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Registration and processing system of digital speckle images

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Abstract. In this paper, we discuss an application of the method of laser-speckle correlation for studying the blood coagulation process. A module for recording and processing speckle images based on a debugging kit for the Atxmega128A1 microcontroller has been developed. The results of testing the developed module as part of a laboratory setup based on a semiconductor laser using standard reagents are presented.

1. Introduction

Blood coagulation (hemocoagulation) is the most important step in the work of the hemostasis system, which is responsible for stopping bleeding when the vascular system of the body is damaged. Disruption of the blood clotting process can be caused by various reasons and entail undesirable consequences. Estimation of hemostasis parameters in real time is an essential task, despite the large number of existing methods and means of measurement. Nowadays several methods have been developed to observe and measure the physical characteristics which accompanied the coagulation process, for example, blood viscosity [1–4], surface tension [5] or electrical conductivity [6]. The main disadvantages of the majority of known methods are invasiveness, the inability to carry out clotting monitoring in real time and performing point-of-care testing.

Currently, diagnostic methods are being developed based on analysis of laser speckle images [7, 8]. Optical methods based on laser speckles make it possible to analyze blood clotting non-invasively. In particular, our team is developing a device for estimating the clotting time of native blood based on the digital speckle image correlation method [8], and an electronic module is required, which is used for an automated processing of speckle images.

In use, the device, which will be developed based on the hardware-software complex presented in the work, makes it possible to carry out actions inaccessible to competitors, namely: carrying out express analysis and continuous monitoring. The first feature will be important for people who need constant monitoring of blood clotting factor. Too fast or too slow blood clotting time may indicate the presence of disorders of the cardiovascular system. The second feature will make a great contribution to surgery. Continuous monitoring of this factor during surgery significantly simplifies the work of the surgeon.

The purpose of this work is to develop an automated microprocessor system for recording and processing digital speckle images.

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2. Technical means

The experiments on plasma clotting were conducted using the existing experimental setup with the designed microcontroller module. The flow chart of the experiment and developing module are shown in Figure 1. The view of the experimental part is shown in Figure 2. Before the experiment, the camera with microcontroller was fixed in the experimental setup, available in the laboratory of the department. For the experiment, a continuous diode laser with the radiation power of 10 mW was used, a control blood plasma and a Techplastin reagent (Technologiya Standard, Russia) with a given coagulation time [9]. A cuvette for the plasma had 0.1 ml volume and was made from plastic using 3D printing.

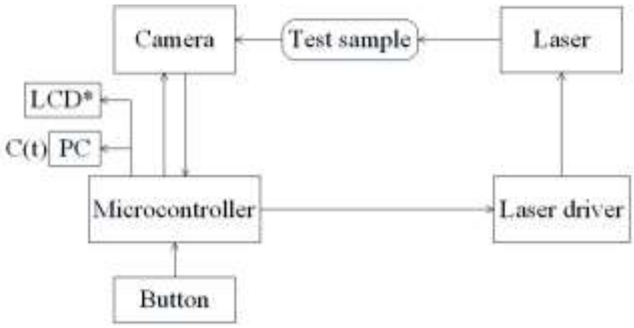

Figure 1. The flow chart of developing module.

Figure 2. Experimental setup: 1 – developed module, which consist of camera and microcontroller, 2 – control plasma in a cuvette on the sample table and a solid-state laser, 3 – laser driver.

During the process of coagulation, the movement of microparticles occurs, and clots form in the sample under study. The illuminating laser beam, due to scattering, forms a speckle images which are presented in Figure 3. We used a monochrome camera mode for recording speckle images because the colour data is excess for the correlation analyses.

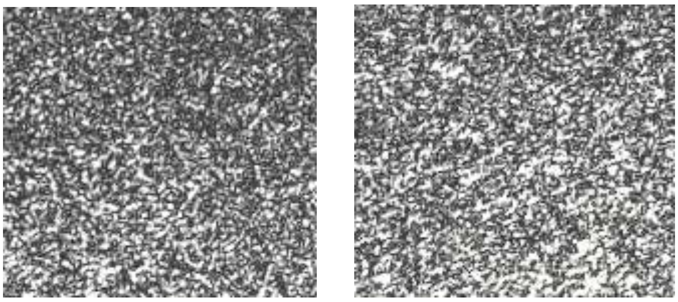

Figure 3. Laser speckle images during the process of control plasma clotting. Moments of time are random.

