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ABOUT ONE MODEL OF MACHINES REMOTE CONTROL ON THE BASIS OF GAZE TRACKING

Abstract: The methodology of control metal- or woodworking equipment based on the determination of the eyeball position and its movement direction. The developed hardware and software system for gaze direction tracking can be used as an alternative method of input, which is closer to the natural way of interaction with the environment, as well as the only way to work with a machine for the users with reduced mobility.

1. Introduction

At the current moment the non-contact interfaces development is a very urgent task. It is associated with variety areas of science and technology. This also includes non-contact data entry for disabled users; behavior analysis of the human operator for the complex production according to his eye movements; psychological testing and research of mental faculties, and many others, where information can be obtained from the observation of the human pupils and then used [1].

In the manufacture of complex shapes using metalworking equipment may appear a situation in which both the operator's hands are occupied. In addition, control with a feet is undesirable because it can unbalance operator's position. In this case, to solve the control issues presented in the current paper technology can be used, which includes non-contact machine control based on analysis of the position and movement of the operator's pupils.

Another use case of such principles is monitoring the state of an operator. It is based on the fact that in the normal state of health an eyeball constantly makes saccades (rapid jumps) observing a certain process. Lack of saccades means an operator either fainted or fell asleep because of slow repetitive routine. Both can lead to injuries and accidents in the workplace and should be avoided by any means.

Therefore, the solution of the issue of machines remote control on the basis of eye movement is highly relevant and important.

2. Theoretical principles of gaze tracking

In the current paper it is necessary to allocate some directions.

First, it is a direction associated with obtaining eye images. In the study, it was found that the best way of eyes video shooting is in infrared light. In this light practically all noise and reflections are eliminated, and also the sensitivity to illumination changes is significantly reduced.

The second direction concerns the analysis of the user's pupil's state. This work required the investigation of different methods of video flow pre-processing in order to obtain stable contours of the pupil and the brightest reflection on it. On the basis of the pupil movements and moves of the reflection can be concluded some desirable human action. In this paper, the essential point is an unambiguous definition of the only reflection on the cornea. An infrared light diode was used IR illumination, which gave the only highlight on the eye cornea. Since the diode is stationary in space, changes of its relative position with the pupil allows to calculate the gaze direction vector. Fig. 1 shows the relative position of the pupil and reflection according to different eye movements.

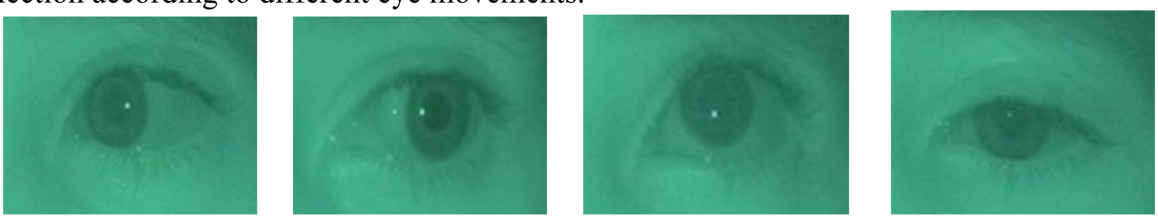

Fig. 1. Relative position of the pupil and reflection during eye movements left, right, up, down

3. Algorithm of gaze tracking

In the process of image pre-processing the original video frame is smoothed with convolution with Gaussian kernel, then on the basis of morphological operations of erosion and dilation edge detection is performed, as shown in fig. 2 [6].

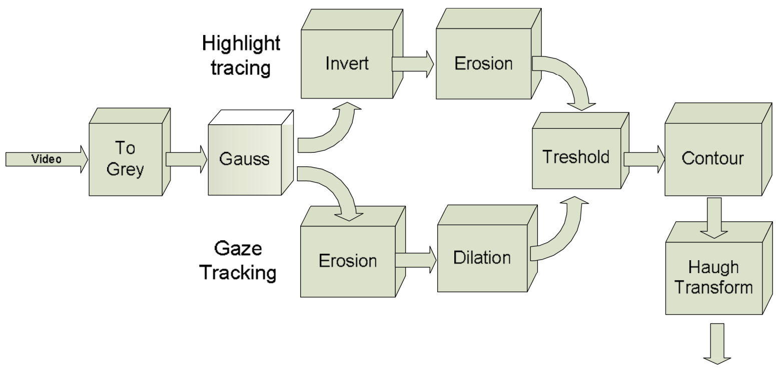

Fig. 2. Video stream processing is parallelized in two directions. Pupils contour and reflection coordinates highlighting

To improve the accuracy of the pupil contour recognition the Hough transform is used, which allows to find circles and retrieved coordinates of reflections from the infrared diode. To reduce the error in the tracking results the coordinates from previous frames are stored in a queue, and then interpolated with coefficients according to normal distribution. Also the coordinates ate normalized by the relative position of the head. As a result, the relative position of pupil and reflection is converted to the gaze direction vector, which is based on previously received data after calibration.

