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Remote control of the quality and safety of the production of liquid products with using fiber-optic communication lines of the Internet

Nadezhda Grebenikova 1*, Vadim Davydov 1,2, Angelina Moroz 1, Maria Bylina 3 and Michael Kuzmin 3

1 Peter the Great Saint Petersburg Polytechnic University, Politechnicheskaya str., 29, Saint Petersburg, 195251, Russia
2 All Russian Research Institute of Phytopathology, Institut str., 5, B. Vyazyomy, Moscow Region, 143050, Russia
3 The Bonch-Bruevich Saint Petersburg State University of Telecommunications, Bolshevikov ave. 22, bld. 1, Saint Petersburg, 193232, Russia

*E-mail: nadyagrebenikova@mail.ru

Abstract. The article describes the necessity to use the Internet for remote quality control and safety of liquid substation production. We present the system which is developed by us and based on a refractometer for remote control of various liquid products quality for flowing through pipeline in the online mode. The new system allows transferring information about the media state from the refractometer by fibre-optic communication line in the Internet over distances of more than 1800 km simultaneously to several computers. The results of experimental studies of the state of various media are presented.

1. Introduction

Today in the consumer goods markets there is a fierce competition. For this reason, the advantages of manufactured goods are reasonable price, quality and safety [1, 2]. To simultaneously provide these benefits (price-quality-safety), various methods and strategies are developed to improve the production process [3, 4]. The most promising of these is automation of production processes, both for food and industrial goods [5, 6]. Operating experience of various production lines and installations showed that automation of production processes leads to an increase in: the quality of manufactured products, an increase in the volumes of manufactured products for a limited time period (cost decreases - the wholesale price decreases) [7, 8]. In cases of working with hazardous and aggressive substances, production safety is increased.

At present, enterprises mainly use methods of remote control of the process of manufacturing products for solving problems of industrial automation [9, 10]. The expansion of the technological base of production leads to the following principle [11, 12]. That part of the components entering the parent company are produced at subsidiaries [13, 14]. In most cases, subsidiaries are located at a great distance from the parent company and very close to the sources of primary raw materials. With this organization of production has an advantage. Significantly reduced transportation costs for the
delivery of raw materials for the production of finished products to the parent company. The parent company must be confident in the quality of incoming products from the subsidiary and compliance with all the technological requirements of production. For this, the parent company must remotely monitor in real time the production of the components that will be supplied to them. Developments in the field of Internet technologies (fiber optic communication lines) allow to realize this. However, the experience of such productions shows that if information about the control of technological processes is transmitted to the parent company through the central computer of a subsidiary, various options are possible for changing it (for example, to hide technological failures during production that occurred due to the subsidiary, etc.) Such situations are very often encountered in construction, in the production of fuels and oils, in perfumery and food products, etc. [4, 10].

At present, a large number of methods have been developed that make it possible to exclude the possibility of changing information about the technological process coming over the Internet from a subsidiary to the parent company. They are mainly associated with software products and employee travel from the parent company to the subsidiary one.

We offer our work another approach to solving this problem. It is necessary to organize the connection of measuring instruments of control to the Internet. This will allow information to be transmitted in parallel to the parent company and to the automation and production control devices of the subsidiary. When implementing this task, a number of difficulties arise. First of all, they are connected with the use of measuring instruments for the automation and control of production processes that allow this to be done. One of their solutions is suggested in our work.

In addition, within the framework of the concept of the Internet of Things, which is currently being implemented, it is proposed to organize the possibility of placing the results of monitoring the production process for users of the Internet. This will allow people to gain more confidence in the products they produce, especially food products (for example, milk, juice, wine, etc.). The demand for this product will increase. The production volumes will increase - its cost price will decrease. Produced products will be more competitive in the market. For this, information on product quality control should be understandable for people who receive information from the Internet of things. This task is also considered in our work.

