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Human Operator Identification in a Collaborative Robot Workspace within the Industry 5.0 Concept

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Abstract: This paper explores the process of a human operator identifying in a collaborative robot workspace, which is critical within the Industry 5.0 concept. Using modern methods of computer vision and face recognition algorithms, a reliable mechanism of interaction between the operator and the robot is provided. Experimental results confirm the high accuracy of identification, which allows for safe and efficient operation of robotic systems in real production conditions. The article emphasizes the importance of integrating such technologies to increase the level of automation and create intuitive and adaptive production environments that meet the principles of Industry 5.0.

Key words: Industry 5.0, Collaborative Robot, Workspace, Computer Vision, Robot Manipulator, Operator Identification, Human Identification.

Introduction

The relevance of research on the implementation of facial identification of a human operator for receiving commands in a collaborative robot workspace within the concept of Industry 5.0 is extremely high. Industry 5.0 is aimed at creating harmonious cooperation between people and machines, where technology works in close relationship with human capabilities [1]-[13]. Facial recognition, as one of the key tools of this concept, allows for a personalized, safe and efficient process of interaction between the robot and the operator. Therefore, various image analysis methods can be used here [14]-[37]. This opens up new horizons for automation, allowing robots to adapt to the individual needs of each worker, recognize them in real time, and execute commands, which increases overall productivity and safety in the workspace. The use of facial recognition technologies ensures a high level of reliability and accuracy in identification, which is critically important for smooth operation in a dynamic production environment. In the context of Industry 5.0, where the emphasis is on individualization and improving the well-being of employees, such a system allows robots not only to perform routine tasks, but also to respond to the emotional state and personal needs of operators [11]-[13], [38]-[42]. This, in turn, contributes to the creation of more flexible, adaptive and efficient production processes, which is necessary in today's conditions of global competition and technological progress. Thus, research in this area is strategically important for the implementation of innovative solutions that will meet the challenges and requirements of Industry 5.0.

Related works

With the constant expansion of the implementation of the Industry 5.0 concept, we must notice that Industry 5/0 is a human-centric technology. Let us look at some recent works related to this problem.

Industry 5.0 blows the whistle on global industrial transformation. It aims to place humans' well-being at the center of manufacturing systems, thereby achieving social goals beyond employment and growth to provide prosperity robustly for the sustainable development of all humanity [43]. The study [43] discusses key enablers, the future implementation path, potential applications, and challenges of realistic scenarios of Industry 5.0.

In most applications, Industry 5.0 showed a significant connection between intelligent systems and humans through accurate manufacturing automation with critical thinking skills [44].

Authors in [45] propose their system for facial recognition through an API using ESP32-Cam and Amazon Recognition Service.

The core values of Industry 5.0 including human-centricity, sustainability, and resilience have prompted formal discussions that manufacturing should be human-centric [46]. The article [46] identifies limitations, barriers, and challenges that will be encountered during the developing, operating, and maintaining human-centric smart manufacturing, and provides valuable research directions to continuously improve human-centric smart manufacturing.

Researchers in [47] propose an architecture that integrates Artificial Intelligence (Active Learning, Forecasting, Explainable Artificial Intelligence), simulated reality, decision-making, and users' feedback, focussing on synergies between humans and machines.

The study [48] tries to identify a specific focus and the major challenges related to the human-centered artificial intelligence approach in the field of Industry 5.0 and the circular economy.

Manufacturing should be human-centric – placing the wellbeing of industry workers at the center of manufacturing processes, instead of system-centric – only driven by efficiency and quality improvement and cost reduction [49].

Thus, we see many works on Industry 5.0 that point to the human-centered nature of this technology. Therefore, to solve many problems, it is necessary to determine the position of a person in the robot's workspace. Later in this article, we will look at a method for determining a person's face.

Mathematical justification of the implementation of the person identification by face

The implementation of the method of identifying a human operator by face in the a collaborative robot workspace using a streaming video camera can be implemented based on the following steps:

- step 1 is to capture the video stream from the camera. A video stream can be represented as F_tF_t where t denotes time, and each frame F_t is a matrix of pixels:

$$F_t=\{p_{ij}|1\leq i\leq H,\ 1\leq j\leq W,\} \qquad (1)$$

H and W - frame height and width, respectively;

p_{ij} - pixel at position (i,j).

- step 2 is designed to detect a face in the frame, a face detection model is used, which defines a set of control points, and is described by the following expression:

$$L=\{l_k\} \qquad (2)$$

$l_k=\{x_k,y_k,z_k\}$ – k-th control point on the face coordinates.

Expression 2 within the framework of these studies can be described as the following function:

$$L=f_{detect}(F_t) \quad (3)$$

F_t – frame sequence;

$f_{detect}()$-a detection function that returns the coordinates of control points on the face.

