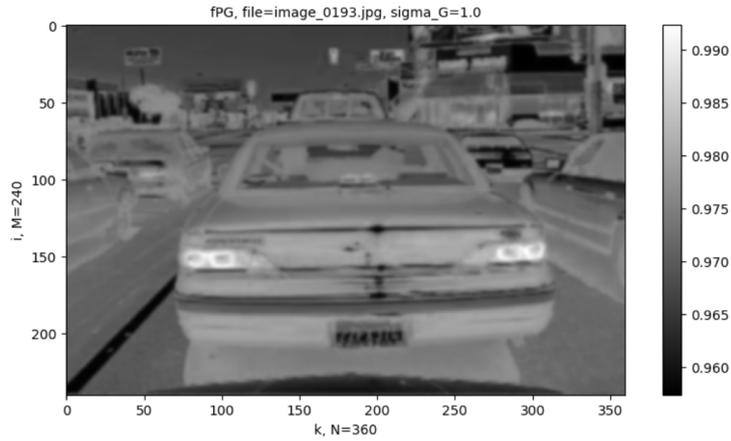


Fig. 4. Image *fPG* with pixel membership values to the studied object (after smoothing with a Gaussian filter with a root mean square deviation /RMS/ of 1.0)

The resulting image *fPG* is binarized with a threshold *Lim_fPb*, resulting in the binarized image *fPb* (Fig. 5).

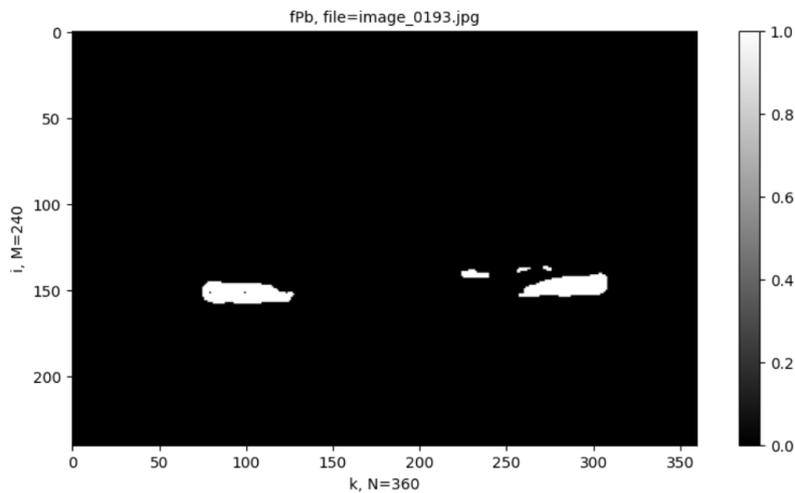


Fig. 5. Image *fPb* with pixel membership values to the studied object (after binarization)

Segmentation is then performed (by the region growing method) on the binarized image *fPb*, resulting in the segmented image *gsL* (Fig. 6). However, the *gsL* image may contain a certain number of small, low-information segments. To

remove such segments, segment selections by size are applied (Fig. 7): only segments whose dimensions exceed the minimum acceptable values *siw_min* and *skw_min* in height and width, respectively, are retained.

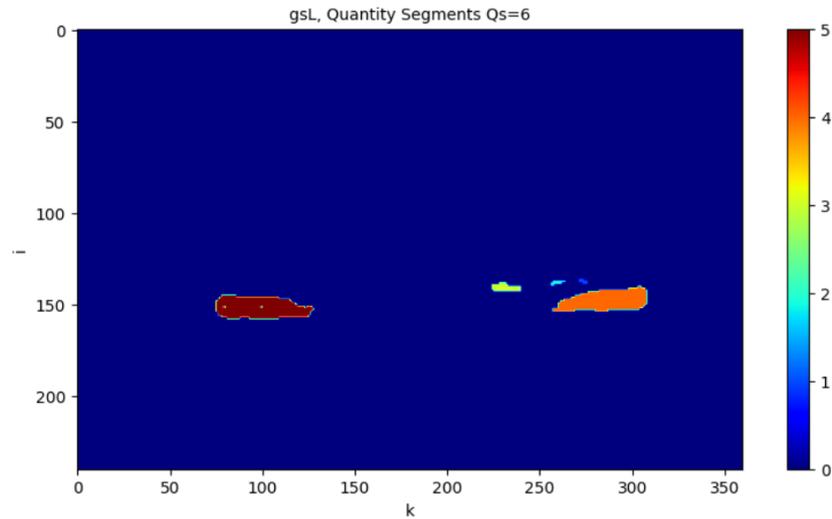


Fig. 6. Initial image of segments gsL ; number of segments $Q_s = 6$; segmentation performed based on the binarized image fPb (Fig. 5); on the color map (strip to the right of the image) segment numbers are indicated

