INTEGRATED COMPUTER SYSTEM FOR RESEARCH IN ATMOSPHERIC OPTICS

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A formal mathematical description of an integrated computer system, which is the basis of a scientific research support system, has been considered. Three main loops of information flow can be identified in this system, namely scientific research, experiment, and design.

We present some software and hardware intended for integrating scientific research and determine the limiting parameters of this software and hardware.

According to independent expert estimates, in the general volume of scientific activity related to the preparation and performance of research, users spend up to 40% of their time for data retrieval, processing, reception, and transmission. Scientific calculations and experiments are accompanied by an information flow which is processed by various algorithms. The widespread adoption and modernization of computers creates the possibility of realizing a computer technology in which a greater part of the information is collected, stored, and exchanged in machines, and complete data processing is performed with the use of computer technology.

A typical operation loop at the Institute of Atmospheric Optics (IAO) and the Wave Propagation Laboratory (WPL) is "scientific research–design–experiment" (SRDE). Under conditions of constant interest of a scientific community in the results of the scientific research and limited budget assignments the necessity arises of decreasing the time of the SRDE loop and the extensive use of front and group methods of performing the research.[1] Therefore, the first problem in the adoption of a computer technology is the development of computer means for the integration of the main stages of the SDRE loop.

The second problem is the research and development of the technological conditions for the acceleration of information exchange, realization of additional information connections between separate parts of the SRDE loop for a more rapid and comprehensive interpretation of the results of scientific research.

From the standpoint of computer technology, research in atmospheric optics is characterized by the complexity and variety of its mathematical models, fast rate of variation of the parameters up to 10^8 bytes/s, large volume of databases growing at a rate of up to 10^{10} bytes per year, and the great spatio–temporal extension and multiparametric interrelation of atmospheric–optical and spectroscopic phenomena. The structural loop of SRDE may be represented in the form shown in Fig. 1. In this loop it is possible to identify three levels of information exchange: 1) research, 2) design, and 3) experiment. Each level is an information flow of data translation and accumulation. The subject–area adaptability processing of the results of scientific research is implemented on central computers. In solving the problem of the synthesis of an integrated computer technology, abstract automata theory is suitable for the analysis. The computer system structure can then be described by the structure of abstract automation

$$S = S(M, A, D), \quad (1)$$

where M is the multiplicity of mathematical methods lying at the basis of the functional structure (S), A is the set of possible algorithms of mathematical method implementations, and D are the databases from which the finite product of operation of the corresponding level and the entire SRDE loop are synthesized.

From the formal point of view, the solution of the research problem P_R reduces to the following. Within the framework of currently available knowledge, there is a great number of structures of the above functional levels. Starting from the problem P_R at each level the requirements for the solution of the problem P^0_{Ri} (i = 1,2,3) are determined. If the problem is correctly formulated (it is possible to find P^s_{Ri} and P^0_{Ri}), the structure of every level S_i is implemented in the form of Eq. 1 by choosing the three control parameters U_{1i}, U_{2i}, and U_{3i}, which perform the following transformation: $M_{Si} \in \{M_i\} \cdot \{M\}$, $A_{Si} \in \{A_i\} \cdot \{A\}$, $D_{Si} \in \{D_i\} \in \{D\}$:

$$U_{1i}(P_{Ri}) \sim \{M_i\} \to \{M_{Si}\},$$

$$U_{2i}(P_{Ri}) \sim \{A_i\} \to \{A_{Si}\},$$

$$U_{3i}(P_{Ri}) \sim \{D_i\} \to \{D_{Si}\}.$$

where ~ denotes correspondence. Thus the theory provides the solution of the problem P_R. If the requirements for the solution of the problem P_{Ri} are ill–posed, the problem can be corrected by finding the structures S_i setting $|P^0_{Ri} - P^s_{Ri}| = \min$.

The above mathematical description of the function of every level of information exchange makes it possible: 1) to formulate the requirements on the software and hardware, needed to accelerate the scientific research and 2) to determine additional communications among the participants of the research.