- in the 3rd step, using the following mathematical apparatus: regression models based on deep neural networks (for predicting the coordinates of the control points of the face), Conformal Mapping Algorithms (for unfolding the surface of the face in two-dimensional space, which allows to effectively model the three-dimensional geometry of the face) and 3D reconstruction (for determining the coordinates of control points in three-dimensional space), which together provide high accuracy and speed of detection and tracking of key points on the face in real time. Using the mathematical devices listed above, it is possible to determine up to 468 control points on the face, each of which corresponds to a certain anatomical part (for example, eyes, nose, mouth). The points are found in three-dimensional space with coordinates (x_k,y_k,z_k), where x_k and y_k are the normalized coordinates on the image plane, and z_k is the relative depth. Based on this, the set of control points L will have the following form:

$$L_k=\{(x_k,y_k,z_k)|k=1,2,\dots,468\} \quad (4)$$

- step 4 is required to identify operators, a comparison of control points with reference data stored in the system is used. Let L_{ref} be a set of control points of the reference face. Then, for comparison with the received image of the operator's face, the Euclidean distance between the corresponding points is calculated, as represented by the following expression:

$$d_k=\sqrt{(x_k-x_k^{ref})^2+(y_k-y_k^{ref})^2+(z_k-z_k^{ref})^2} \quad (5)$$

(x_k,y_k,z_k) - coordinates of a point on the current frame;

$(x_k^{ref},y_k^{ref},z_k^{ref})$ - coordinates of the reference point.

- step 5 is required to evaluate the similarity of the face of the current frame with the reference one, the average value of the Euclidean distances between the corresponding points is used:

$$D=\tfrac{1}{N}\sum_{k=1}^{N}d_k \quad (6)$$

N - the number of control points being compared.

- the last 6th step is decision-making. Face identification is performed on the basis of comparing the average distance D with a given threshold value θ. If $D<\theta$, the face is considered to match the benchmark, and the command to the robot can be executed.

Software implementation of the method of identification of a person-operator by face

The Python programming language is the optimal choice for developing a program to implement the human-operator facial identification method due to its numerous advantages, which make it ideal for computer vision and machine learning tasks. First, Python has a large number of powerful libraries, such as OpenCV, Mediapipe, TensorFlow, Keras, which greatly facilitate the development of algorithms for image and video processing, as well as the creation of neural networks. These libraries are actively supported by the community, which ensures that the solutions are up-to-

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date and effective. Second, Python is an interpreted language that allows for high speed code development and testing because it does not require compilation, which is an important aspect in rapid development of prototypes and changes to the program. The language's simple syntax allows developers to quickly write and read code, which reduces the likelihood of errors and simplifies program maintenance. In addition, Python has a rich ecosystem of tools for scientific computing, such as NumPy, SciPy, and Matplotlib, which allow complex mathematical calculations and data visualization without the need for third-party software. An important aspect is also the wide support of Python on different platforms and operating systems, which makes the program easily portable and compatible with different environments. Python supports integration with other programming languages, making it possible to use already existing libraries written in C++ or Java to increase productivity. For real-time tasks, such as identifying a person from a video stream, Python allows you to optimize critical sections of the code through modules on Cython or use hardware acceleration, for example, through CUDA libraries for working with GPUs. With plenty of examples and documentation, Python is also a good choice for learning and working in an academic environment, allowing beginners to quickly learn the concepts of computer vision and machine learning. Thus, Python provides a balanced set of tools and capabilities that allow you to effectively solve the task of identifying a human operator by face in a collaborative robot workspace.

Based on this, we will give a description of the implementation of the most interesting functions of the human-operator identification program by face in a collaborative robot workspace for receiving commands within the Industry 5.0 concept.

```
mp_face_mesh = mp.solutions.face_mesh
face_mesh = mp_face_mesh.FaceMesh(static_image_mode=False, max_num_faces=1, min_detection_confidence=0.5)
```

This piece of code is used to initialize the Mediapipe Face Mesh module, which is used to detect and track key points on a human face. The face_mesh object is created with settings that allow real-time processing of the video stream, with the maximum number of detected faces limited to one and the minimum detection confidence set to 0.5. This allows for effective face identification in a dynamic environment.

```
def euclidean_distance(point1, point2):
    return np.linalg.norm(np.array(point1) - np.array(point2))
```

This code snippet defines a function to calculate the Euclidean distance between two 3D points (x,y,z). The `euclidean_distance` function takes two points as input parameters, calculates the difference between their coordinates, and returns the length of this vector, which is the distance between the points in three-dimensional space.

```
sample_landmarks = np.load('venv/face_landmarks_sample.npy')
```

