Determination of Direction and Velocity of the Objects

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Abstract: In this paper the analysis of methods for determination the direction and velocity of the objects is given. As applied to the problem of geometry assessment for round timber the optimum by the ratio of accuracy and performance is phase correlation method. Nonetheless the pointed problem requires better accuracy and validity, so we had to improve this method and adapt it to the concrete conditions. Modified algorithm was tested on the image database of real technological process of round timber movement on the conveyer belt. The offered method has shown its high effectiveness and validity.

1 INTRODUCTION

Determining the direction and velocity of the objects is possible by combining two adjacent frames in the video sequence. For two given images:

$$I_1 : S \to \mathfrak{R},\quad I_2 : T \to \mathfrak{R},\quad S,T \subset \mathfrak{R}^d \qquad (1)$$

where d is dimension of the images (usually d=2), the task of combining the images is to find such a spatial transform $g : S \to T$ and brightness transform $f : \mathfrak{R} \to \mathfrak{R}$which allow to convert one image to another so that a correspondence points of these images match each other:

$$I_1(x) = f\left(I_2\big(g(x)\big)\right), x \in S, g(x) \in T \qquad (2)$$

That is, every frame is processed by the certain mathematical apparatus, which allows to determine the movement of the scene's object between the current and previous frames in the sequence of images.

The most promising methods for the problem under investigation are: method of determining the displacement on the basis of cross-correlation functions (CCF) (Jänne, 2007), the method based on the phase correlation (Gonzalez and Woods, 2005) and Lucas-Kanade method based on the optical flow (Lucas and Kanade, 1981). Although a number of methods discussed in this article are not complete, they are typical representatives of the motion analysis technique, commonly used in practice. Each of these methods has advantages and disadvantages as well as they require the optimum conditions, which depend on the particular application.

2 BODY OF ARTICLE

Method based on the cross-correlation functions of the two images is calculated according to the formula:

$$C(x,y) = \frac{\sum_{y'=0}^{N-1}\sum_{x'=0}^{M-1}[I(x',y')\cdot T(x'+x,y'+y)]}{\sqrt{\sum_{y'=0}^{N-1}\sum_{x'=0}^{M-1} I^2(x',y')\cdot \sum_{y'=0}^{N-1}\sum_{x'=0}^{M-1} T^2(x'+x,y'+y)}}, \qquad (3)$$

$$x = \overline{0, K-M-1}, y = \overline{0, L-N-1}$$

With this method it is possible to select section of one image on another and the difference between the location of these sections on the images is equal to displacement of the object against the camera occurred at the time of a new frame arrival. Among the shortcomings of the method based on CCF should be noted the instability to rotations and affine distortions, as well as high sensitivity to brightness variations.

Lucas-Kanade method searches for the bias in the vicinity of the singular point (Shi and Tomasi, 1994). This approach is often called differential as it is based on the calculation of the partial derivatives by horizontal and vertical directions of the image. In case of founding the bias in the vicinity of the singular point, its position updates for further search. Otherwise, the singular point is excluding from

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further analyses. By its nature, this method is local, that is, the area only around the pixel is taken into account for the determination of the particular pixel displacement. As a consequence, it is impossible to sufficiently determine the bias within the large uniformly colored sections of the frame.

Fast Fourier Transform method (FFT) for the phase correlation function is based on the assumption that if the signal has spatial and temporal shift, the frequencies and amplitudes of the harmonic components remain constant, only the initial phases change (phase-frequency spectrum), and the phase of each harmonic component varies proportional to the frequency and shift of the signal at that.

Block diagram of moving vectors receiving by the phase correlation method is shown on the Figure 1.

The result of transformation is a correlation surface which is function of two spatial values on the image plane. If there was no movement the difference of phase spectra is equal to zero. In this case spectral components sum up during the synthesis in phase. It results in surge with spike in origin of coordinates. When the object moved several number of maximums appear on the correlation surface.

