Specialized software for a wavemeter as a part of a bichromatic laser spectrometer

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A simple algorithm is proposed for searching centers of interference fringes. The structure of a specialized software for the IDV–3 wavemeter of a bichromatic laser spectrometer is described. The software is intended for operation in a multitasking operating system.

To experimentally check the method of precision diagnostics of molecular composition of a medium,[1] a spectrometer with a bichromatic yttrium aluminate laser emitter has been developed at the Institute of Atmospheric Optics SB RAS.[2] Experimental conditions impose strict requirements on the wavelengths and intensities of both components of pump radiation. Because of low level of an expected signal, we have to use the accumulation mode, therefore the laser emitter operates periodically with the pulse repetition rate of 12.5 Hz. Every laser pulse is to be processed under constant check of the spectral composition and intensities ratio of the laser radiation components. The cases “unsuitableB by the conditions of the task should be rejected. Besides, principal information, including the re-emission spectrogram, should be displayed during the experiment.

The IDV–3 wavemeter manufactured by Angstrem Ltd. (Novosibirsk, Russia) serves for checking the wavelength ratio and pre-checking the laser spectrum in the spectrometer. The IDV–3 wavemeter has two identical optical channels each consisting of the generator of a parallel beam (from the fiber optics input) and three Fiseau interferometers with different parameters $L_{1,2,3}$, $\alpha_{1,2,3}$, $x_{1,2,3}$ (L is the effective thickness, α is the wedge angle, x is the distance to the photoreceiver plane). The interference pattern in every channel is recorded with a 1024-element linear-array photodiode receiver. The wavelengths are calculated using a personal computer, which is not a part of the device. The IDV–3 wavemeter was designed to operate individually, so we faced the problems of joining it with other devices of the spectrometer. It proved to be impossible to calculate the wavelengths of the laser bichromatic radiation and simultaneously record its other parameters. The main disadvantage of the IDV–3 wavemeter was in the errors periodically arising at the wavelengths calculation.

The analysis of possible sources of the errors has revealed that they were caused by the algorithm employed by the IDV–3 wavemeter to find the centers of Fiseau interference fringes ignoring the presence of a substructure. As is well-known,[3] the presence of a substructure and interference fringes blurring is characteristic of the Fiseau interference pattern. A deviation of the radiation incidence angle from the optimum value Θ by only fractions of milliradian results in a sharp increase in the blurring and growth of the substructure.[3] The optimum value Θ proves to be different for each of the three Fiseau interferometers.

The blurring of a fringe depends also on the beam divergence angle Θ'. Since the interference order m for the beam with the divergence Θ' is equal to $2L \cos \Theta'/\lambda$ and its change

$$\Delta m = 2L(1 - \cos \Theta')/\lambda , \qquad (1)$$

the fringe blurring at $\lambda \approx 530$ nm is small in comparison with its halfwidth at $\Theta' \le 4{\cdot}10^{-4}/\sqrt{L}$ rad. Because of mechanical and physical causes, small variations of the angles Θ' and Θ are inevitable. As a result, the interference pattern varies from pulse to pulse. The width and substructure of the interference fringes vary correspondingly. The design of the IDV–3 wavemeter does not allow adjusting by the angles Θ and Θ' with the accuracy needed for obtaining the optimum interference pattern. To avoid errors in measurement of the wavelength, one should use an algorithm insensitive to the substructure and fringe blurring (that is, resistant to hindering variations of Θ and Θ'). The IDV–3 wavemeter employs the empirical algorithm. The recorded interference pattern is scanned by a sliding window of 30 pixels width. The number of local maxima and minima in the interference pattern is determined at every working interval falling in the window. The parameters $n_1 \approx [(\max + 6 \times \min)/7] + 0.5$ and $n_2 \approx [(\max + \min)/2] + 0.5$ are calculated, where max and min are the values of local extreme points. A local maximum is sought for as a point at the interference pattern with the intensity greater than n_1. If the intensity at the point is greater than n_2, then it is taken as n_2. The number of the point at which the intensity becomes less than n_1 is determined. The transition through this point is taken as a fringe center. Then the distance to the neighboring center is checked; if it is less than 15 points, the center is rejected. The scanning window shifts right by 20 points, and the cycle is repeated. This algorithm is weakly sensitive to varying intensity of points at the interference pattern, but it is rigidly related to the shape of an interference fringe. Therefore, an appearance of the pronounced substructure of a fringe results in a marked deviation of the calculated fringe centers from the actual ones.

