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OPTIMAL CONTROL OF MANIPULATOR GRIP POSITION TO MOVE FLAT OBJECTS

Andrej Ivanovich Abramov
Kalashnikov Izhevsk State Technical University, Department of Mechatronic Systems, Studencheskaya 7, 426069, Izhevsk, Russia, hitech1015@yandex.ru

Ivan Vasilevich Abramov
Kalashnikov Izhevsk State Technical University, Department of Mechatronic Systems, Studencheskaya 7, 426069, Izhevsk, Russia, abramov@istu.ru

Pavol Božek
Department of Control and Information Systems, Institute of Applied Informatics, Automation and Mechatronics, Faculty of Materials Science and Technology, Slovak University of Technology, 917 24 Trnava, Slovak Republic, pavol.bozek@stuba.sk

Timur Mazitov
Kalashnikov Izhevsk State Technical University, Department of Mechatronic Systems, Studencheskaya 7, 426069, Izhevsk, Russia, rymit1991@yandex.ru

Alexey Palmov
Kalashnikov Izhevsk State Technical University, Department of Mechatronic Systems, Studencheskaya 7, 426069, Izhevsk, Russia, palmov-a@yandex.ru

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Abstract: The methodology to explicitly define the flat object orientation in 2D space is proposed. A number of experiments with modelled data have been carried out, as a result, the developed methodology has been successful tested and importance of precise contour extraction of the object has been confirmed. The methodology obtained can be applied during the automation of processes of moving flat parts, sorting out of parts by shape and other similar operations.

1 Introduction

In the process of industrial enterprise automation, flat objects (parts) are traditionally represented in 2D form in a large number of technological operations. Contour extraction is one of such methods. The application of contour analysis makes it possible to define the most important parameters of objects (area, center of mass, etc.). Moment characteristics of contour and moment invariants calculated on their basis, which are the most important tools for image identification due to their insensibility to orientation, scale, viewing angle and other measurements are widely spread [1], [2]. However, the use of such contour features and characteristics does not allow explicitly defining a part orientation on a plane. When representing an object as a contour it is necessary to precisely extract the part outline – to separate the object and background. The incorrect contour definition results in the change of its characteristics and identification errors.

2 Contour extraction

Contour is an object outline, which separates it from the background or other objects. The contour analysis allows finding, describing, storing and comparing objects. A number of coding methods are used to store and describe a contour. Freeman code, in which the aggregate of pixels in the object outline is represented in the form of vectors with definite length and direction, is widely applied [3].

Limitations imposed onto the application area of contour analysis are mainly connected with problems of contour extraction on images: due to the same brightness with the background the object sometimes does not have a vivid outline or can be blurred resulting in the impossibility of contour extraction; object overlapping results in improper contour extraction and mismatch with the object outline.

There are a number of algorithms of image transformation to extract contours [4], [5]:

- Threshold transformation
- Canny operator
- Sobel operator
- Laplace operator
- Prewitt operator
- Roberts operator

Each of the algorithms has its own advantages and disadvantages, the correct selection and combination of different filters and algorithms when processing images

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and extracting contours play an important role [6], [7], [8].

The application of contour analysis allows significantly decreasing computational complexity as it gives the possibility to move from 2D image processing to contour processing based on the comparison of their characteristics.

3 Contour characteristics

Moment is a contour characteristic calculated through the integration (summation) of all contour pixels. The moment (k, s) is defined by the following formula [1]:

$$M_{ks} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} m^k n^s x(m,n)dmdn, \quad k,s = 0,1,\ldots \qquad (1)$$

The moments found by the above formula depend on coordinate system, therefore, they do not allow defining a turned figure, and they are also sensible to scale – they do not allow comparing contours with the same shapes but different sizes.

To provide the invariability to image scaling, first it is necessary to normalize the moments – bring them to one length (operation of contour equalization). Such moments are called central.

Computation of central moments [1]:

$$\mu_{ks} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (m-\overline{m})^k (n-\overline{n})^s x(m,n)dmdn, \quad k,s = 0.1,\ldots, \qquad (2)$$

where: $\overline{m} = \frac{M_{10}}{M_{00}}$, $\overline{n} = \frac{M_{01}}{M_{00}}$ — center of mass defining the object position.

The characteristics invariant to image turning are defined with the help of central moments.