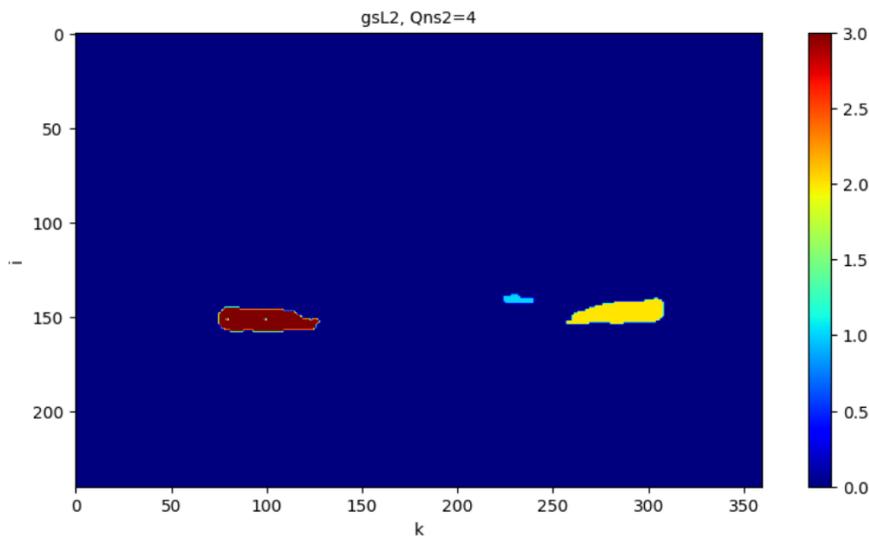


Fig. 7. Image of segments $gsL2$ after their selection by size; number of segments $Q_{ns2} = 4$; segments retained whose dimensions in height and width exceed 3 pixels

Fuzzy membership functions for all segments of the image $gsL2$ (Fig. 7) are calculated with respect to the object of study (left rear automotive light):

- Functions $\mu_h(siw)$ (Fig. 8) describe the membership of a segment to the object of study considering the normalized height of the segment siw (for an image height $M = 1000$ pixels), for other values of M – the height of the segment siw changes proportionally;
- Functions $\mu_w(skw)$ (Fig. 9) describe the membership of a segment to the object of study considering the normalized width of the segment skw (for an image width $N = 1000$ pixels), for other

values of N – the width of the segment skw changes proportionally;

- Functions $\mu_c(sic)$ (Fig. 10) describe the membership of a segment to the object of study considering the normalized center coordinate of the segment in height sic (for an image height $M = 1000$ pixels), for other values of M – the center coordinate of the segment in height sic changes proportionally;
- Functions $\mu_c(skc)$ (Fig. 11) describe the membership of a segment to the object of study considering the normalized center coordinate of the segment in width skc (for an image width $N = 1000$ pixels), for other values of N – the center coordinate of the segment in width skc changes proportionally.