A more detailed overview of the developed gaze tracking algorithm is given below.

The application receives an input video stream from an infrared camera. Stream is split into 30 frames per second and frames are represented as images, which is in terms of image processing an array of pixels.

Then the original colour image is converted into an 8-bit black and white (greyscale) image. This operation is included to carry out for further image processing and resources saving. In a colour image each element of the image array contains four 8-bit values: alpha, the amount of red, green and blue in a certain pixel. Greyscale representation, on the other hand, contains only the brightness value in the range [0, 255], where 0 refers to black and 255 to white. So a two dimensional array is processed instead of three dimensional.

For noise and artefacts reduction the image is blurred with convolution matrix with Gaussian kernel.

After the blurred image is received, there are two options for further algorithm actions:

- In the first case, highlight from an infrared diode tracking on the frame is selected. The highlight is the brightest spot in the image with the round shape. However, the amount of light areas significantly exceeds the amount of dark ones. Therefore, initially blurred image is inverted so the highlight becomes a dark spot. Further erosion operation is performed with a structural element size 15. The result of erosion operation is an expansion of dark objects and reduction of unnecessary light areas. Thus, the possible reflections from external illumination merge with highlight from the infrared diode or are simply removed.
- In the second case, the pupil tracking is selected. A pupil is the darkest spot in the image, so there is no need in inversion. Consistently operations of erosion and dilation with a structural element size 20 are applied to the blurred image. The purpose of this operation is to smooth contours, to cut the narrow isthmus, and eliminate ledges of small width. In other words, artefacts reduction.

An ability to select the point of interest (pupil or highlight) is included due to the fact that in dim ambient light pupil tracking becomes inconvenient. It is nearly impossible to unambiguous define the darkest area on the image among the high number of shadows. Therefore, in the dim light or in the dark it is more productive to use the highlight tracking.

Regardless of the point of interest - the pupil or highlight – an image binarization is made. All pixels with the brightness value of less than 150 are colored black (ie, the value is 0), and more - white (ie, the value is 1). Binarization operation is need for contours detection.

The next step is contours detection. Binary image is cloned and morphological operations erosion with a structural element in the form of a cross is applied to the cloned image. Then the modified image is subtracted from the original binary image. The result is a binary image containing the contours of a threshold high enough to weed out the unwanted areas and not to lose the pupil or highlight.

The final procedure of the developed gaze tracking algorithm is the circle search based on Hough transform. A binary image containing the selected contours is an input. The application of Hough transform gives a sequence of circles contained in the image. Circle parameters are coordinates of the center and its radius.

To improve the recognition accuracy, a queue is instantiated according to the results of the algorithm performance on four previous frames. These coordinates and radii are approximated according to the values of the queue with the given weights coefficients. Such memory queue help to increase the tracking results in approximately 2.7 times. However the number of the queue elements cannot be expanded due to the possibility of significant drop in performance.

4. Model of machine control on the basis of gaze tracking

The third stage of the research was an application development to control a machine on the basis of the derived coordinates of the reflection and the pupils' circles. At this stage the input information is the coordinates of the circles centers and their radiuses (regardless to the area of interest - pupil or reflection), which are interpreted as the state of the eye: their position, blinking left or right eye and closed eyes, or the lack in the field of the camera point of view, as shown in fig. 3.