2. Problems and methods of solution
At present, a large number of devices have been developed for solving the problems of production automation and quality control of products [15, 16]. Each of them is designed to solve specific production problems [17, 18]. Very rarely, such devices are used to control the quality of various products (for example, in the form of a liquid or gel) with different technological cycles [19, 20]. This makes the process of manufacturing automation an expensive tool. It should be noted that these devices must carry out continuous monitoring of production. They should start working simultaneously with the process line [4, 20].

As the experience of enterprises has shown, in the automation of production, great difficulties arise in monitoring the state of liquids that flow through the pipeline [15, 16]. Especially when it comes to the production of liquid food (for example, milk, juice, wine, oil, etc.), medical suspensions or aggressive liquids (for example, acid, alkali, etc.). In the first two cases, when performing measurements required compliance with the conditions of sterility. In the third case, it is desirable to exclude the contact of the measuring elements of the device with the liquid medium.

Among the developed devices that allow determining the state of the medium in a contactless way, only two are in operation: refractometers and nuclear magnetic relaxometer flow meters [21, 22]. The latter need a certain time to start after the beginning of the process [6, 19]. This circumstance makes this device less versatile for monitoring the state of a flowing liquid than a refractometer.

The method of refractometry allows the study of liquids, measuring their refractive indices \( n_m \). Using the ratios of refraction, according to the results of the measurements made \( n_m \), one can qualify chemical compounds, determine the parameters of various media, and carry out structural and quantitative analysis [23, 24]. When working with liquid flows, there are often cases when large
insoluble compounds are found in a liquid medium (for example, juice with pulp, medical suspensions, etc.). Introducing the concept of index of refraction for such an environment is incorrect. In addition, it is not clear with what the base value of the refractive index of the medium under investigation should be compared.

It should also be noted, very often in the production of liquid media, the velocity of the flowing liquid due to the small diameter of the pipeline is high. We have to work with turbulent fluid flows. There is a number of additional difficulties, both in the measurements and in the installation of the measuring device.

To solve the tasks we have developed a new design of the optical part of the refractometer. Figure 1 presents its structural diagram.

![Figure 1](image)

Figure 1. The structural diagram of the optical part of the refractometer.

The use of the newly developed design of the optical part made it possible to implement the monitoring of the state of a liquid medium by detecting the position of the boundary-light shade on the photodiode array (figure 1). Information about the position of the light-shadow border is transmitted via an analog-to-digital converter (ADC) to the input of the microcontroller, which processes information and controls the position of the measuring elements of the optical part of the refractometer using a digital code. In addition, the information in the digital code is very convenient for solving problems of production automation. The output of the microcontroller is connected to the input of the transmitting laser module (TLM), which is located in the design of the refractometer. The output of the TLM is connected to the fiber-optic communication line - the main device for transmitting data on the Internet. Further, along the fiber-optic communication line, an optical signal in which information on the state of the medium is laid is simultaneously transmitted to the parent company and to the computer of the subsidiary. Most of the developed production automation systems, especially if it is necessary to control the technological process at several stages, work through the main computer of the enterprise. For management the digital code is used.

The proposed scheme for transferring information from a refractometer after appropriate processing allows you to post data on the quality of products at all stages on the Internet (online) on the social platform “Internet of Things”.

In the case of low flow rates of the liquid medium (low flow rates), the pipeline may not be completely filled. In this case, in order to eliminate measurement errors (there is no direct contact between the measuring medium and the optical part of the refractometer), the device is deeply immersed in the liquid stream. This created a lot of problems. The developed optical design with digital information processing devices made it possible to place the new design of the refractometer on
the vertical section of the pipeline. Figure 2 shows our proposed option for placing the developed digital design of a refractometer on the pipeline.