The standard algorithm[7] based on differentiation of the interference pattern behaves even worse: it is sensitive to the substructure and all inhomogeneities of a photoreceiver. The Block algorithm[8] gives good results, but it takes too much time, therefore its use by the available computer does not allow measuring λ of every radiation pulse.

To achieve the acceptable accuracy in calculation of λ of the laser pulses emitted with the repetition rate of 12.5 Hz, we propose the following algorithm.

Upon transformation of the equation from Ref. 3, we can find that the profile of the Fiseau interference fringes is described by the Airy formula

$$I = K_{\mathrm{tr}}^2 \left[\Big(\sum_{i=0}^{N} K_{\mathrm{ref}}^i \cos\delta_i\Big)^2 + \Big(\sum_{i=0}^{N} K_{\mathrm{ref}}^i \sin\delta_i\Big)^2 \right] \qquad (2)$$

with the addition δ_i for the path difference of rays having experienced i and $i + 2$ reflections:

$$\delta_i = \frac{4\pi L}{\lambda}\,[i - i(i+1)\,(2i_1)\Theta^2/3]\ .$$

Here K_{tr} and K_{ref} are the transmission and reflection coefficients of the interferometer mirrors; $i = 0, 1, 2, \dots, N$ is the number of a ray. We use Eq. (2) as a model function. The constants of the interferometers ($L_{1,2,3}$, $\alpha_{1,2,3}$, and $x_{1,2,3}$) are refined from the interferogram recorded from the LGN-302 frequency-stabilized He-Ne laser. Then they are substituted to the model function (2) which is tabulated for the mean value of the working wavelength range. One peak of the model interference pattern obtained is separated by the method of gradient descent.[6] Its spline coefficients are constructed using the formulas from Ref. 5 and the trial run method

$$\phi(j) = a_i + b_i(j - j_{i-1}) + c_i(j - j_{i-1})^2 + d_i(j - j_{i-1})^3, \qquad (3)$$

where a_i, b_i, c_i, and d_i are the spline coefficients at every interval; j is the number of a point. The obtained coefficients describe the smoothed profile of an interference fringe, including the influence of the substructure. They are used for searching the centers of interference fringes of the interference pattern under study. The searching process involves the following steps:

1) FWHM (full width at half maximum) of the interference fringe is determined from the model data. The size of the scanning window is set equal to this value;

2) the interference pattern is scanned point by point, and local peaks falling in the scanning window are determined;

3) for every passage through a local maximum, the coordinate $x_{\max}$ is determined by interpolation by the given spline coefficients; this value is taken as an actual center of the fringe.

The properties of the spline functions described in Ref. 5 ensure an exclusion of the hindering effect of the substructure. Processing of an interference pattern (2048 points × 7 bit) takes no more than 12 ms on the computer with AMD-5x86-133 processor, so the speed of the IDV-3 wavemeter proves to be enough for processing of every pulse.

The problem of the IDV-3 wavemeter joining with other devices of the spectrometer is solved by using a multitasking, multithreading operating medium for programs and processes servicing different devices of the spectrometer. In this case the spectrometer software is subdivided into “critical,B “normal,B and “unnecessaryB processes, each is assigned the corresponding priority. The problem of optimal distribution of the processor time in such a case falls to the scheduler of the operating system. To provide for interaction between software of different devices of the spectrometer, we have chosen the client/server architecture.