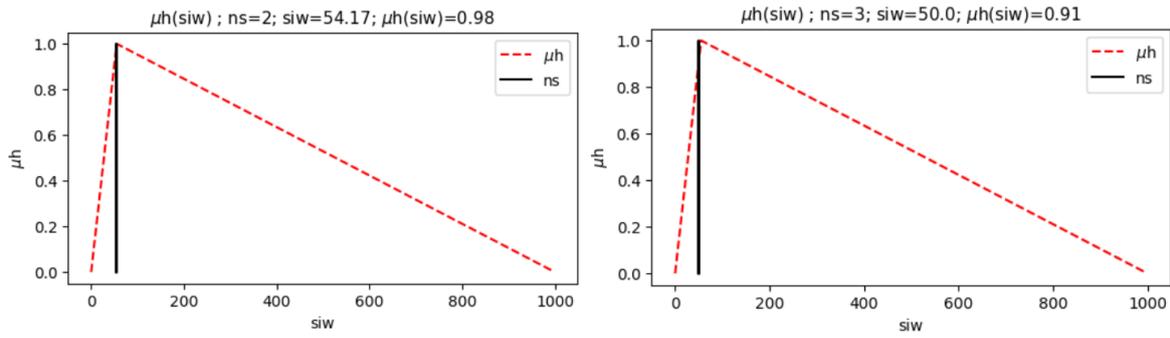


Fig. 8. Values of fuzzy membership functions $\mu_h(siw)$ of a segment to the object of study (left rear light of a car) considering its height for segments with numbers $ns=2$, $ns=3$; siw – normalized height of the segment

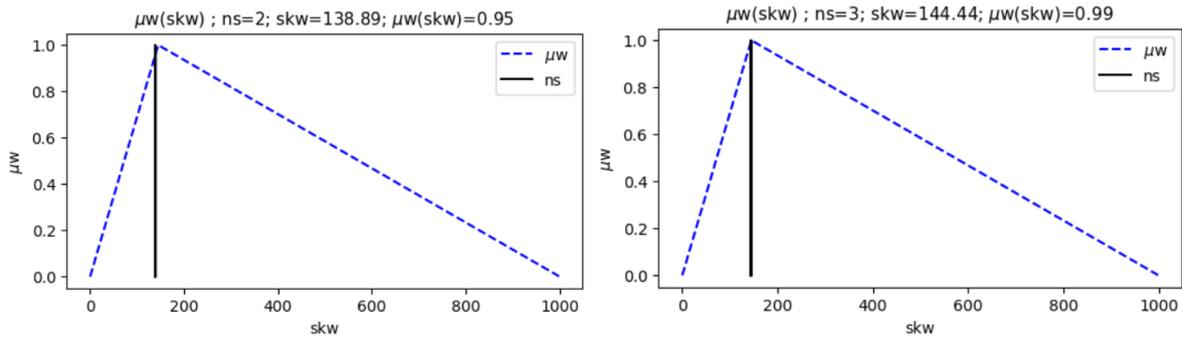


Fig. 9. Values of membership functions $\mu_w(skw)$ of a segment to the object of study (left light of a car) considering its width for segments with numbers $ns=2$, $ns=3$; skw – normalized width of the segment

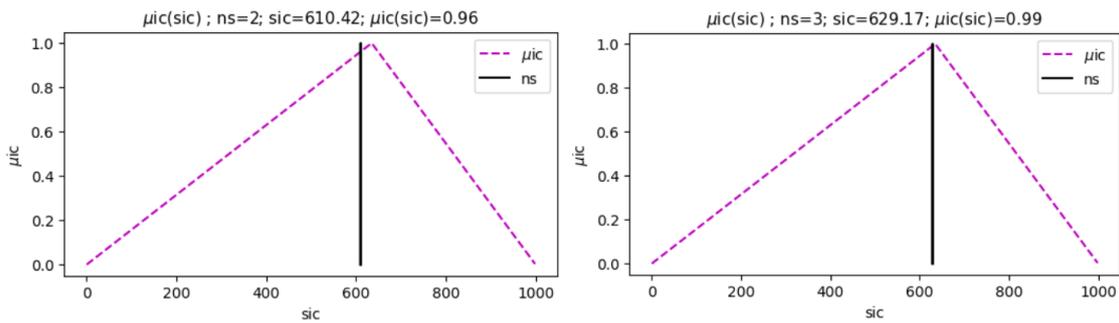


Fig. 10. Values of membership functions $\mu_{ic}(sic)$ of a segment to the object of study (left light of a car) considering its center coordinate in height for segments with numbers $ns=2$, $ns=3$; sic – normalized center coordinate of the segment in height

