Conference materials
UDC 53.082
DOI: https://doi.org/10.18721/JPM.153.254

Development of a control algorithm for a fluid flow monitoring system in a microfluidic system

E. D. Serov [1, 2]✉, A. I. Kavaler [1, 2], V. A. Kruglov [2],
V. S. Reznik [2], A. S. Saraev [2], V. V. Davydov [1, 3]

[1] Peter the Great St. Petersburg Polytechnic University, St. Petersburg , Russia;
[2] Institute for Analytical Instrumentation of the Russian Academy of Sciences, St. Petersburg , Russia;
[3] All-Russian Research Institute of Phytopathology, Moscow Region, Russia
✉ egorserov22021998@gmail.com

Abstract. Microfluidic systems are widely used in the preparation and analysis of liquid samples in biology, pharmacology and medicine. Each individual device using microfluidic systems differs in structure from others, and the accuracy of fluid control inside is an important factor. In this paper, we will consider the microfluidic system of a DNA analyzer. An algorithm that reads information from flow sensors in real time and transfers it to microcontroller STM32 has been developed for it. The received information was further processed, and on the basis of the received data, a conclusion was drawn about the correctness of the work performed by the device. The error handler, in case of deviation from the process, made the necessary adjustments by sending an error code to the necessary part of the device.

Keywords: Microfluidic system, control algorithm, fluid control, flow sensor, DNA analysis

Funding: The work was carried out within the framework of State Task 075-00761-22-00 of the Ministry of Science and Higher Education.

Citation: Serov E. D., Kavaler A. I., Kruglov V. A., Reznik V. S., Saraev A. S., Davydov V. V., Development of a control algorithm for a fluid flow monitoring system in a microfluidic system, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 15 (3.2) (2022) 296–301. DOI: https://doi.org/10.18721/JPM.153.254

Материалы конференции
УДК 53.082
DOI: https://doi.org/10.18721/JPM.153.254

Разработка алгоритма контроля системы мониторинга потока жидкости в микрофлюидной системе

Е. Д. Серов [1, 2]✉, А. И. Кавалер [1, 2], В. А. Круглов [2],
В. С. Резник [2], А. С. Сараев [2], В. В. Давыдов [1, 3]

[1] Санкт-Петербургский Политехнический Университет Петра Великого, Санкт-Петербург, Россия;
[2] Институт Аналитического Приборостроения Российской Академии Наук, Санкт-Петербург, Россия;
[3] Всероссийский Научно-Исследовательский Институт Фитопатологии, Московская область, Россия
✉ egorserov22021998@gmail.com

Аннотация. В данной работе рассматривается микрофлюидная система анализатора ДНК. Для нее был разработан алгоритм, считывающий информацию с датчиков потока в режиме реального времени и передающий ее на микроконтроллер STM32. Полученная информация подвергается дальнейшей обработке и на основании полученных данных делается вывод о правильности работы прибора. Обработчик ошибок при необходимости вносит необходимые коррективы, отправляя код ошибки в нужную часть устройства.

Ключевые слова: Микрофлюидная система, алгоритм контроля, контроль потоков, датчик потока, анализ ДНК

Финансирование: Работа выполнена в рамках Госзадания 075-00761-22-00 Минобрнауки РФ.

Ссылка при цитировании: Серов Е. Д., Кавалер А. И., Круглов В. А., Резник В. С., Сараев А. С., Давыдов В. В. Разработка алгоритма контроля системы мониторинга потока жидкости в микрофлюидной системе // Научно-технические ведомости СПбГПУ. Физико-математические науки. Т. 15. № 3.2. С. 296–301. DOI: https://doi.org/10.18721/JPM.153.254

Introduction

At present, with the development of scientific and technological progress, much attention is paid to various research methods [1–8]. This is especially true in the context of an increase in the influence of various negative factors on biological systems [8–14]. Therefore, for the study of biological systems, as well as condensed media associated with them, a large number of methods have been developed [2–5, 7–9, 15–21]. They have various advantages and disadvantages. This determines their direct application.

