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Using Contouring Algorithms to Select Objects in the Robots' Workspace

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Abstract:

This paper explores the application of contouring algorithms to accurately highlight objects in the robots' workspace. We present a mathematical description of the developed algorithm and a Python program that implements it in the PyCharm 2022.2.3 (Professional Edition) environment. Experiments carried out using this algorithm focused on outlining a matchbox while changing the pixel intensity threshold. The results obtained confirm the effectiveness of the method and highlight its potential for optimizing the processes of robotic perception of the environment and interaction with objects.

Key words: Industry 5.0, Computer Vision Systems, Mobile Robots, Work zone.

Introduction

The modern implementation of the Industry 5.0 concept is closely related to the increasing spread of collaborative robots, that is, for robots working in close connection with humans.

Collaborative robots, also known as cobots, are robots designed to work collaboratively with people in a work environment. Unlike traditional industrial robots, which tend to work in isolated areas from people, collaborative robots are designed with human safety and cooperation in mind.

The main characteristics of collaborative robots include: safety; ease of programming; collaboration; flexibility. Such robots are equipped with a variety of sensing systems, that is, sensors. Cobots are equipped with various sensors such as cameras, lasers, touch sensors, which allows them to perceive the environment and interact with it effectively. They can recognize speech, "see the environment", etc. [1]-[5]. Accordingly, many scientific works are devoted to solving such problems [6]-[14].

Collaborative robots are widely used in industry, manufacturing, and other industries that require effective collaboration between a human and a robot. Their appearance helps increase productivity, reduce labor costs and improve safety on production sites.

In the context of the active development of Industry 5.0, where industrial systems are becoming increasingly automated and interconnected, the use of contouring algorithms to highlight objects in the work area of robots is a relevant

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research. Accurate object selection is a critical element in robotics, where robots are integrated into manufacturing processes. This approach can significantly improve the efficiency and accuracy of tasks such as sorting, positioning, and object manipulation. Various methods and approaches can be used here [15]-[25]. Research into contouring algorithms as part of Industry 5.0 promises to improve process flow and help create more flexible and intelligent manufacturing systems.

Related works

Since our research is devoted to technical vision systems, namely, the object contour detection, we will consider some works on this topic.

Scientists in [26] propose a new enhancement method to enhance the scene contours and improve the visibility of images captured underwater based on Contour Bougie (CB) morphology.

Lin, X. and co-authors in [27] consider inconsistent edges of mechanical workpieces in the same batch. They propose an intelligent hybrid strategy for edge inconsistent feature detection by machine vision, in which deep learning is combined with variable geometric model together to conduct the function.

Article [28] proposes a new computer vision-based algorithm from face detection technology and face recognition technology. In the face detection technology, it is mainly introduced from the OpenCV method. Face recognition technology is improved in practical applications through the Seetaface method and YouTu method.

Zheng, S. in the work [29] presents the design of an intelligent manufacturing product recognition and detection system based on machine vision.

Researchers [30] consider the problem of automation the reading of analog meters. High-level features of the meter, including the graduation values and angles, are extracted using a cascade of image contour filters with a series of digit classifiers.

The paper [31] investigates recent research on diagram image retrieval and analysis, with an emphasis on methods using content-based image retrieval (CBIR), textures, shapes, topology and geometry.

In [32] authors propose an automatic manipulator control algorithm, implemented in the high-level object-oriented language Python 3.7.2, includes operations to determine the x and Y coordinates of the berry, its degree of maturity, as well as to calculate the distance from the manipulator to the berry. It was found that the efficiency of detecting berries, their area and borders using the camera and the OpenCV library 300 Lux illumination reaches 94.6 of percent.

Study [33] presents a complex review convolutional neural network implementation for industrial fields. Firstly there are analyzed the major tasks of

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CNN in computer vision researches, including image classification, object detection, edge detection and image segmentation, which are frequently used techniques in surface defect inspection. After that, there are described in detail the applications of computer vision based on CNN models in a variety of industrial scenarios for surface defect detection tasks, which mainly cover the steel surface defect inspection, magnetic tile surface defect inspection, rail surface defect inspection, screen surface detect inspection, solar cell surface defect inspection, and some others. As an emerging representative of artificial intelligence technology, we believe that deep learning will gradually become one of the mainstream technologies for industrial vision in the future.

An image analysis method based on identifying changes in brightness in an image

In computer vision systems, contouring is the process of determining the outlines of objects in an image. A contour is a line that connects points of the same brightness or color. Edging can be used to highlight objects in the robot's work area. In robotics systems, contouring can be used for the following purposes:

– determining the position of objects allows you to determine the position of objects in the working area of the robot. This can be useful for robots that need to manipulate objects or avoid obstacles.

– object recognition can be used to recognize objects in an image. This could be useful for robots that must perform tasks that require object identification, such as sorting or assembly.

– object size measurement can be used to measure the size of objects in an image. This could be useful for robots that must perform tasks that require measuring the dimensions of objects, such as packaging or manufacturing.

Within the framework of these studies, it is proposed to use a method of image analysis based on identifying changes in brightness in the image. Let us describe the implementation of this method using mathematical expressions. Let be the brightness of the image at the point with coordinates. Let's transform the original image of the robot's working area into a binary image using threshold binarization:

$$B(x,y) = \begin{cases} 1, if\ I(x,y) > Threshold \\ 0 \end{cases} \quad (1)$$

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The next step is to determine the connected areas (components) in the binary image. This creates many connected components, each representing a group of pixels connected by a connection within that group. At the initial stage, each pixel is considered a separate component, and each component contains only one pixel.

$$R=\{(x_1,y_1),(x_2,y_2),\ldots,(x_m,y_m)\} \tag{2}$$

where: m – pixels number.