This code snippet loads from the file `'venv/face_landmarks_sample.npy'' a sample of facial landmarks that was previously saved. This sample is used to compare with facial reference points obtained in real time to identify or verify a person.

```
def is_face_matching(landmarks, sample_landmarks, threshold):
    distances = []
    for i in range(len(landmarks)):
        # We make sure that both arrays have the same size (for example, (x,y,z))
        if len(landmarks[i]) == len(sample_landmarks[i]):
            distances.append(euclidean_distance(landmarks[i], sample_landmarks[i]))
```

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```
    mean_distance = np.mean(distances)
    return mean_distance < threshold
```

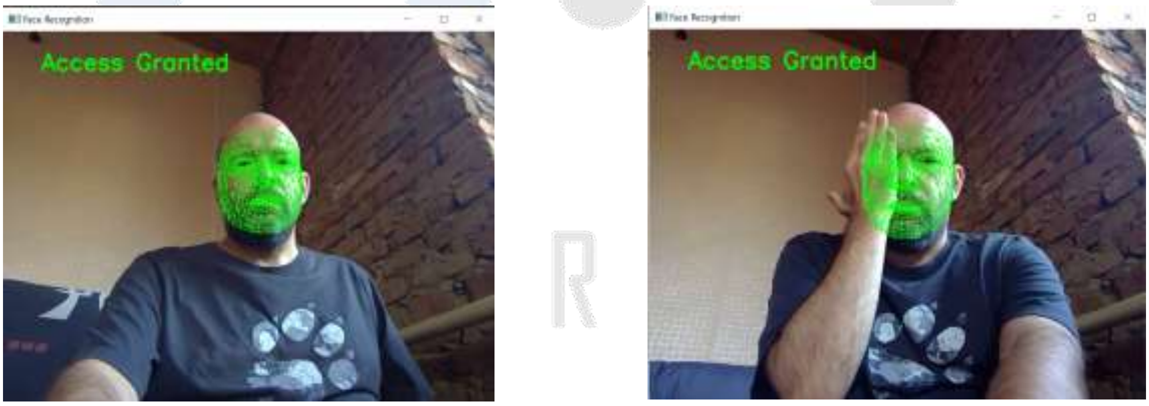
This code snippet defines a function to check the similarity of face control points to their sample. The function `is_face_matching` calculates the Euclidean distance between the corresponding points of two sets of control points (current and sample) and checks whether the average distance is less than a given threshold. If so, the function returns `True', which means that the face matches the pattern.