The sequencing method of DNA is currently extremely demand for solving of the different tasks in medicine and biology [22–27]. For example, sequencing methods widely used in different medical researchers related with viruses and diseases.

Thus, in sequencing devices, it is necessary to transfer a given volume of liquid at a given speed for the correct analysis.

The performance of microfluidic systems depends on monitoring and adjusting the fluid flow in them. The various sensors or flowmeters are performing this task, in particular, a fluid flow sensor [28–31]. Information from the sensor must be read and processed during the entire operation of the hydraulic system.

Therefore, it is important to create an optimal algorithm that is able to carry out the task throughout the entire sequencing process. Also, an important part of this algorithm is the logging of all received data to eliminate and troubleshoot microfluidic systems.

As a consequence of this, the algorithm described above serves not only as a way to control and adjust the hydraulic system, but also to collect data for post-processing of the experiment.

Structure of the algorithm

The fluid in the microfluidic system of the sequencer moves through thin capillaries using a pump. The pump, having received a command from the control algorithm, adjusts the direction and speed of the fluid supply. To check the correctness of its operation, a liquid flow sensor is installed in front of the element holding chemistry reactions for sequence.

The sensor detects the presence of a stream and sends a command via the exchange protocol to the board responsible for processing data from the sensor. Information exchange under the protocol proceeds continuously and regardless of the main process of the hydraulic system, however, as soon as the hydraulic system finishes executing all the commands from the control algorithm, the data exchange is suspended until the hydraulic system is restarted. This is necessary for the sequencing device to work correctly [22–27]. The block diagram of the signal processing algorithm is presented in Fig. 1.

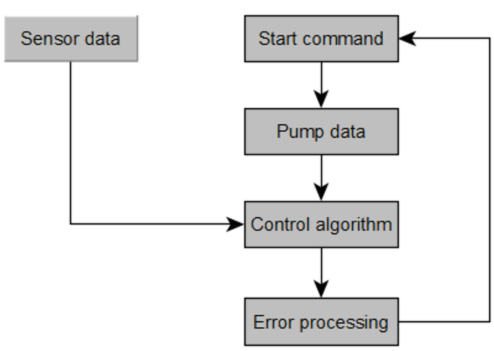

Fig. 1. Data processing algorithm

The data exchange between the sensor control board and the fluid flow sensor is carried out using the symbols of the binary system, where the unit corresponds to the state of the sensor in which the fluid flow is fixed, and zero corresponds to the state in which the sensor does not observe the flow. Obviously, this information is not enough to control the algorithm, so the data received from the sensor must be compared with what is expected to be seen at the present moment. In other words, starting its work, the pump sends information about how long it is necessary to observe the fluid flow at the sensor installation point. Thus, having received a signal from the pump and the sensor, it is necessary to compare them.

As shown in Fig 1, when a command is received from the program controlling the device, the pump starts its work, while sending the necessary information to the control algorithm. At the same time, the interrogation of the flow sensor begins. In case of discrepancy between the expected and accepted values from the flow sensor, this data goes through the error processing algorithm.

Further, the processor can continue the operation of the device, if the error was not critical, or suspend the experiment by calling the user's dialog box with a choice of further actions.

The entire process of polling the sensor and the operation of the hydraulic system is logged with time stamps. Thus, if necessary, it could be determined the cause of the failure by examining the relevant documentation.

Realization of algorithm in hydraulic test model

The main aim of developing described algorithm is to use it in sequencing systems. To ensure that described algorithm correctly works the hydraulic system test model was developed. This system is shown in Fig. 2.