The computation of normalized central moments:

$$\eta_{ks} = \frac{\mu_{ks}}{M_{00}^{(\frac{k+s}{2}+1)}}. \qquad (3)$$

Certain combinations of the moments give the possibility to make the following 7 transformations of moment characteristics, which are invariant to shifts, turns, expansions and compressions (scaling) and where initially proposed by M. K. Hu [1].

Moment invariants by Hu:

$$Hu_1 = \eta_{02} + \eta_{20}; \qquad (4)$$
$$Hu_2 = (\eta_{02} + \eta_{20})^2 + 4\eta_{11}{}^2; \qquad (5)$$
$$Hu_3 = (\eta_{30} + \eta_{12})^2 + (3\eta_{21} - \eta_{03})^2; \qquad (6)$$
$$Hu_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} - \eta_{03})^2 \qquad (7)$$
$$Hu_5 = (\eta_{30} + 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} - \eta_{03})^2] + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]; \qquad (8)$$
$$Hu_6 = (\eta_{02} + \eta_{20})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + 4\eta_{11}(\eta_{30} - \eta_{12})(\eta_{21} + \eta_{03}); \qquad (9)$$
$$Hu_7 = (3\eta_{21} + \eta_{03})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] - (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]. \qquad (10)$$

Contour comparison of two objects is brought to the correlation of corresponding Hu moments. The correlation is defined by one of the following formulas:

$$Kor_1(\alpha,\beta) = \sum_{i=1\ldots7}\left|\frac{1}{H_i^\alpha} - \frac{1}{H_i^\beta}\right| \text{ or} \qquad (11)$$
$$Kor_2(\alpha,\beta) = \sum_{i=1\ldots7}\left|H_i^\alpha - H_i^\beta\right| \text{ or} \qquad (12)$$
$$Kor_3(\alpha,\beta) = \sum_{i=1\ldots7}\left|\frac{H_i^\alpha - H_i^\beta}{H_i^\alpha}\right|, \qquad (13)$$

where $H_i^\alpha = |Hu_i^\alpha| * \log Hu_i^\alpha$, $H_i^\beta = |Hu_i^\beta| * \log Hu_i^\beta$.

Another important characteristic of a contour is inertia moments [6]. The inertia moment is a scalar quantity characterizing the inertia degree in rotation about an axis. The quantity J_a is the figure inertia moment about a fixed axis ("axial moment of inertia") equaled to the total of products of mass of all *n* material points of the system and the squares of their distances to the axis [9]:

$$J_a = \int r^2 dm, \qquad (14)$$

where dm is mass of body element and *r* is distance from the element to axis *a*.

The main central axes of inertia pass through the center of figure mass – axes relating to which the product of inertia equals zero:

$$J_{xy} = J_{xz} = 0,$$

where $J_{xy} = \int xydm$, $J_{xz} = \int xzdm$.

Let us assume that *u* and *v* are the main. Then:

$$J_{uv} = \frac{J_x - J_y}{2} sin2a + J_{yz} cos2a = 0. \qquad (15)$$

Hence:

$$tg\ 2a = \frac{2J_{yz}}{J_x - J_y}. \qquad (16)$$

This equation defines the position of main axes of inertia of the figure in the given point relating to the initial coordinate axes. However, in this formula *a* changes from 0 up to 180^0 that does not allow explicitly defining the contour orientation. The algorithm based on the additional contour extraction was proposed to solve this problem.

4 Algorithm for defining contour orientation

The algorithm is applied on the preliminarily extracted, by correlation coefficient of Hu moments, the

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pair of similar contours, one of which is the reference standard.

The algorithm comprises two parts: teaching by the given reference standard and orientation computation relating to the reference standard.

Teaching:

1. Divide the contour into 2 parts along the small axis of inertia.
2. Select one of the contours obtained.
3. Define moments for the contour selected.
4. Define the orientation as a vector from the part center of mass to the center of mass of the contour obtained at the second stage.

Definition of relative orientation:

1. Divide the contour into 2 parts along the small axis of inertia.
2. Define moments for the contour selected.
3. Find the most similar contour by correlation coefficient of Hu moments extracted at the teaching stage.
4. Construct the vector from the part center of mass to the center of mass of the contour obtained at the third stage. The vector obtained characterizes the part orientation.
5. The difference between vector angles of the reference standard and contour investigated defines the object turning angle relating to the reference standard position.