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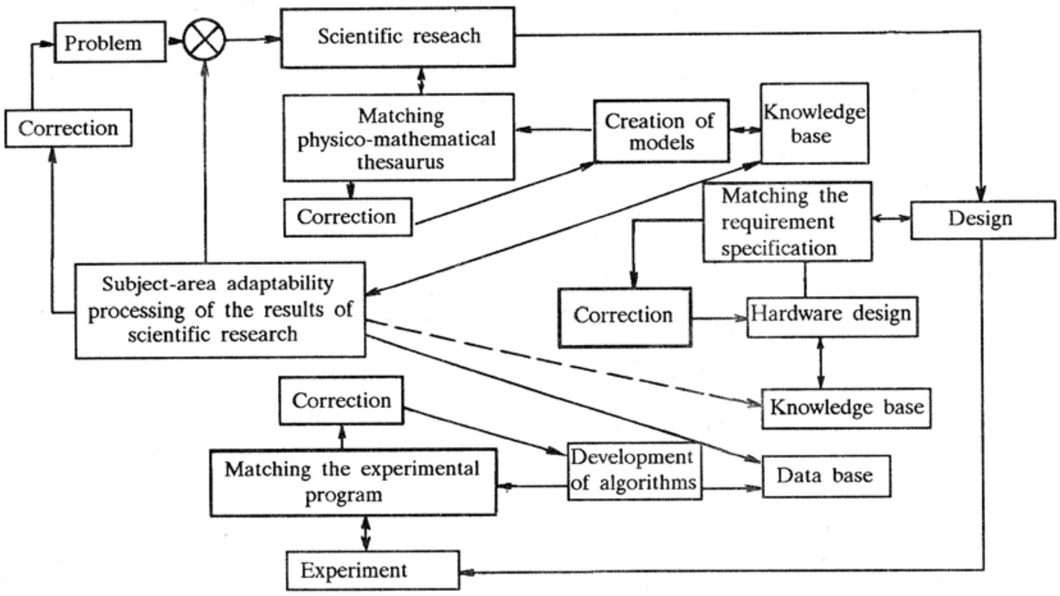

FIG. 1

In fact, the main type of operation of each level is the search for algorithms and mathematical methods of data processing. Therefore, the acceleration of scientific research can be realized not only by improving the technical parameters of the individual computer facilities but also by changing the structure of the information exchange to provide "walk through" exchange among the machines in the SRDE loop.

An integrated computer technology of scientific research can be realized in the simplest way using homogeneous computers. Such computers may be, for example, the IBM PC–compatible work stations with an integrated workbench, which supports the professional activity of theoreticians, engineers, and experimenters. The integration of the work stations can be made by the local–area network (LAN). The work station of the theoretician (WST) is intended for computer service of a scientist in the field of atmospheric optics and spectroscopy and it allows one

1) to carry out computer calculations, simulation, and processing of very large databases in an interactive environment;

2) to operate both in the local–area network of a scientific institution and at a remote terminal of large central computers;

3) to prepare intermediate and final scientific documents (papers, reports, transparencies);

4) to provide long–term data storage in hard disks and tapes (in archives);

5) to display scientific data in various forms.

The development of hardware and software has already made it possible to realize a "Personal Intelligence–Amplifier".[7] These capabilities can be realized in stations that provide the possibility of storage of $10^9 - 10^{13}$ bit of information, the reproduction of information with a rate of the order of 10^8 bytes/s, and image exchange with the user. The hardware which provide for the realization of the above parameters consists of auxiliary memory in the form of optical disks, multiprocessor computer architecture, for example, the Intel "Hypercube",[11] and a color graphics monitor with resolution of the order of 1024×1024 pixels.

The software of such a WST should include the following:

1) artificial intelligence software, for example, a decision support system (DSS);

2) digital integrated visualization environment (DIVE);

3) integrated computer environment with a local area network, with both national and international hookup.

An analysis of the DSS software for atmospheric optics research were performed in Ref. 2. The main conclusions of this paper are the following:

1. A DSS for problems in atmospheric optics requires special–purpose software based on a program structure in the form of a hierarchical tree of expert systems.

2. Organization of databases should be implemented in the form of a system of distributed heterogeneous databases.

3. Data processing must be performed on a multiprocessor computer.

A digital integrated visualization environment in atmospheric optics can solve two problems, i.e., acceleration of information exchange with the user and intelligence amplifier of scientific research methods. The DIVE represents an interactive environment with databases by means of computer graphics, software, and simple language for communication. The most promising system of programs for the solution of the problems of atmospheric optics is the PV = WAVE system,[3] which allows one to perform a visual data analysis (VDA), as well as mathematical and statistical operations with vector and/or raster graphics in a two–dimensional or, for that matter, multidimensional form (Fig. 2). In performing theoretical calculations and in modeling it is convenient to use mathematical integrated program systems such as MACSYMA (analytic calculations) and MATHLAB as well as special–purpose program systems such as LARA, ATLAS, etc. The software package LARA[8] makes it possible to perform on–line calculations of the Rayleigh and aerosol extinction coefficients as well as of the atmospheric transmission function on slant and horizontal paths using the sources of quasi–monochromatic narrow– and broad–band optical radiation.

