Algorithm for markers detection on fringe images

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Abstract. Thanks to non-contact scanning technology and its harmlessness to human health, the usage of numerous 3D scanners in various fields of medicine has considerably increased. For example, in orthopaedics, medical topographic system TODP uses structured light with fringe projection to determine the 3D relief of the dorsal surface of the trunk for the urgent task of diagnosing spinal deformities. To improve the accuracy of postural states analysis, anatomical landmarks of the skeletal bone structures are marked with high-contrast small-sized markers of the reflective film. Thus, the task of the marker’s detection in the image appears. The article discusses the algorithms for detection of small-sized bright markers in fringe images, obtained by the computer optical topography method. The experimental results have shown that the proposed algorithm can detect 99.94% of the reflective markers in a sample of 1000 images with 8350 markers in total.

1. Introduction
Numerous 3D scanners work by using the optical triangulation principle [1]. Projection of structured light onto a shaped object produces distortions of pattern in proportion to an object shape [2]. These distortions register from other perspectives than that of the projector. The resulting image can be used for the geometric reconstruction of the surface shape with high accuracy and optical spatial resolution [3].

The most common and simple structured light is the fringe projection. Phasemetry methods [4, 5] allow processing a fringe image as a two-dimensional sinusoidal signal and reconstructing the surface shape in each point of the image. To assure safety for human health, 3D scanners with structured light are used in medicine, for example, in the TODP system [6] for scoliosis diagnostic and body posture analysis.

2. Statement of the problem
To improve the accuracy of the analysis of the postural state, the anatomical landmarks of skeletal bone structures are marked with high-contrast small-sized markers of the reflective film. The high contrast of the markers makes it possible to distinguish them on the fringe background as bright dots of 3-4 pixels in size. During the detection stage, the bright markers on the image are pulsed noises, which can significantly distort the local shape of the reconstructed human body surface. Therefore, all reflective markers must be identified and “erased” from the fringe image.

The article discusses the algorithms for the detection of the reflective markers on the fringe images, used in TODP system.
2.1. Obtaining an image for the reflective marker detection

Reflective markers are usually clearly visible on a grayscale fringe image, which illustrates Figure 1. However, using amplitude detection often is not enough for its automatic identification. In practice, the individual markers may be inclined at a large angle to the light source. It leads to a significant drop of marker’s brightness, making it comparable to the fringe’s brightness. To ensure the detection of poor-quality markers, a special image is prepared. Firstly, an image with no fringe is created row by row via low-pass filter “triangular window” with impulse response:

\[
h(n) = \frac{2M - |n|}{4M^2},
\]

(1)

where is \( M \) – window size, \( n \) – discrete image’s coordinate. Second, using (1) with \( M_2 > M \) another image with smoothed markers is generated.

![Figure 1. Image with fringe and reflective markers.](image1)

![Figure 2. Image for markers detection.](image2)

When subtracting from the first image, the second image and addition of brightness code 128, a special grayscale image for markers detection is obtained as shown in Figure 2. Zero values of the difference are represented by gray background (code 128), the positive ones are in the form of light ones, and the negative ones are in the form of the dark pixels. There are no fringes on this image and markers are still visible. However, some pseudo markers can be detected on the external contour of a human’s body.

2.2. Specific marker’s shape on an image for markers detection

All source image (Figure 1) transformations for preparing an image for markers detection (Figure 2) are linear and correspond to a smoothing differentiator (1). It removes the energy of the fringes and leaves reflective markers on the image. The markers have the form of the impulse response of a linear filter, due to small size they can be approximated as a Dirac delta function. The brightness characteristic of the markers along the horizontal axis is presented in Figure 3.

The shape of the marker (excluding background brightness code 128) is the main positive impulse at the marker’s center and two negative side lobes are oriented along the smoothing direction. The amplitude ratio of the main pulse and side lobes and their lengths are determined by the characteristics of the smoothing differentiator (1). The specific shape of the markers allows using recognition algorithms in accordance with their characteristics.
2.3. The structure of the algorithm for markers recognition

The algorithms for recognition of markers are developed using three principles: phasing, hierarchy, and adaptability. In accordance with these features, the process of identification of the markers is divided into stages arranged in a hierarchy from simple to complicated.

![Figure 3. Brightness characteristic of the markers.](image)

In the beginning, the simplest amplitude criteria are used for all pixels in an image, and it gives many pseudo markers. At the next stages, the complexity and amount of calculations increases, but an insignificant part of the pixels of the entire image is being processed. Due to different filming conditions, the quality of the source images varies greatly, so the algorithms are adaptive to processing of poor-quality images.