The proposed methodology allows explicitly defining the flat object orientation for further manipulations with it.

5 Finding the optimal position of manipulator grip

When moving parts, the manipulator performs linear and rotational motions which result in dynamic loads that need to be minimized. Moments of inertia create the main additional load. Centrifugal moments of inertia relating to the main central axes equal 0, therefore, it is necessary to fix the part in such a way as to align the part rotation axis and main axes of inertia. The grip for parts needs to be positioned on the manipulator following the same rule. The main central axes of inertia of the part (a) and manipulator grip (b) are demonstrated in Figure 1 [10, 11].

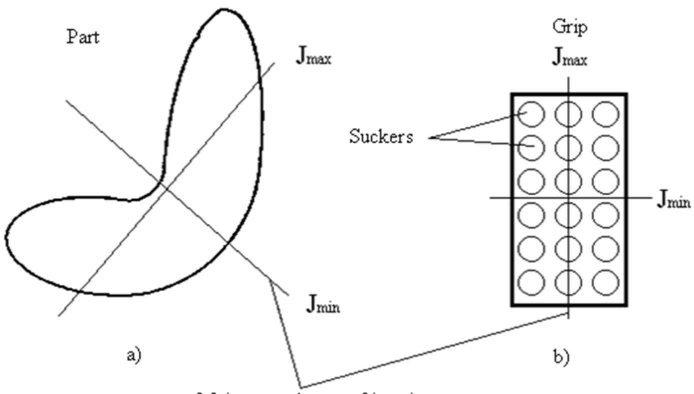

Figure 1 Main central axes of inertia of the part and manipulator grip

The manipulator grip for moving flat objects is the structure on which vacuum suckers are fastened to fix objects.

The alignment of central axes of inertia of manipulator grip and part with the rotation axis allows minimizing dynamic loads.

6 Experiment results

The samples of flat parts, demonstrated in Figure 2, were generated to test the algorithm obtained.

Figure 2 Trial samples of flat parts

Samples A,B,C imitate typical parts of furniture manufacturing, sample D – more complicated part.

Fig. 3 demonstrates the trial sample processed following the algorithm obtained. The extracted features are vividly illustrated.

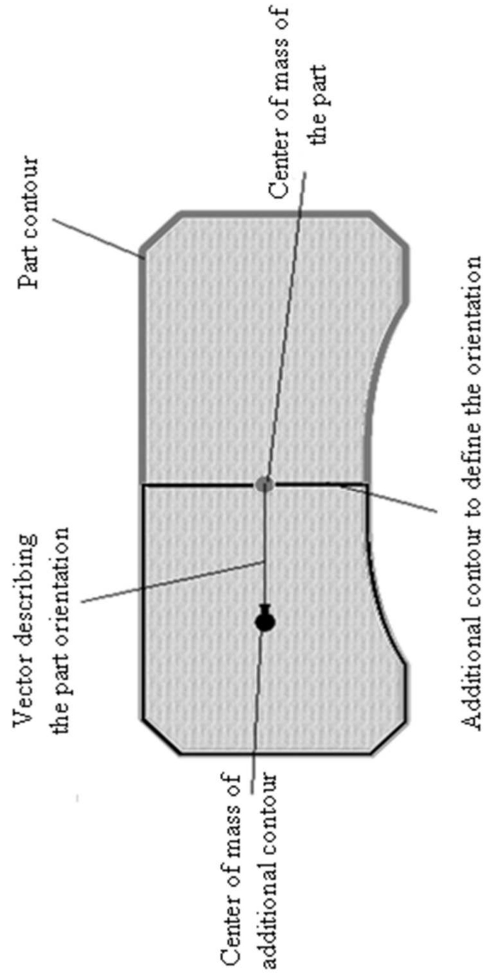

Figure 3 Processed trial sample

The part contour and additional contour are indicated in the figure, which allow making an orienting vector going through the centers of mass of the part and additional contour.

To evaluate the accuracy of orientation definition, the trial samples were turned around 45^0, 90^0, 180^0, 200^0 and 270^0. During the experiment the actual angles were compared, around which the parts were turned, and the angles calculated following the algorithm. The results are given in the table.