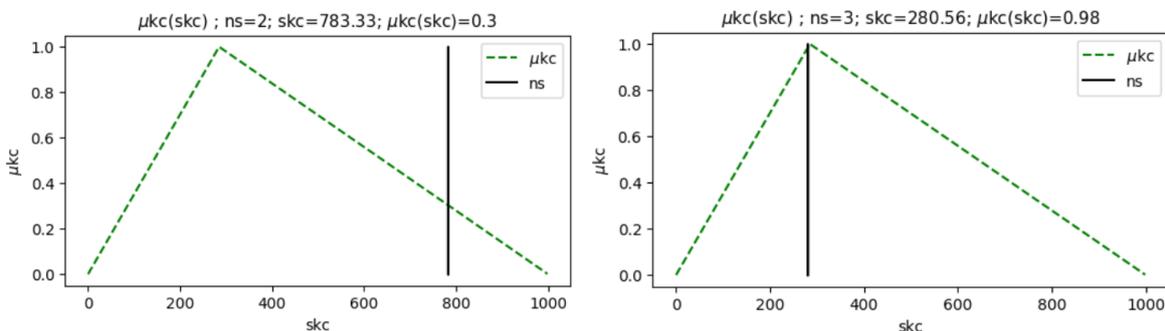


Fig. 11. Values of membership functions $\mu_{kc}(skc)$ of a segment to the object of study (left light of a car) considering its center coordinate in width for segments with numbers $ns=2$, $ns=3$; skc – normalized center coordinate of the segment in width

Based on the analysis of the parameters of segments corresponding to the objects under study,

parameters of fuzzy triangular membership functions have been determined. The values of the

resulting membership functions $\mu_s(ns)$ (Fig. 12) for the segment with number ns to the objects under study, taking into account all the segment

parameters (height, width, center coordinates by height and width), are determined as the product of the values of the respective membership functions:

$$\mu_s(ns) = \mu_h(siw) \cdot \mu_w(skw) \cdot \mu_{ic}(sic) \cdot \mu_{kc}(skc) \quad (1)$$

By the maximum of the membership function $\mu_s(ns)$, the segment number $ns1_ws$, which

most fully belongs to the studied object (Fig. 13), is calculated.

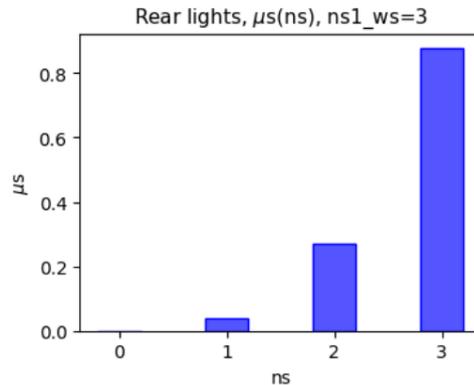


Fig. 12. Resulting values of the membership functions μ_s of the segment to the studied object (left car headlight) for segments with numbers ns