3. The marker’s detection algorithm

The flowchart of the marker’s detection algorithm is shown in Figure 4. The algorithm can be divided into three main stages. At the first stage (Blocks 2–4) the potential markers (PM) are selected using the amplitude threshold and the specific shape of the markers. These simple and fast algorithms can process a large amount of data in an acceptable time (less than 0.15 sec). At the second stage (Block 5) the local area around PM is analyzed by applying more complicated criteria. Then, due to the rejection of all PM with “bad” surroundings, the number of PM significantly decreases. At the third stage (Blocks 6–8), all characteristics of PM and its surroundings are compared with the mathematical marker’s model characteristics. The marker’s model is obtained by the statistical methods via processing a large amount of the training sample data.

Image processing is carried out sequentially in columns. In the first cycle, pixel-by-pixel usage of simple criteria detects potential markers in the columns of the image. The second cycle analyzes PM, rejects the false markers and indicates the true ones. If no true markers are found (due to the poor-quality image), the cycles are repeated with other threshold parameters. Consider the algorithm logic block by block next.

3.1. Block 1. The initial condition’s setup

In the initial condition’s setup block, the global thresholds and other parameters are to be initialized. These parameters represent the amplitude detection threshold, expected value of the marker’s amplitude, shape’s characteristics of the marker, asymmetry of lobes, expected value of the marker’s surrounding, characteristics of the marker’s statistical model, etc. Some parameters, such as the amplitude threshold, depend on the quality of the source fringe image, that is why they are selected automatically and adaptively.
3.2. Block 2. The amplitude detector

In this unit, the brightness amplitude for all pixels in the image for detection markers is calculated via the equation of the second finite-difference for vertical direction:

\[ A(y) = \frac{2I(y) - I(y - 3) - I(y + 3)}{4}, \]

where is \( A(y) \) – calculated amplitude of pixel, \( I(y) \) – pixel’s brightness. Further \( A(y) \) is compared with a threshold value \( A_T \). If \( A(y) > A_T \), the current pixel is indicated as a potential marker, otherwise, the next pixel in the column is to be checked. All columns are processed sequentially in the same way.

![Flowchart of the marker’s detection algorithm](image)

**Figure 4.** Flowchart of the marker’s detection algorithm.
3.3. Block 3. The side lobe symmetry detector
As mentioned, the true markers have a specific shape with the main positive impulse and two symmetric negative side lobes stretched in the horizontal direction (Figure 3). In the vertical direction, it has a few bright pixels in a uniform background. For most of PM, the shape is different from the true marker, including the lack of symmetry of the side lobe shape. To detect the true markers asymmetry coefficient of the left and right side lobes shapes in the horizontal direction is calculated using the following equation:

\[ K(x) = 50 \frac{I(x-5) - I(x+5)}{2I(x) - I(x-5) - I(x+5)} \]  

(3)

The value \( K(x) \) is compared with the threshold \( K_{asm} \). If it is exceeded, PM is to be discarded.

3.4. Block 4. The storage of the potential markers
All potential markers, which have passed through Block 2 and Block 3, are to be stored in array PMA for their further selection by more complex criteria.

3.5. Block 5. The potential marker’s surroundings analysis
In this block, the parameter, showing the heterogeneity of the surrounding pixels, is calculated. Area 9×9 surrounding pixels near PM is considered and determines 8 estimates of the brightness amplitude of the central pixel PM via the second finite difference in eight directions – horizontal, vertical, and diagonals:

\[ S_i = 2I(m) - I(m+4) - I(m-4), \quad k = 1, 8 \]

where is \( m \) – coordinates \( x \) or \( y \) of the surrounding pixels which depends on direction \( k \). Using \( S_1, \ldots, S_8 \) calculates a parameter showing the heterogeneity:

\[ tpa = 0.125 \left( \sum_{i=1}^{4} S_i^2 - S_{i+4}^2 \right) - 1 \]  

(4)

In (4) parameters \( S_i \) and \( S_{i+4} \) are calculated in opposite directions. For true marker point \( S_i \approx S_{i+4} \approx \ldots \approx S_n \) hence \( tpa \) value trends to zero. For the pseudo markers located on the torso edge, values \( S_i \) in opposite directions significantly differ due to various brightness: on the one side it is a human body, on the other side it is background, so, \( tpa \) is compared with some threshold \( tpa_1 \). If \( tpa > tpa_1 \), the current PM is rejected. The given procedure allows to reject most of the pseudo markers onto a human’s torso edge.

3.6. Block 6. Calculating of the marker’s parameters
For the next comparison of PM with the statistical marker’s model some additional parameters are to be calculated:

- Marker’s brightness \( B \). It is taken from the source image (Figure 1).
- The amplitude of the pulse \( I_p \) – brightness value in the extreme pulse point.
- Amplitudes of the left and right-side lobes \( K_{L} \) and \( K_{R} \) – the value of brightness in lobe’s extreme points.
- Asymmetry of the side lobes \( K_{l} \). It is calculated using (2), but instead of values \( I(x \pm 5) \) and \( I(x) \) the \( K_{L}, K_{R}, I_p \) values are applied.
- The amplitude ratio of the main pulse and side lobes \( K_{LR} \):
  \[ K_{LR} = \frac{256 - K_{L} - K_{R}}{|I_p - 128|} \]
- PM area size \( SZ_{S} \) on the source image and \( SZ_{p} \) – PM area size on the image for detection of the markers.