Analyzing images, we check if two adjacent pixels have value (1), then we combine the components to which they belong:

$$Union(R_i,R_j), if\ pixels(x_i,y_i)\ and\ (x_j,y_j)>1 \tag{3}$$

After combining the components, we find a set of related components and merged pixels.

$$R=\{R_1,R_2,\ldots,R_k\} \tag{4}$$

where: k – connected components number.

For each connected component R_k, we retrieve the list of pixels that belong to this component.

$$R_k=\{(x_{i1},y_{i1}),(x_{i2},y_{i2}),\ldots,(x_{in},y_{in})\} \tag{5}$$

After this, we perform indexing so that each component is uniquely identified.

The next step is to extract contours for each component that represents an object. This can be done using the object boundary following algorithm. Each contour is represented by a list of points (x_i,y_i):

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$$c_i = \{(x_{i1}, y_{i1}), (x_{i2}, y_{i2}), \ldots, (x_{in}, y_{in})\} \tag{6}$$

After this we create a hierarchy of contours. Hierarchy indicates the relationships between circuits, such as which are internal, external, or on the same level. Let c_i be a contour and let H_i be the corresponding hierarchy information for the contour i.

$$H_i = [Next_i, Prev_i, FirstChild_i, Parent_i] \tag{7}$$

where: $Next_i$ – the next circuit at the same hierarchy level. If it is -1, then there is no next contour on the level;

$Prev_i$ – the previous circuit at the same hierarchy level. If it is -1, then there is no previous contour at the level;

$FerstChild_i$ – the first path, which is a child of the current path. If it is -1, then the path has no child paths.

$Parent_i$ – is the parent of the current path. If it is -1, then the outline is at the top level of the hierarchy.

Thus, the hierarchy of contours is an array H, where each element H_i contains information about the connections of the i-th contour with other contours at the same hierarchy level, as well as connections with child and parent contours

Software implementation and experiments

To check the correctness of the reasoning, we will develop a program in Python in the development environment PyCharm 2022.2.3 (Professional Edition). Let us give an example of software implementation of the above described mathematical expressions.

```
# Apply filtering and binarization to highlight contours
    gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
    _, thresh = cv2.threshold(gray, 120, 120, cv2.THRESH_BINARY)
```

The use of filtering and binarization in the context of extracting contours in an image plays an important role in improving the quality and accuracy of the analysis of object boundaries. Filtering, such as using a Gaussian filter, helps smooth the image, reduce the impact of noise, and increase the contrast between objects and

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the background. Binarization converts an image to binary, highlighting bright objects and eliminating details at less significant brightness levels. Together, these steps simplify the edge processing process and enable more accurate extraction of feature boundaries for further analysis.

```
# Finding contours
contours, _ = cv2.findContours(thresh, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
```

Finding contours in an image allows you to highlight the boundaries of objects and determine their shape, size and location. This process is an important step in image processing and has applications in various fields such as computer vision and medical diagnostics. Edge extraction facilitates shape analysis of objects, pattern recognition, and can also be used to extract important parameters such as the area and perimeter of objects. The resulting contours can also serve as the basis for subsequent processing steps, such as recognizing objects or measuring their characteristics.

```
# Drawing outlines on an image
contour_img = img.copy()
cv2.drawContours(contour_img, contours, -1, (0, 255, 0), 2)
```

Drawing contours on an image visualizes the results of the finding contours process, making them more visual and understandable. This is useful for visually checking that the boundaries of objects are correctly selected. Let's conduct a study of the influence of the threshold value of pixel intensity on the contours of an object in the frame. The results of the study are shown in Figure 1.

a)

b) (50x50)

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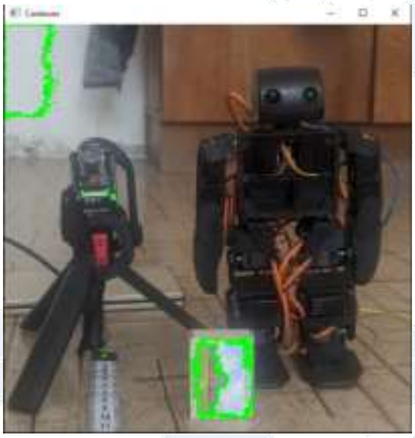
c) (100x100)

d) (150x150)



e) (200x200)

f) (250x250)

a) original image; b) pixel intensity threshold 50; c) pixel intensity threshold 100;
d) pixel intensity threshold 150; e) pixel intensity threshold 200;
f) pixel intensity threshold 250;

Figure 1: The influence of the pixel intensity threshold on object contouring

As you can see from the experiment, in this case, for outlining a matchbox that is located in the workspace, the recommended threshold value of pixel intensity is approximately 200; for more precise settings, it is necessary to experimentally adjust $\pm\Delta$ for this number.

Conclusion

This article explores the use of contouring algorithms to identify objects in the working area of robots. The article presents a mathematical description of the algorithm used, on the basis of which a program was developed in Python in the development environment PyCharm 2022.2.3 (Professional Edition). Experiments were carried out on the extraction of matchbox contours, taking into account the

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influence of the threshold value of pixel intensity on the process of object contouring. The results obtained confirm the effectiveness of the proposed method and make it possible to optimize the algorithm parameters for specific operating conditions of robots in real time. The presented approach can be useful in various robotic applications where it is necessary to accurately identify objects in the robot's workspace.

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