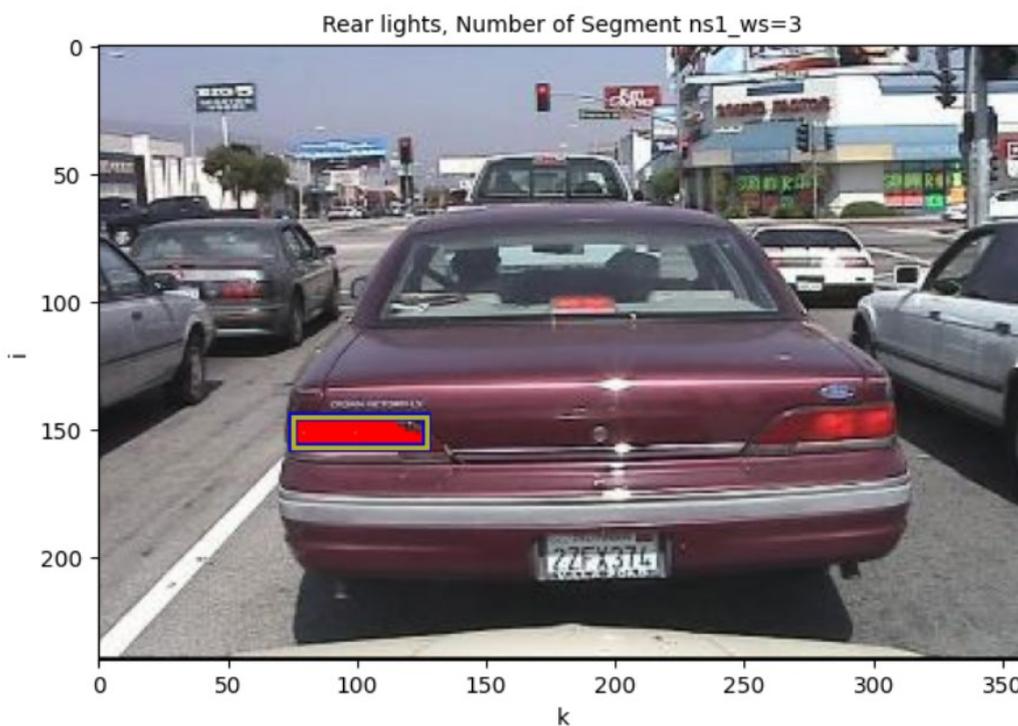


Fig. 13. Image with the identified segment belonging to the studied object (left car taillight); the segment is highlighted with a rectangle

Thus, the segment labeled $ns1_ws$ is correctly identified as the research object (left car taillight). Other objects in the image are recognized similarly.

Conclusions. The developed computer system for segmenting images of vehicles using fuzzy logic can be integrated into the professional

training of future specialists in engineering and pedagogical fields. The system employs comprehensive methods of image preprocessing, segmentation, and fuzzy logic, providing students with theoretical knowledge and practical skills related to intelligent image processing systems. Segmentation methods are used to isolate objects in

the images, which are then recognized using fuzzy logic. Thanks to fuzzy membership functions, elements of vehicle images are reliably recognized, as they simultaneously take into account the sizes

and positions of the segments. The example of fuzzy segmentation of images demonstrated a correct result in recognizing objects in car images.

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ВИКОРИСТАННЯ ІНТЕЛЕКТУАЛЬНИХ СИСТЕМ НЕЧІТКОЇ СЕГМЕНТАЦІЇ ЗОБРАЖЕНЬ У ПРОФЕСІЙНІЙ ПІДГОТОВЦІ МАЙБУТНІХ ФАХІВЦІВ ІНЖЕНЕРНО-ПЕДАГОГІЧНИХ СПЕЦІАЛЬНОСТЕЙ

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Реферат:

Актуальність: у статті розглядається актуальне питання інтеграції інтелектуальних систем сегментації зображень, що використовують нечітку логіку, в процесі професійної підготовки майбутніх фахівців інженерно-педагогічних спеціальностей, що є важливою компонентою цифровізації вищої освіти.

Мета: реалізація інтелектуальних систем сегментації зображень транспортних засобів із використанням нечіткої логіки для навчання майбутніх фахівців інженерно-педагогічних спеціальностей.

Методи: попередню обробку зображень досліджуваних об'єктів (транспортних засобів) виконано методами цифрової фільтрації, виділення контурів, аналізу профілів і підвищення контрасту; сегментацію зображень виконано методами водорозділів, контурних ліній та нарощування областей, після чого проведено селекцію отриманих сегментів за розмірами; нечіткі функції належності застосовано для визначення ступеня належності сегментів до змістовних частин досліджуваних об'єктів, що забезпечує надійне розпізнавання таких частин об'єктів та стабільну роботу інтелектуальної системи в умовах впливу зовнішніх факторів на отримані зображення об'єктів.

Результати: розроблено комп'ютерну систему для сегментації зображень транспортних засобів із використанням нечіткої логіки, яку інтегровано у професійну підготовку майбутніх фахівців інженерно-педагогічних спеціальностей; методами сегментації виконується виділення об'єктів на зображенні, що в подальшому використовується для їх розпізнавання з використанням нечіткої логіки; завдяки нечітким функціям належності надійно розпізнаються елементи зображень транспортних засобів навіть при певній неоднозначності форми сегментів; розроблена система має прикладне значення, що продемонстровано на прикладі обробки зображення автомобіля.

Висновки: інтеграція розробленої системи в освітній процес надає здобувачам освіти теоретичні знання та сприяє формуванню навичок, пов'язаних з інтелектуальними системами обробки зображень.

Ключові слова: *цифровізація освіти; заклади вищої освіти; інтелектуальний аналіз даних; нечітка логіка; сегментація зображень; майбутні фахівці інженерно-педагогічних спеціальностей.*

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