Figures 2-3 present results of transforming by phase correlation obtained with the help of Image Processing Toolbox.

Transformation was applied to the whole image and as a result we have one vector (spike) correspond to the direction of object's movement. Disadvantages of this method are

- Impossibility of determination the value of movement in case of several moving objects on the frame
- High noise susceptibility

In case of intense noise on the one of the frames (e.g. camera noise) the dedicated spike may correspond to the noise (Figure 4), so the information about direction and velocity of movement will be inconsistent. In the problem of geometry assessment of round timber target object (log) is measured 180-250 times during scan, so propagation error leads to incorrect result, which is unacceptable for this task.

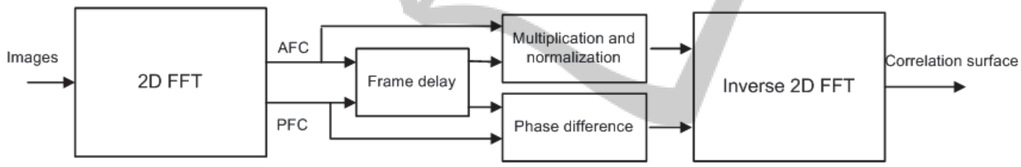
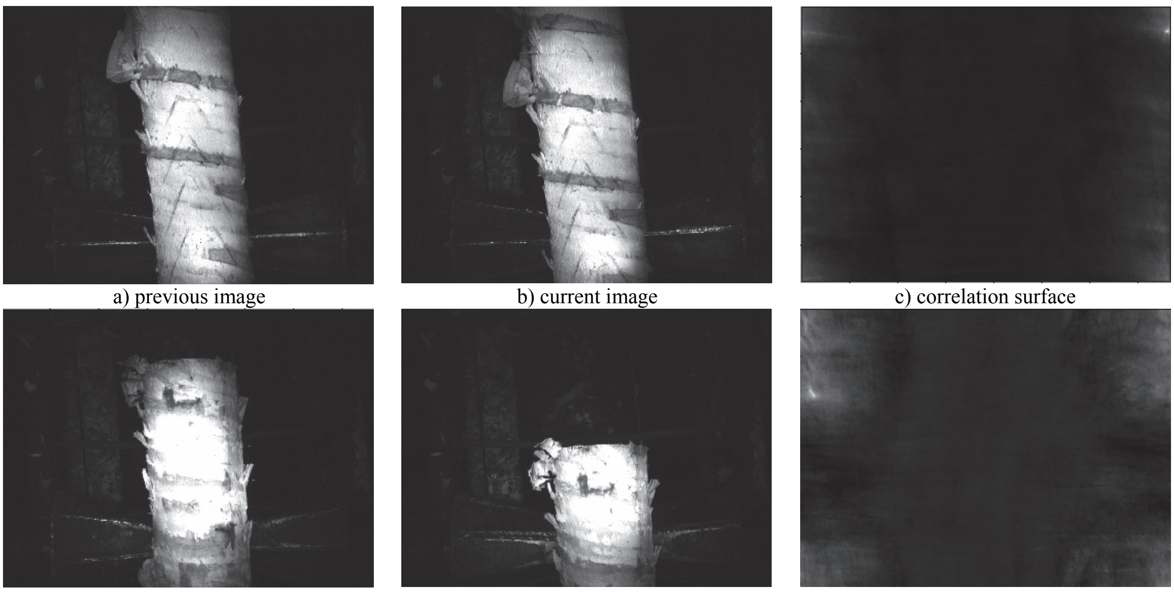