Table Angles calculated following the algorithm

Angle \ Part	A	B	C	D
45	45.01	45.04	44.84	45.23
90	90.08	90.00	90.00	90.15
180	180.08	180.00	180.00	180.15
200	200.22	200.02	199.93	199.96
270	270.64	270.09	270.00	270.00

The maximum deviation was 0.2396^0. The deviation is explained by slight distortions in images during turning as in the modeled data not the part contour but the whole image rotated. The average time spent on computation of the part orientation on the image of 1800x1600 pixels was 0.231 second.

The developed algorithm was also tested on the actual sample. The experiment results are demonstrated in Fig. 4.

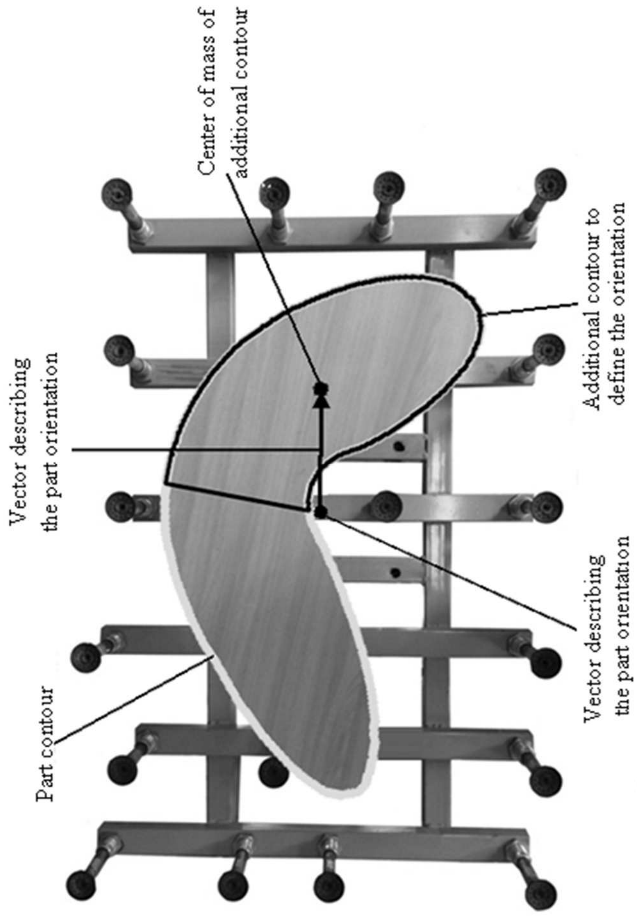

Figure 4 Actual sample

The figure demonstrates the part and its characteristics found according to the methodology developed that allow defining the orientation. The part is positioned on the manipulator grip.

Conclusions

The methodology based on extracting an additional contour in the object investigated is proposed. It allows explicitly defining the orientation of a flat object in 2D space. A number of experiments with modeled data were carried out. As a result, it was revealed that precise contour extraction is the most important condition as all the computed characteristics depend on it. The precise contour extraction is reached with the help of the correct selection and combination of different filters and algorithms when processing images. The methodology obtained can be applied during the automation of processes of moving flat parts, sorting out of parts by shape and other similar operations.

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References

[1] HUANG, Z., LENG, J.: Analysis of Hu's moment invariants on image scaling and rotation, *Computer Engineering and Technology (ICCET)*, 2nd International Conference on, Vol. 7, pp. 476-478, 2010.

[2] FLUSSER, J., SUK, T.: Pattern recognition by affine moment invariants, *Pattern recognition*, Vol. 26, No. 1 pp. 167-174, 1993.

[3] FREEMAN, H.: Computer processing of line-drawing images, *ACM Computing Surveys (CSUR)*, Vol. 6, No. 1 pp. 57-97, 1974.

[4] KHRYASCHEV, D.A.: *On one method of contour extraction on digital images*, Bulletin of Astrakhan State Technical University. Series: Control, computer engineering and informatics. No. 2, 2010.

[5] SOIFER, V.A.: Computer processing of images. Part 2. Methods and algorithms, *Soros educational journal*, No. 3, P. 110-121, 1996.

[6] MAINI, R., AGGARWAL, H.: Study and comparison of various image edge detection, *International journal of image processing (IJIP)*, Vol. 3, No. 1, P. 1-11, 2009.

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