The hardware for the microcontroller module was selected according to the requirements specification. The requirements were: the speed of registration of speckle images – 30 frames per second, the frame resolution – 100×100 pixels and the time of continuous recording – 10 minutes.

We used the speed of registration of speckle images 30 frames per second, because it’s an average speed that enough to record speckles and in order to optimize the performance of selected resources. The frame resolution is also average, because minimum is 50×50, when it is possible to recognize speckles. The time of continuous recording is 10 minutes because in future we are planning to work with the whole blood and the time of the whole blood coagulation is 3–5 minutes, we take 10 minutes to record pathologies or disorders if they exist.

To develop an automated microprocessor system, microcontroller ATxmega128A1 (Atmel) and video camera module OV7670 with the with parallel connection interface (Omni Vision) were chosen. The selected hardware in connection is shown in Figure 4. The chosen hardware meets the requirements and sufficiently productive. Important factor is that it is possible to write a script for every register either of camera or of microcontroller.

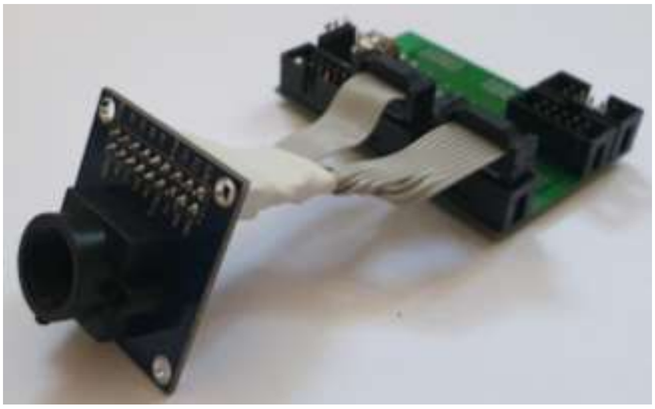

Figure 4. The selected hardware in connection.

To write scripts for the microcontroller and the video camera, the XRobot (developed in TUSUR, Russia) programming language was used to simplify the writing of scripts. The implemented script was loaded into the LabView software product, with the help of this modeling environment a virtual device – programming unit for the microcontroller ATxmega128A1 was developed. To process the speckle images, the multi-level computer simulation environment MARS, also developed in TUSUR, was used.

In computer studies of complex technical objects and their virtual analogs, the actual question is the visualization of measurement and simulation results in their natural form, as well as the implementation of the ability to control the topology and parameters of the object model. MARS has a multi-layer editor that makes it possible to visually separate the computer model of the object under investigation, the system for processing the simulation results and the means for visualizing them and controlling the parameters of the technical object [10].

The camera registers the speckle image, then, with the help of the microcontroller and the multi-level computer simulation environment MARS [10], the obtained frames are processed. The developed software script allows to calculate the correlation coefficient automatically by the formula given in [11], which compares the subsequent image with the previous one. The graph of correlation coefficient versus fibrin formation time is plotted in real time.

In the process of working on the hardware and software part, a device was created for recording and processing digital speckle images. The performance of the device was confirmed by experiments.

3. Results

Using the developed module of images registration it was possible to record image sequences with the length of about 1500 frames. The primary calculation of the correlation coefficient is a curve with quite intense noise (black curves in Figures 5, 6). Therefore, the data were smoothed using the sliding averaging method (red curves in Figures 5, 6). For smoothing the Mathlab software was used. According to the data obtained, it is possible to determine the time of fibrin formation. The obtained time coincides with the visually observed change of speckles during the coagulation recorded on a video camera.

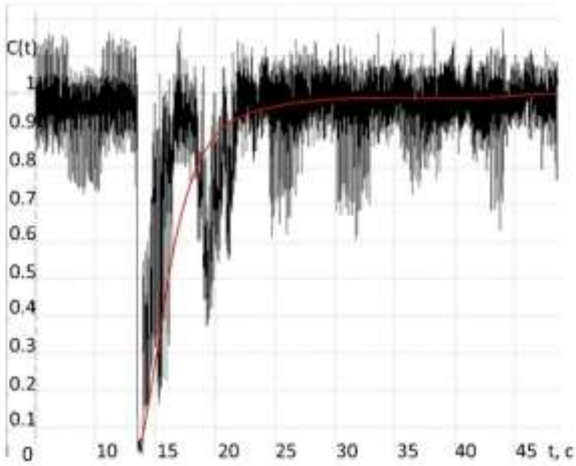

Figure 5. Real and smoothed correlation coefficient versus time of fibrin formation.