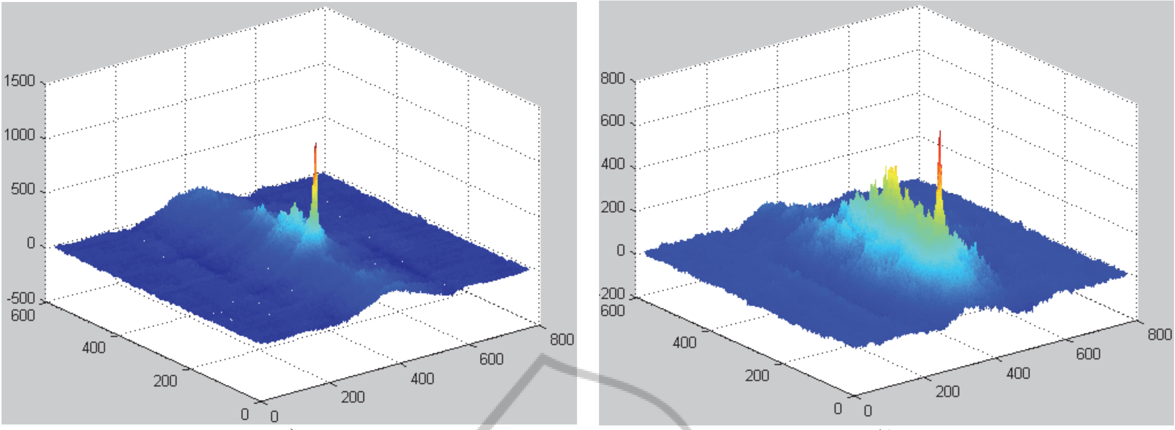
Figure 1: Block diagram of FFT phase correlation workflow (AFC – amplitude-frequency characteristic, PFC – phase-frequency characteristic).



a) previous image | b) current image | c) correlation surface

d) previous image | e) current image | f) correlation surface

Figure 2: Phase correlation method for two pairs of frames (a-b and d-e).



a) b)

Figure 3: 3D-images of correlation surfaces from figures 2,c and 2,f respectively.

Moreover, phase correlation method is not capable to carry out analysis of several objects in general case because each object (log on the conveyer belt) has its own direction and velocity of movement which don't match with these characteristics of other objects.

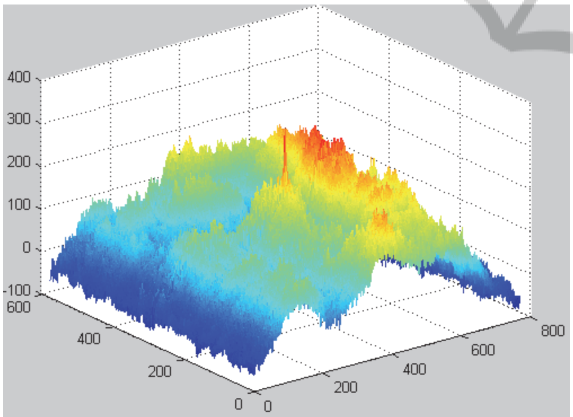


Figure 4: 3D-image of correlation surface with intense noise.

Unfortunately, each of these methods has limitations so the use of any one for this task becomes difficult. Method based on the CCF is not resistant to the affine distortions and rotations, and leaves out of account a particular texture. Lucas-Canada method is not resistant to affine distortions, highly sensitive to changes in brightness and shows insufficient result in the absence relief sections on the image. FFT phase correlation algorithm has a lower performance compared to the previous ones, but it is more accurate.

Thus, based on these findings, an algorithm that adapt to the scene conditions and the features of the objects on the image in order to operate with maximum efficiency for solving the motion estimation of roundwood on the conveyor was developed.