The wavemeter software is based on the server, namely, the idvserv.exe module. This module includes only the routines for determination of the fringe centers and calculation of the wavelengths. The idvserv.exe program is always running with the regular priority. To exchange the data between programs, the mechanism of named I/O pipes and/or the mechanism of shared memory[4] are used. The program idvserv.exe is responsible only for calculations, while the other program with the real-time priority deals with reading the interference pattern from the linear photodiode arrays of the IDV-3 wavemeter.

The computing module idvserv.exe runs as follows. It generates the bi-directional buffer channel PIPE\IDVINPUT and “falls asleepB in the mode of waiting for communication with this channel. Any other program calling the wavemeter has to open this channel (as an ordinary file) and place a command and (possibly) input data in it. Having received the data from the channel, the program idvserv.exe processes them, calculates the wavelengths, and places the result in the same named channel. Thus, the program servicing the IDV-3 wavemeter proves to be separated from all not concerning directly the process of wavelength calculation, including the operator's interface. If one needs to change the data source (for example, to calculate λ from the earlier recorded interferogram), no changes in the IDV-3 software are needed; it is sufficient to use the standard command of the operating system that redirects the threads. This approach allows us to easily change the configuration of measuring devices of the spectrometer. An additional advantage is that now the IDV-3 program can be executed at any computer connected to a local network without changes in the software.

To process the data from the linear photodiode arrays of the IDV–3 wavemeter, the mechanism of shared memory is used in spite of the input (output) pipes. In this case, the program responsible for operation with the devices of the spectrometer transmits to PIPE\IDVINPUT the special command and the name of the box in the shared memory it has opened. At this time the additional thread of the program idvserv.exe starts, which functioning is controlled by semaphores placed in the shared memory. This allows a minimization of the time lost for data transfer, because the mechanism of the shared memory blocks is the fastest way to transfer data between the parallel processes.

All other routines associated with calculation of wavelengths (recording the reference interference pattern, correcting the constants of the interferometer, and graphical interface) are made as separate programs; they can be activated by an operator when needed.

Figure 1 shows the structure of the specialized client/server IDV–3 software operating in the multitasking and multithreading medium. Figures 2–4 illustrate how the proposed spline-interpolation algorithm favors elimination of failures in calculation of wavelengths. Figures 2 and 3 show the interference patterns of the stabilized He–Ne-laser radiation and results of searching the centers of interference fringes with the algorithm based on differentiation and the initial algorithm of the IDV–3 wavemeter, respectively. The interference pattern was recorded with overilluminating; it models a typical "failureB situation arising in operation of a pulsed solid-state laser: radiation intensity in one pulse significantly exceeds the mean and the interference pattern falls in the saturation area. One can see from Fig. 2 that the algorithm based on differentiation has found 76% of false centers. Figure 3, in turn, demonstrates that the initial algorithm of the IDV–3 wavemeter failed to find the centers of fringes falling in the saturation region (23% of centers were not found). In none of the cases the procedure of calculation of the wavelength has correctly determined λ.