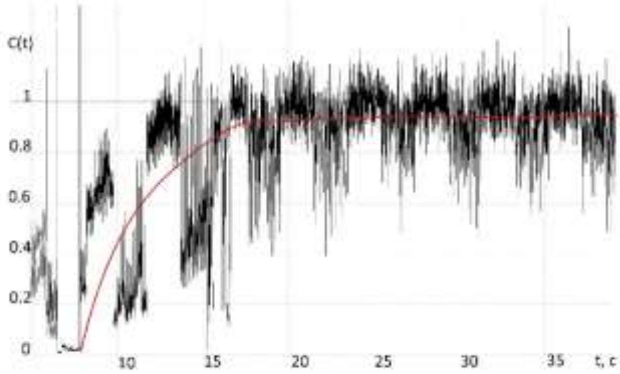

Figure 6. Real and smoothed correlation coefficient versus time of fibrin formation.

We conducted eight experiments with the same reagents. The resulting time was 11–13 seconds and it is coinciding with the known coagulation time of the reagent. The results of experiment are shown in Figure 7.

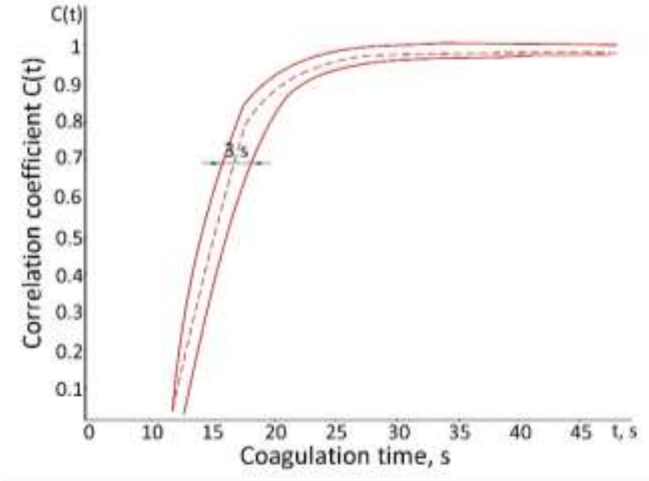

Figure 7. Range of curves of correlation coefficient versus fibrin formation time.

4. Conclusion
In this work, an automated module based on ATxmega128A1 microcontroller was developed. The module allows to record and process digital speckle images. Image processing is carried out in real time with a slight delay. The module was tested using the standard reagents for blood clotting time measurement.

In the future, it is planned to improve the algorithms of the system, to work out the method of analysis of blood coagulation, to install visualization tools on-board to display the dependence of the correlation coefficient on the fibrin formation time.

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References
[1] Hansson K M, Vikinge T P *et al* 1999 *Biosens. Bioelectron.* **14** 671–682
[2] Puckett L G, Barrett G *et al* 2003 *Biosens. Bioelectron.* **18** 675-681
[3] Huang C C, Wang S H *et al* 2005 *Ultrasound Med. Biol.* **31** 1567–1573
[4] LibgotCallé R 2008 *Ultrasound Med. Biol.* **34** 252–264
[5] Mintz M 1989 Method and Apparatus for Detecting a Blood Clot: US Patent No 4787369
[6] Tyutrin I I, Sorokozherdiev V O *et al* 2006 A Method for Evaluating the Functional State of the Hemostatic System: RF Patent No 2282855
[7] Li L, Sytnik I D *et al* 2018 *Biomedical Engineering* **52** 177–180
[8] Li L, Sytnik I D *et al* 2019 *Proc. SPIE* **11065** 110650E
[9] Kits and reagents for evaluating the hemostatic system. Available at: https://tehnologia-standart.ru/
[10] Dmitriev V M, Shutenkov A V *et al* 2011 *MARS – environment for modelling technical devices and systems* (Tomsk: In-Spectrum) p 278
[11] Gubarev F A, Li L *et al* 2016 *MATEC Web of Conferences* **48** 04003