This method is as follows. At the first stage of the frame processing the selection of the front-stage objects is carried. Then, several sections (7-15 pcs.) are taken on each selected object, and each section of the current frame $F_i(t)$ is compared with the corresponding block of the previous frame $F_i(t-1)$, $i \in (0,n)$ by FFT phase correlation as follows:

$$R(u,v) = \frac{F_m(u,v) \cdot F_{\text{э}}^*(u,v)}{P_m \cdot P_{\text{э}}} \quad (4)$$

where R(u,v) is a spectral unit function which phase is equal to the phase difference between the functions F_m and $F_{\text{э}}$. Variables u and $v$are angular frequencies. Further the inverse Fourier transform is computed via the function of mutual phase spectrum:

$$P(x,y) = F^{-1}[R(u,v)] \quad (5)$$

Function $P(x,y)$gives a clear peak which determines the measure of similarity of the images, and the peak position corresponds to the shift of one picture relative to another. The basic idea of this step is to identify the most informative sections within each region $F_i(t)$ and to establish by them matching with the region on the previous frame. In this case, it is necessary that each section contains enough information (relief texture) to establish a correct match. To achieve this, the procedure of stacking the measuring sections by elliptical curve relative to the center of the field $F_i(t)$ with subsequent measurement of the value reflecting the information content of each section is implemented. Information content is measured in the horizontal E_H and vertical

E_V directions as follows:

$$E_H(x,y)=\sum_{i=0}^{M_i-1}\sum_{j=0}^{M_j-1} I_t(x+i-a_i, y+j-a_j)S_H(i,j)$$
$$E_V(x,y)=\sum_{i=0}^{M_i-1}\sum_{j=0}^{M_j-1} I_t(x+i-a_i, y+j-a_j)S_V(i,j) \quad (6)$$

where S_H, S_V are Sobel functions for horizontal and vertical directions which applied to the image I_t at the point (x,y) and (a_i, a_j) – tie point in kernel coordinates

$$S_H=\begin{pmatrix}1 & 0 & -1\\ 2 & 0 & -2\\ 1 & 0 & -1\end{pmatrix} \quad S_V=\begin{pmatrix}1 & 2 & 1\\ 0 & 0 & 0\\ -1 & -2 & -1\end{pmatrix} \quad (7)$$

It is necessary to make a number of adjustments to the current step, concerning certain aspects of the algorithm. Firstly, the search sections for each region of interest are stacked along the elliptic curve within each log (blue dots in Figure 5).

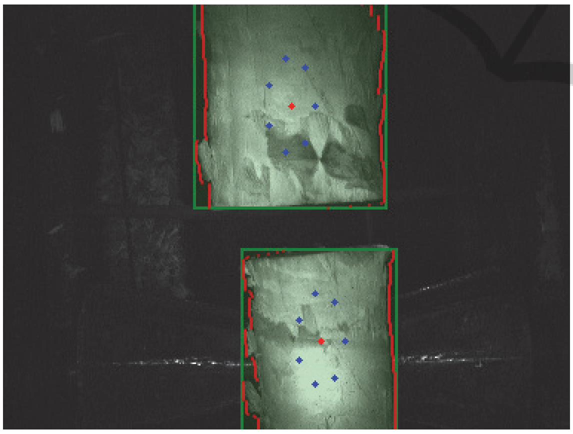


Figure 5: Visualisation of sectional FFT phase correlation in video sequence in the task of roundwood analysis. Centers of each section of the objects are marked with blue dots.

This step is stipulated by the necessity of compact and uniform distribution of the regions of interest within each log. It is this method will be by far the best in terms of uniform stacking of sections due to the fact that the logs have the elongated along the motion's direction profile with a relief texture on the image. Secondly, the magnitude of the information content of each section in fact is meaning of the contrast ratio within a region of interest so it provides a priori information for solving the problem of searching the best vector. In other words, the contrast value establishes a connection, i.e. indirectly affect the probability of a correct definition of the shift. Intuitively, the more contrasting matching sections, the higher probability that the motion vector for this section will be the most correspond to the real shift.

With this approach the matching is performed in two stages. At first, the discrete correlation function is computed and its "rough" maximum is determined, then the peak position is adjusted by the intensity interpolation method (Gonzalez and Woods, 2005). In the next step, among formed candidate vectors search for the best one, which value is considered as the shift of the object, is implemented by heuristic search method.