```
mp_drawing.draw_landmarks(frame, face_landmarks,
mp_face_mesh.FACEMESH_TESSELATION,
        landmark_drawing_spec=None,
        connection_drawing_spec=mp_drawing.DrawingSpec(color=(0, 255, 0),
                                                        thickness=1, circle_radius=1))
cv2.imshow('Face Recognition', frame)
```

This piece of code is used to render the control points of a face in a video frame. The function `mp_drawing.draw_landmarks` draws these points and the connections between them on the image that is passed to the video stream. The frame with the displayed points is then displayed in a window called "Face Recognition" using the `cv2.imshow` function.

An example of the work of the developed human-operator identification program by face is shown in Figure 1.

In order to check the correctness of the selected mathematical models for solving the problem of human operator identification in a collaborative robot workspace within the Industry 5.0 concepts, we will conduct an experiment. The purpose of the experiment was to evaluate the accuracy and reliability of the developed program for human identification by facial control points. The tests included testing the app on different users, under different lighting conditions, and at different distances from the camera. This made it possible to determine how accurately the program is able to recognize faces and compare them with a previously saved sample.



a) b)

a) identification of a person without obstacles; b) identification of a person with an obstacle covering 40% of the face

Figure 1: An example of the operation of the program for the identification of a person-operator by face within the concepts of Industry 5.0.

For this, the following indicators were used: the average Euclidean distance between the control points of the face and the threshold value for successful identification. The results are presented in Table 1.

Table 1: Effectiveness of human identification by facial control points using the developed program

№	User	Lighting conditions	Distance to the camera (m)	Average Euclidean distance	Threshold value	Identification result (Match/No Match)
1	User 1	Bright light	0.5	0.045	0.050	Match
2	User 1	Dim light	0.5	0.062		No Match
3	User 2	Bright light	1.0	0.048		Match
4	User 2	Dim light	1.0	0.053		No Match
5	User 3	Normal light	0.7	0.047		Match
6	User 3	Bright light	1.2	0.051		No Match
7	User 4	Dim light	0.8	0.049		Match
8	User 4	Normal light	1.0	0.054		No Match

The results showed that the developed program effectively identifies faces in bright and normal lighting at distances of up to 1 meter. In conditions of dim lighting and when the distance to the camera increases, the accuracy of identification decreases, which requires adjusting the threshold value or improving the algorithm to increase the reliability of identification.

For the convenience of analyzing the obtained experimental data, let us present them in the form of a combined graph, which is presented in Figure 2.

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VOLUME-4, ISSUE-9

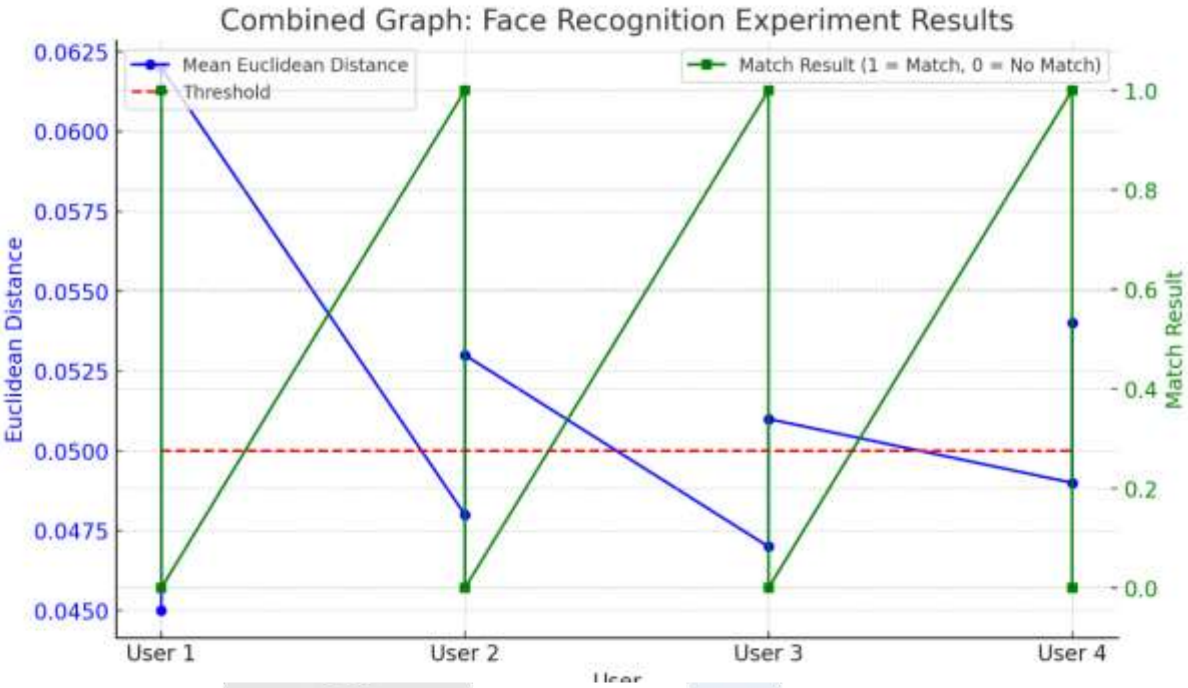

Figure 2: Combined graph for the obtained results of the experiment

Figure 2 shows a combined graph based on the experimental results (Table 1). The plot shows the average Euclidean distance between the detected facial landmarks and the stored sample with a threshold marked for comparison. In addition, match results are displayed on the secondary axis, where a value of 1 means a match and 0 means no match. This visualization helps to analyze the performance of the face recognition system under different lighting conditions and for different users.

Conclusion

In the context of the concept of Industry 5.0, which aims to harmonize the interaction between people and robots, the identification of a human operator in a collaborative robot workspace becomes especially important. The use of modern methods of computer vision, in particular face identification, allows to ensure a reliable and safe mechanism for receiving commands from the operator. This, in turn, makes it possible to increase the efficiency of robotic systems, reducing the risk of errors caused by incorrect recognition of commands or the presence of outsiders in the work area. During the conducted experiments, it was confirmed that the use of algorithms built on the Mediapipe library demonstrates high accuracy in face recognition, even under variable lighting conditions and different distances to the camera. This allows for stable operation of the system in real production conditions. The implementation of such systems at enterprises helps to increase the level of automation and create a safer working environment for employees that meet the requirements of Industry 5.0. In particular, the identification of the operator by face allows the robot to adapt its actions depending on the context, which provides more intuitive and effective management of processes. It also opens up new opportunities to create more interactive and adaptive production environments where human and robot can work in close collaboration, complementing each other. In general, the introduction of face recognition technologies in the working areas of collaborative robots contributes to achieving a high level of integration of technologies and the human factor, which is a key aspect in the transition to Industry 5.0.

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