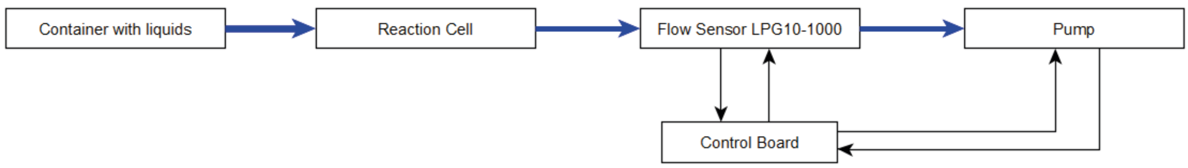

Fig. 2. Block scheme of hydraulic system test model;
blue lines correspond to liquid capillaries, black lines to data exchange

One of the parts of the hydraulic system test model is flow sensor LPG10-1000. The parameters of this sensor are presented in Fig. 3. It is necessary to define flow state (logical unit corresponds to fixed fluid flow, logical zero to absence of fluid flow) for algorithm to work correctly. Because of described sensor could perform information about flow rate, it is necessary to determine flow rate threshold value. The threshold value was equalized to 50 μl/min, due to the LPG10-1000 characteristics. Thus, the flow rate values below the determined threshold are defined as logical zeroes for algorithm.

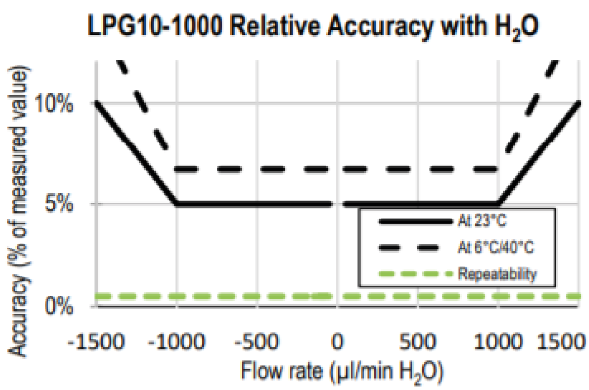

Fig. 3. LPG10-1000 sensor accuracy and repeatability (% of measured value)
across the sensor's flow range

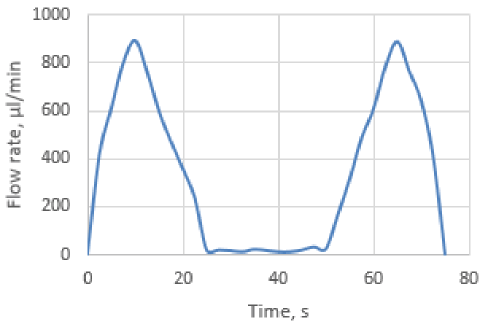

Fig. 4. Visualization of flow rate data from sensor

In developed test model, the control algorithm is performed via control board with microprocessor. The board is connected to pump via UART protocol and to flow sensor via I^2C protocol. The connection between the board and the pump is necessary to get data from pump (pump status – in work or not).

The control board sends command to pump to start aspirating then control board receives the answer from pump with its status. While pump is aspirating the flow sensor is exchanging its data with control board every 1 second. That provides control of flow status in every iteration. The data from pump and flow sensor is processed on control board and goes through error processing afterwards. It is necessary to avoid issues such as value below threshold on flow sensor while pump is aspirating.

Results

As a result, the algorithm was implemented in hydraulic system test model and the acquired information is confirming correctness of described algorithm. This information shows correlations between flow rate from flow sensor, working state of pump and real aspiration process as shown in Fig. 4.

Conclusions

The developed algorithm allows to control the correct operation of the hydraulic system of the sequencing device. If necessary, the algorithm has the ability to suspend the operation of the entire device, or a specific part thereof, notifying the user at the same time, and will wait for further instructions.

Moreover, developed algorithm can be used not only in sequencing system which described below, but also in another types of hydraulic systems, were is necessary to control the flow rate or flow status.

Acknowledgment

The work was carried out within the framework of the state task 075-00761-22-00 of the Ministry of Science and Higher Education.