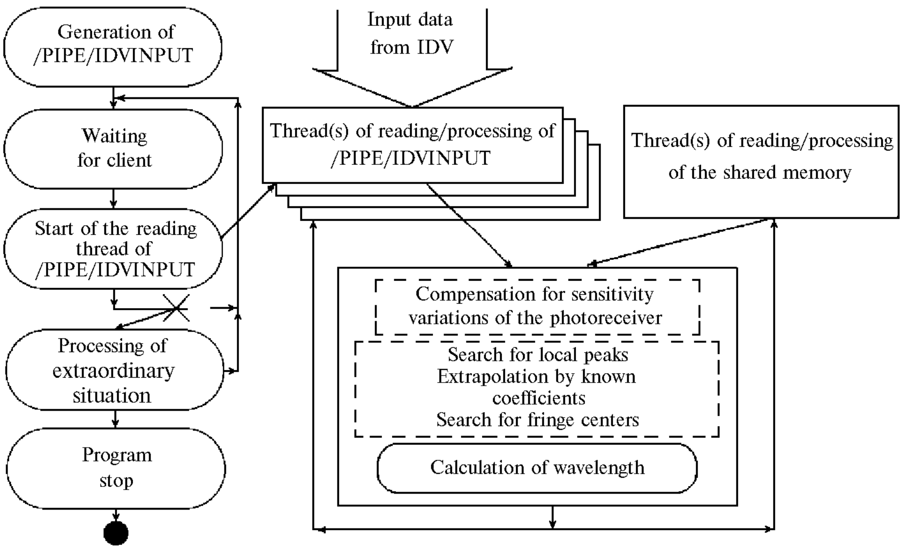

Fig. 1. Structure of the specialized software of the wavemeter.

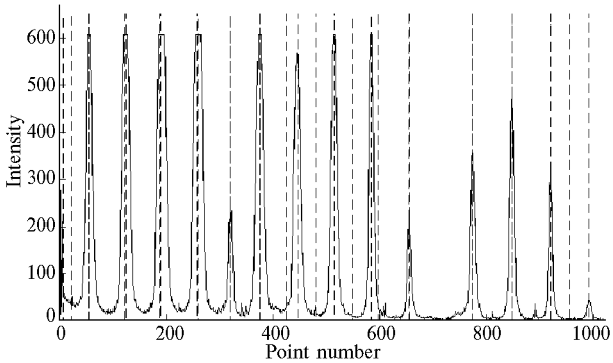

Fig. 2. The interference pattern (solid curve) and centers of the interference fringes found by the algorithm based on differentiation (dashed curve).

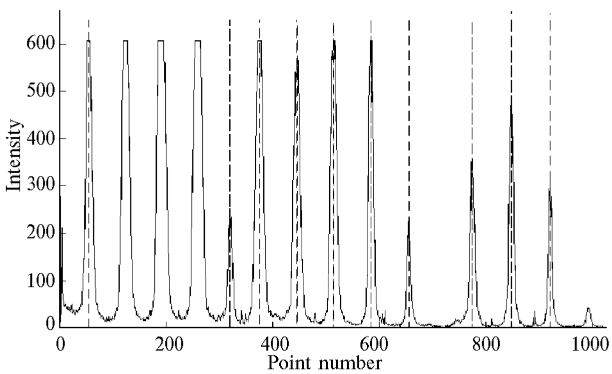

Fig. 3. The interference pattern (solid curve) and centers of the interference fringes found by the initial IDV–3 algorithm (dashed curve).

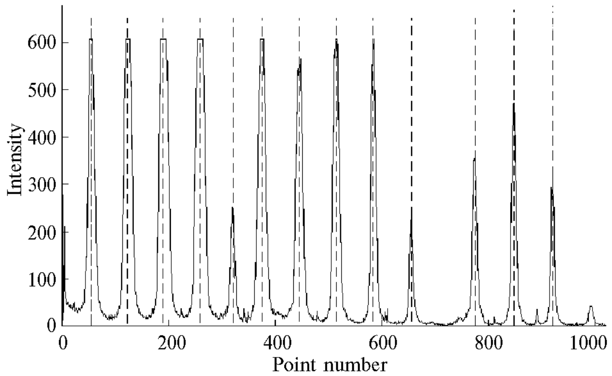

Fig. 4. The interference pattern (solid curve) and centers of the interference fringes found by the proposed algorithm (dashed curve).

Figure 4 illustrates how the proposed algorithm processes the same interferogram pattern. All the centers of the interference fringes are determined correctly including those falling in the region of saturation. The only one fringe (near the point No. 1000) was not processed by that algorithm because its intensity proved to be less than the threshold set by the operator.

The calculation of the wavelength gives the value 632.9914 nm which corresponds to the value specified for the stabilized He–Ne laser.

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