These parameters, as well as the parameters previously calculated, are stored in an array PML:

\[ PML = \{A, K, tpa, B, I_p, K_L, K_R, K_{LR}, SZ_S, SZ_p\} \]  

(5)
Finally, the array $PML$ is transferred into Block 7 for the next calculations.

### 3.7. Block 7. The comparison with marker’s model

By processing a large amount of training sample data, the mathematical model of the reflective maker as an average value of data has been created. The parameters $IML$ as in (5) and standard deviation $\sigma_i$ for each parameter in the marker’s model have been calculated. To estimate the proximity of the marker parameters to the model one uses the following equation:

$$
\text{dipa} = \left( \sum_{i=1}^{11} \left( \frac{PML_i - IML_i}{\sigma_i} \right)^2 \right)^{1/2}.
\tag{6}
$$

In (6), every parameter has a different contribution to $\text{dipa}$’s estimate. It has been discovered that the maximum weight has $tpa$ (up to 40% on false PM) and $SZ_i$ (12%) values. Compared to the marker’s model and real reflective marker, at least one of the false marker’s parameters does not fit in the standard deviation $\sigma_i$. Thus, using an empirical value $d_T$ as $\text{dipa}$’s threshold almost each of the false PM can be discarded.

### 3.8. Block 8. Placement geometry analysis

The algorithm for rejecting markers by geometric criteria is used as the final step for removing the false markers. It is based on the analysis of the relative position of the found markers. To label patients for computer optical topography, the standard scheme is used, which includes marking the spine line and two points of the pelvis. It allows to identify and remove those markers which location does not match the geometry of the standard marking, including the false-positive markers that cannot be rejected by the previous algorithms.

### 3.9. Block 9. The storage of true markers in the output array

If a potential marker passes all the previous blocks it is considered a true reflective marker. The marker and its characteristics are stored in the output array of the algorithm ($TMA$) for the next proceedings.

### 3.10. Block 10. New threshold’s setup

Fifteen markers are quite enough to compute the optical topography. The algorithm is designed to detect up to 20 markers. If the output array $TMA$ counts over 20 markers, some markers in $TMA$ can be false-positive. The presented situation may arise due to improper lighting conditions during the filming of the image or presence of any undesired objects in the frame. Facing the problem mentioned above, the new threshold values for Blocks 2–8 are to be calculated and the algorithm is to be repeated starting with Block 1. The number of the possible transitions to Block 1 is limited to two for the preventing of algorithm looping. With the execution of instructions of this block, the algorithm is finished.

### 4. The experimental results

The process of marker’s detection algorithm and final result are presented in Figure 5.
Figure 5. The stages of the reflective markers detection process: amplitude detector (a), side lobs symmetry detector (b), analysis of surroundings (c), comparison with the model (d).

The whole test is run on Intel Core i3-4350 PC with 2 GB RAM. Source fringes image size (Figure 1) is 256×256 pixels (65536 pixels in total) and all reflective markers are clearly visible. An amplitude filter (2) with threshold, as expected, has found many potential markers: 545 PM have been detected as shown in Figure 5a. A lot of false PM are located at the edge of the background and human body due to fast brightness drop at that place on the source fringe image. After applying side lobs symmetry detector (3) the number of the PM has decreased to 303 units (Figure 5b). The primary image processing cycle takes 0.08 sec to complete and store potential markers in PMA array. Analysis of surroundings (4) has allowed to remove most of the pseudo markers from human’s body boundary and only 39 PM last including the true reflective markers as shown in Figure 5c. All false PM have been rejected while compared with the marker’s mathematical model (6). The geometry analysis has confirmed that the remaining 8 markers shown in Figure 5d are real ones.

Notice that the source fringe image has a good quality and the detection of all reflective markers does not present any difficulties. The experiment with images of random quality has shown that the algorithms allow to detect 99.94% of the true markers in a sample of 1000 images with 8350 reflective markers in total, and no false-positive markers have been detected. In the sample of 5000 real markers on different quality images, the first type probability error value is about 0.22% (algorithm can’t detect 11 markers), and the second type error probability is 0.06% (3 false markers was found).
5. Conclusion
The proposed algorithms allow detecting and recognizing the small-sized reflective markers on the fringe image used for medical topography tasks. The algorithms provide a high accuracy of the detection of the true markers with full automation of processing at high speed due to the principles of phasing and hierarchy. The principles of the adaptability of the basic algorithm and usage of the statistical model of the markers make it possible to detect the reflective markers even on images obtained under incorrect lighting conditions.

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