REFERENCES

1. **Grevtseva A. S., Smirnov K. J., Rud V. Yu.,** Development of methods for results reliability raise during the diagnosis of a person's condition by pulse oximeter, Journal of Physics: Conference Series. 1135(1) (2018) 012056.
2. **Grevtseva A. S., Smirnov K. J., Greshnevikov K. V., Rud, V. Yu., Glinushkin, A. P.,** Method of assessment the degree of reliability of the pulse wave image in the rapid diagnosis of the human condition, Journal of Physics: Conference Series. 1368(2) (2019) 022072.
3. **Marusina M. Y., Karaseva E. A.,** Automatic segmentation of MRI images in dynamic programming mode Asian Pacific, Journal of Cancer Prevention. 19(10) (2018) 2771–2775.
4. **Davydov R. V., Rud V. Yu., Yushkova V. Y.,** On the possibility of analysis using the wavelet transform of the pulse waveform from the bloodstream, Journal of Physics: Conference Series. 1695(1) (2020) 012064.
5. **Myazin N. S., Yushkova V. V., Rud V. Y.,** On the possibility of recording absorption spectra in weak magnetic fields by the method of nuclear magnetic resonance, Journal of Physics: Conference Series. 1038(1) (2018) 012088.
6. **Logunov S. E., Vysoczky M. G.,** New method of researches of the magnetic fields force lines structure, Journal of Physics: Conference Series. 1038(1) (2018) 012093.
7. **Kuzmin M. S., Rogov S. A.,** On the use of a multi-raster input of one-dimensional signals in two-dimensional optical correlators, Computer Optics. 43(3) (2019) 391–396.

8. **Makeev S. S., Grevtzeva A. S., Glinushkin A. P., Matorin D. N.,** Possibilities of using spectral analysis in method of nuclear magnetic spectroscopy for condensed media investigation, Journal of Physics: Conference Series. 1695(1) (2020) 012112.

9. **Mazing M. S., Zaitceva A. Yu., Kislyakov Yu. Ya., Kondakov N. S., Avdushenko S. A., Davydov V. V.,** Monitoring of Oxygen Supply of Human Tissues Using A Noninvasive Optical System Based on A MultiChannel Integrated Spectrum Analyzer, International Journal of Pharmaceutical Research. 12(2) (2020) 1974–1978.

10. **Dyachenko S. V., Vaseshenkova M. A., Martinson K. D., Cherepkova I. A., Zhernovoi A. I.,** Synthesis and properties of magnetic fluids produced on the basis of magnetite particles, Russian Journal of Applied Chemistry. 89(5) (2016) 690–696.

11. **Grebenikova N. M., Smirnov K. J., Rud V. Yu., Artemiev V. V.,** Features of monitoring the state of the liquid medium by refractometer, Journal of Physics: Conference Series. 1135(1) (2018) 012055.

12. **Nikitina M., Grebenikova N., Dudkin V., Batov Y.,** Methodology for assessing the adverse effects of the use of nuclear energy on agricultural land, IOP Conference Series: Earth and Environmental Science. 390(1) (2019) 012024.

13. **Gryznova E., Batov Y., Rud V.,** Methodology for assessing the environmental characteristics of various methods of generating electricity, E3S Web of Conferences. 140 (2019) 09001.

14. **Davydov R., Antonov V., Moroz A.,** Parameter Control System for a Nuclear Power Plant Based on Fiber-Optic Sensors and Communication Lines, In: IEEE International Conference on Electrical Engineering and Photonics (EExPolytech), Saint Petersburg, Russia, 13-15 October 2019. Vol. 8906791 (2019) 295–297.

15. **Smirnov K.J., Glagolev S.F., Tushavin G.V.,** High speed near-infrared range sensor based on InP/InGaAs heterostructures, Journal of Physics: Conference Series. 1124(2) (2018) 022014.

16. **Dyumin V., Smirnov K., Myazin N.,** Charge-coupled Device with Integrated Electron Multiplication for Low Light Level Imaging, Proceedings of the 2019 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech. 8906868 (2019) 308–310.

17. **Myazin N. S., Dudkin V. I., Grebenikova N. M.,** On the Possibility of Express Recording of Nuclear Magnetic Resonance Spectra of Liquid Media in Weak Fields, Technical Physics. 63(12) (2018) 1845–1850.

18. **Rakhmatullin I., Efimov S., Tyurin V., Varfolomeev M., Klochkov V.,** Qualitative and quantitative analysis of heavy crude oil samples and their SARA fractions with ^{13}c nuclear magnetic resonance, Processes. 8(8) (2020) 995–1009.