This process has three important features. Firstly, the subpixel search of the peak position of the correlation surface would greatly increase the accuracy of determining the shift of the objects. Secondly, the search operator is applied not to the entire image, but to the regions where objects were detected. Thirdly, due to the exhaustive search within a few number of motion vectors (for the current task which characterized by objects with feebly marked relief and possible lack of the specific features the number of candidates is 7 for each object) and parallel processing (Kruglov et al., 2013), a high speed of the algorithm is achieved (Figure 5).

Tracking objects assumes the establishment of correspondence between the objects of the previous frame and the objects detected in the current frame (Kruglov and Kruglov, 2013). Correspondence between the objects considered to be established if these objects are spatially close, displacement is small and both are sufficiently similar. Proximity criterion is the fulfillment of the following conditions:

- the Euclidean distance between the centers of mass of the objects is small;
- the size of the object does not vary much from one frame to another (also by the Euclidean distance).

The resulting algorithm for determination the direction and velocity of the logs on the basis of the phase correlation method was tested on the images database of the actual video sequence process (435,000 frames). The size of the sections for phase correlation was 64 * 64 pixels, the number of blocks - 7 for each selected front-stage object. Test was carried out in MATLAB framework on the IBM PC IntelCore i7 2.8GHz. The results of the test are shown in Table 1.

Table 1: Performance of the algorithm.

	1 object 7 sections	2 objects 14 sections	3 objects 21 sections
Without multithreading	15 ms	28 ms	40 ms
With multithreading (OpenMP)	7 ms	11 ms	14 ms

According to the results, it should be noted that offered method for determination the direction and velocity of the objects based on the phase correlation demonstrates high efficiency on the test images. Reliability and performance of the algorithm fully comply with the conditions of use in machine vision systems for real-time control of technological processes associated with the analysis of fast-moving objects.

3 CONCLUSIONS

As is known from mechanics, solid body moving in three-dimensional space, can have a six degrees of freedom maximum: three translational and three rotational. Degrees of freedom are a set of coordinates that certainly defines the position of an object in an associated coordinate system.

Log, like a solid body moving in the plane of the conveyor, has four degrees of freedom (two rotational and two translational) This limitation should be considered in solving the problem of measuring the volume of logs by observing their movement in front of the camera. It is possible to simplify the problem by assuming that the log moves along rigid rails, i.e. it does not have the ability to move sideways and rotate, then it has only one degree of freedom. When using such simplification, in the sequence of images would be observed the shift with a constant orientation, wherein only the instant amplitude varies from frame to frame. But the fact is that in the real conditions of logs transportation such ideal type of movement does not exist. Therefore, it is recognized as necessary that the log has four degrees of freedom and all four components of the movement must be taken into account to accurately measure log's length; or at least we can consider the log as material point with one degree of freedom in the main approximation (and make corrections due to its vibrations in other directions when its main movement is calculated with proper accuracy).

Task of determining the movement of the log can be formulated as follows: if the log's shift on the image is defined by offered method for two neighboring frames, and its value can be written as a vector with coordinates (x, y), then how the value characterizing the physical movement of the log can be obtained from the resulting vector? How to get the four-dimensional vector from the two-dimensional? How to solve a system of two equations and four unknowns?

In the photo and video camera, an image is formed under the law of the central projection. As we know, such a mapping of three-dimensional space on a plane is not unambiguous because all three-dimensional points lying along a single ray are projected at one point on two-dimensional image. In other words, once we got the log's image, i.e. from three-dimensional space transformed into a two-dimensional, we lost a lot of information related to the depth of the observed scenes and objects in it.

Recovering of this information is not possible while using only one camera. The only way of further developing for this task is to use multiple cameras for reconstruction of the log in three-dimensional space. In that case the information about the depth of the scene and objects on the image allows to convert the value of the motion vector, obtained by the offered method, to the physical movement of the log.

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