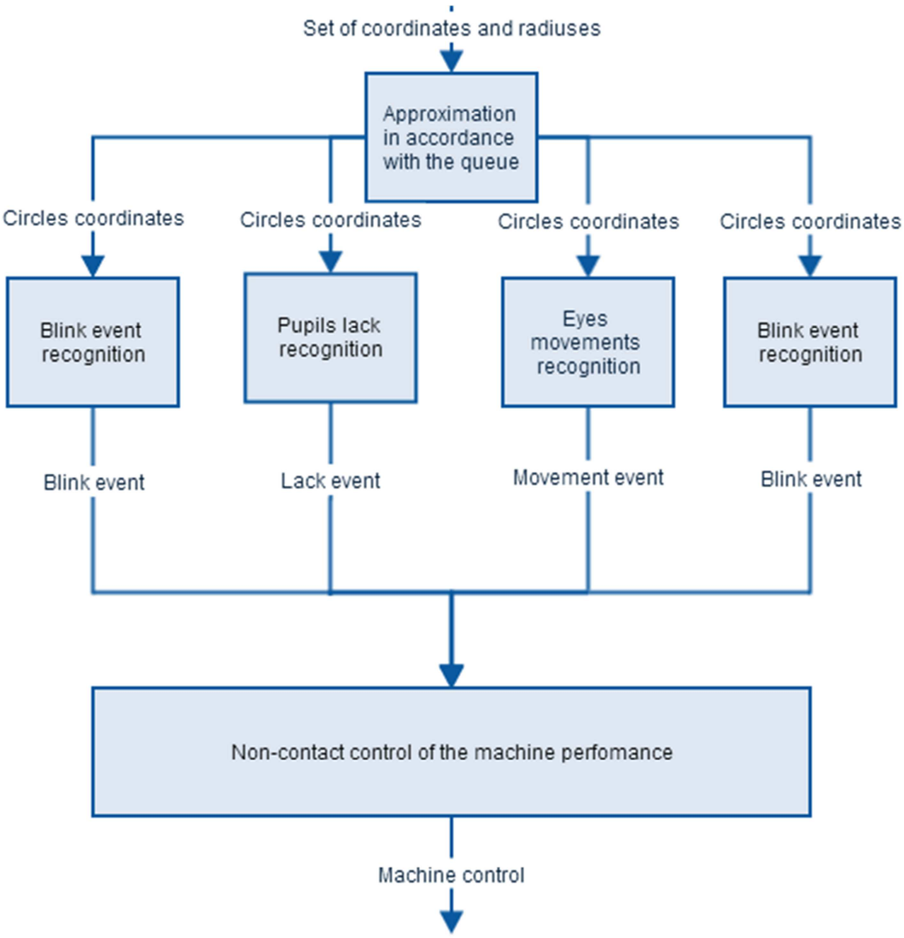

Fig. 3. The scheme of information processing in the third stage - machine control

Two options of the machine control in accordance with the developed semantics are possible:

- Action control. The event of the lack of a circle within a certain time is detected and associated with a blink. When a blink event occurs operating system signal is sent to the commission of some specific action to be performed on the machine. With long-term absence of circles on the image some process can be terminated to diminish the risk of some factory accident. Such control features provide great opportunity in hazardous manufacture. An operator's hands can be occupied with some item, but in the same time he can control another process by blinking.

- Position control. An original interface was developed to control the position of some object, which detects eyes movements (fig. 4). Eyes movements are associated with some item position changes.

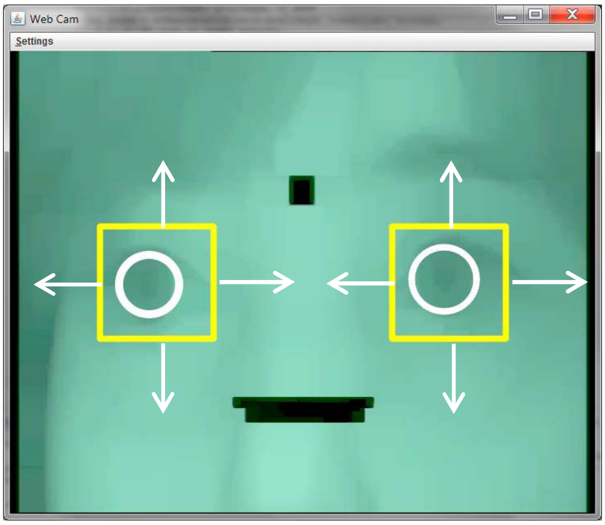

Fig. 4. Interface for position control

Yellow rectangles are the bounding boxes for each eye. When the centers of the two pupils are inside the bounding box, the object does not move.

Otherwise, the current coordinates of the associated item are detected and then the dislocation of both centers of the pupils in the bounding boxes is checked. If the centers are located in the left margin, the item is moved to the left until the centers of the pupils do not cross the right border. Movements to the right, up and down are processed similar to the left one.

5. Features of the application implementation

The fundamental objective in creating this application was the realization of eye tracking algorithm at a speed of 30 frames per second. To speed up the work of the various methods special techniques based on the properties of convolution, morphological operations, etc. were used. With the implementation of the "greedy" algorithm processing speed was about 1.5 frames per second.

The program is implemented in Java 1.6, using standard Java-libraries for creating graphical user interface, video conversion into separate frames, as well as emulation of the keyboard and mouse control.

6. Conclusion

Based on the achieved results the following conclusions are carried out:

1. System for gaze tracking can be easily implemented on one of the industrial controllers with addition of a microcamera and infrared diode on a flexible cord.

2. The Usage of a micro camera and an infrared illumination allows to quickly and steadily track the position of the eyeballs under high ambient lighting changes.

3. Application of such additional equipment in hazardous manufactures for controlling and/or managing the process of complex shapes treatment. Allows additional control and tool for machines management.

4. The existence of such a device in the assembly-line production allows to monitor the state of the operator in the process of repetitive routine. In the case of fatigue or inattention machine can be turned off automatically based on the absence of eye movements.

5. It is possible to build human-machine systems with motion control components based on the observation of the movement of the operator’s eyeballs. It can be claimed in complex damage control work when the operator's hands are occupied by monitoring the state and position of a workpiece.

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