19. **Myazin N. S.,** Features of formation of structure of a nuclear magnetic resonance signal in weak magnetic field, Journal of Physics: Conference Series. 1135(1) (2018) 012061.

20. **Davydov R.V., Antonov V.I., Molodtsov D.V.,** Computer implementation of the mathematical model for water flow management by a hydro complex. Journal of Physics: Conference Series.1135(1) (2018) 012088.

21. **Kruzhalov S. V., Grebenikova N. M., Smirnov K. J.,** Method for Determining Defects on the Inner Walls of Tubing from the Velocity Distribution of the Flowing Fluid, Measurement Techniques. 61(4) (2018) 365–372.

22. **Reznik V. S., Kruglov V. A.**, Using of «bubble sensors» to control the quality of sequencing by the Illumina / Solexa method, Journal of Physics: Conference Series. 2086(1) (2021) 012120.

23. **Kruglov V. A., Reznik V. S., Glinushkin A. P.,** Development of a hydraulic system for bridge amplification, Journal of Physics: Conference Series. 1695(1) (2020) 012067.

24. **Reznik V. S., Kruglov V. A., Petrov A. I., Glinuchkin A. P., Rud V. Y.,** Development of a measuring device for the study of thermal processes during the polymerase chain reaction, Journal of Physics: Conference Series. 1410(1) (2019) 012078.

25. **Matvienko I. V., Bayramov V. M., Parygina N. A., Kurochkin V. E., Alekseev Y. I.,** Synthesis of Dihydroquinoline-Based Derivatives of Fluorescent Rhodamine Dyes for Nucleic Acid Analysis by a Real-Time Polymerase Chain Reaction, Russian Journal of Bioorganic Chemistry. 46(3) (2020) 349–359.

26. **Fedorov A. A., Berdnikov A. S., Kurochkin V. E.,** The polymerase chain reaction model analyzed by the homotopy perturbation method, Journal of Mathematical Chemistry. 57(4) (2019) 971–985.

27. **Natyrov A. N., Vlasova N. A., Matvienko I. V., Kurochkin V. E., Alexeev J. I.,** Synthesis of Unsymmetrical Polymethine Cyanine Fluorescent Dyes for Nucleic Acid Analysis by Real-Time PCR, Russian Journal of Bioorganic Chemistry. 44(5) (2018) 562–571.

28. **Davydov V.V.,** Nuclear magnetic spectrometer for studying flows of liquid media, Measurement Techniques. 59(1) (2017) 1202–1209.

29. **Davydov R., Davydov V., Dudkin V.,** The Nuclear Magnetic Flowmeter for Monitoring the Consumption and Composition of Oil and Its Complex Mixtures in Real-Time, Energies. 15(9) (2022) 3259.

30. **Myazin N.S., Dudkin V.I., Davydov R.V.,** Determination of the Longitudinal Relaxation Time of a Flowing Liquid Using a Differential Nuclear Magnetic Spectrometer, Technical Physics Letters. 46(11) (2020), 1147–1151

31. **Myazin N.S., Kiryukhin A.V.,** Nuclear-Magnetic Flowmeter-Relaxometers for Monitoring Coolant and Feedwater Flow and Status in Npp, Atomic Energy. 127(5) (2020) 274–279.

THE AUTHORS

SEROV EGOR
egorserov22021998@gmail.com
ORCID: 0000-0002-2083-4091

KAVALER Alexey
RepelLeha@yandex.ru
ORCID: 0000-0003-2991-9072

KRUGLOV Vladislav
vladislav.kruglov98@yandex.ru
ORCID: 0000-0001-5370-6224

REZNIK Vladislav
vlreznik97@gmail.com
ORCID: 0000-0003-3545-8620

SARAEV Alexey
alex.niispb@yandex.ru
ORCID: 0000-0003-4387-996X

DAVYDOV Vadim
davydov_vadim66@mail.ru
ORCID: 0000-0001-9530-4805

Received 09.08.2022. Approved after reviewing 10.08.2022. Accepted 16.09.2022.