![Figure 2. The example of the placement of the refractometer on the pipeline.](image)

It should be noted that the device developed by us requires a preliminary calibration of the position of the light-shade boundary on the photodiode line from the temperature of the test medium $T$ in the event of a change in the type of medium (for example, juice per serum) flowing through the pipeline. It is necessary to determine the points of the light-shade boundary on the photodiode line (range of digital codes) corresponding to the standard state of the medium.

To ensure a high degree of contrast of the light-shadow border $R_c$, which allows you to capture even minor changes in the medium, the following is necessary. The center of the laser beam should fall on the upper face of the prism (Figure 1) at a critical angle $\alpha_c$:

$$\alpha_c = \arcsin\left(\frac{n_m}{n_p}\right)$$

where $n_p$ is the refractive index of the material from which the prism is made.

By the displacement of the light-shadow boundary, under the condition that the temperature of the liquid medium is monitored, any deviations from the standard state are recorded with high accuracy.

3. Results of experimental investigations and discussion

Studies of various media have shown that the use of the refractometer design developed by us allows us to control not only biological solutions, medical suspensions, food products (for example, wine, juices, etc.) but also aqueous solutions of chemical fertilizers by the light-shadow position. Preparation of these solutions is conducted in the continuous technological mode. Production of fertilizers, depending on their type, belongs to different hazard classes. The most dangerous of them are phosphate fertilizers. The process of making aqueous solutions of these fertilizers must be controlled at various stages of production.

Figure 3 shows, as an example, the dependences of the intensity of laser radiation $I$, detected by a photodiode array at various concentrations of phosphorus $N_p$ in the liquid aqueous solution of potassium phosphate (the solution is used for feeding in greenhouses). This fertilizer is successfully used as a fertilizer for growing both vegetables and grain crops.
Analysis of the results shows that when using calibration tables, measuring the temperature of the current medium, you can set the concentration of phosphorus in it by shifting the light-shadow border. The temperature of the liquid medium has a particularly significant effect on the light-shadow boundary displacement, which in some cases with a continuous production process needs to be changed to 20–30 °C upwards and 10–15 °C to decrease. It is rather difficult to take into account the large correction in the light-shadow boundary displacement by the measured value T by a specialized sensor using calibration tables when monitoring the state of the liquid environment. If admixture enters the medium, an error may occur in determining the state. Therefore, on the basis of our studies, we proposed a method of adjustment using digital signals in the optical scheme of a refractometer to position the light-shadow boundary when T was changed, so that the $R_c$ value was not lower than 0.75.

It should be noted that in the design of the refractometer developed by us, taking into account the established features of monitoring the state of the liquid environment, various functionalities for measuring other parameters are preserved. This allows you to quickly rebuild the developed device to solve other problems.

Figure 4 shows as an example the experimental dependences of the change in the relative density of an aqueous solution in Brix units with added sugar in various concentrations as a function of temperature T. The value of $\Delta N = 0$ at $T = 293$ K is taken as a starting point for the change in relative concentration.
Our results in figure 4 is in good agreement with the measurement results obtained on other types of refractometers. This shows the validity of our proposed technical solutions.

4. Conclusion
The research results showed that the developed design of a refractometer to monitor the state of the liquid environment along the light-shade boundary significantly expands the functionality of production automation using this device.

Digital information about the state of the environment from the output of the microcontroller made it possible to bring the receiving and transmitting devices of the fibre-optic communication lines of the Internet inside the case of its design. This eliminates a large number of interference and errors during the transmission of information about the state of the environment, which were previously when using analogue communication lines. Such a construction of the control and automation of production is fully consistent with the concept of the digital economy and provides the ability to simultaneously control the production process on several computers located at different distances from each other.

The experiments showed the following. Since the digital signal (information about the state of the environment) has a simple structure, it can be transmitted over FOC without additional amplification up to 250–300 km. With a large number of amplifications (more than 5), the information contained in it is slightly distorted. This allows the parent company to continuously monitor the technological process at a subsidiary at a distance of up to 1.800 km without using other computers to convert information. This makes the proposed method more promising than others.

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