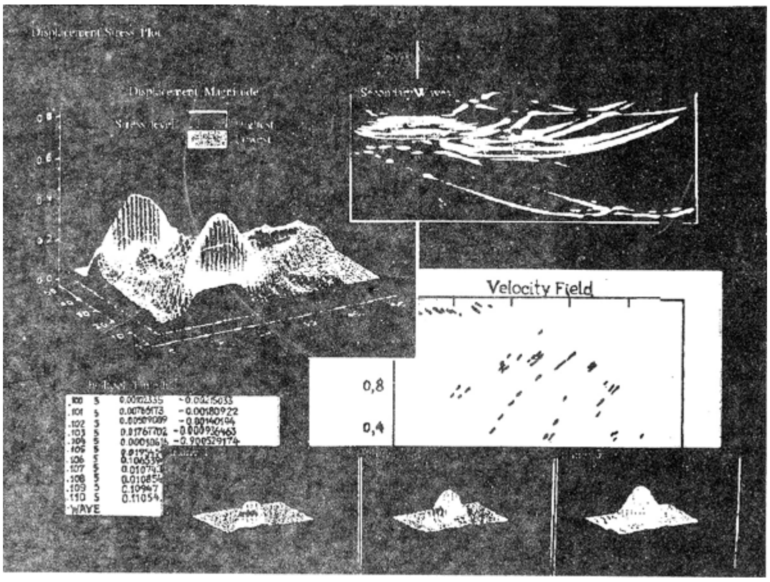

FIG. 2.

The automated system of programs ATLAS[9] provides for the storage, systematization, and on–line access of spectroscopic information. It selects the heterogeneous data and extrapolates the data on the spectral line parameters to the experimentally uninvestigated spectral ranges with statistically reliable estimate of accuracy.

The local area network (LAN) in the SRDE loop solves not only the problems of the file exchange among the users' computers, computer mail, and multiple access in the expensive peripheral devices but also the main problem — the management of multiple access to the databases for a great number of users. One of the most inportant problems is the necessity of storing the LAN system software in the RAM of the interconnected work stations. Therefore, when the system software is operated on the basis of inexpensive communication interface adapters, the user has a great loss of memory capacity, for example, when using (3 + CHARE). The system ETHERNET with the communication protocol TSP/IP is used at WPL as the basic network. There is the LAN of ARCNET type which is used at IAO. The system "3 + OPEN" based on OS–2 is the most promising for the network of IAO. Multitasking for any IBM PC–compatible personal computer has been achieved using the popular MS–DOS system for collective use by applying the program LAN MANAGER.

The work stations of the experimenter (WSE) are intended for computer measurements, data recording, and processing when making observations of natural phenomena. The WSE is realized usually in a structure of combined software and hardware modules for data processing, control, and digitization.

At present there are two directions of development of network architecture, i.e., a personal computer for instrumentation (PCI) and work station for measurement (VXI–standard).[6] The PCI–complex includes a personal computer with a collection of cards realized in the standards PC, ISA, EISA, MCA and a set of measuring devices with IEEE–488 interfaces. The VXI–device is realized as a collection of CPU cards, signal, special, and arithmetic processors, peripheral devices, individual digitizing modules, and/or single–card measuring devices, which are set in CRATE and are linked with the VME and VXI buses.

Application of both technologies to research in atmospheric optics is possible. However, for performing complex experiments under field conditions the VXI technology is preferable because of its high noise protection. Research in atmospheric optics can include both one–shot and routine experiments, whose goal is an elaboration of models, the obtaining of empirical data, and studies which make use of well–known models, the parameters of which are computed based on the experimental data. The process of experimental research represents a successive transformation of *a priori* and *a posteriori* data using formal and/or heuristic algorithms. Hence it appears suitable to use for data recording and processing interactive program systems based on spreadsheet technology. The data analysis and digital signal processing (DADiSP) system[4] is an example of a well–known integrated system for computer processing of the results of measurements. This system operates in the MS–DOS protected mode.

DADiSP has made it possible to create up to 100 windows where the user can observe the results of the work of more than 200 different algorithms: signal arithmetic, Fourier analysis, frequency domain analysis, correlation analysis, digital filtering, and others. The user can observe on the monitor screen the processing of any algorithm and can even create his own version of processing (Fig. 3). This integrated system supports the work of measuring devices with the IEEE–488 interface and allows one to prepare scientific and technical documents. The program LIDAR[10] is a convenient software package for the ecological monitoring of air over industrial centers using aerosol lidar. This program makes it possible to observe in various windows two–dimensional maps and graphs of industrial air pollution with 20 m spatial resolution using various algorithms to process the results of the measurements (Fig. 4).

Extensive application of graphic software packages of GEM type for control of experiments in real time is also very important. This is not only convenient for the user but also economical. The user can save on the equipment cost of a complex experiment when utilizing a single–card device without a front control panel. In this case the user can observe all the front panels of the devices on the display.

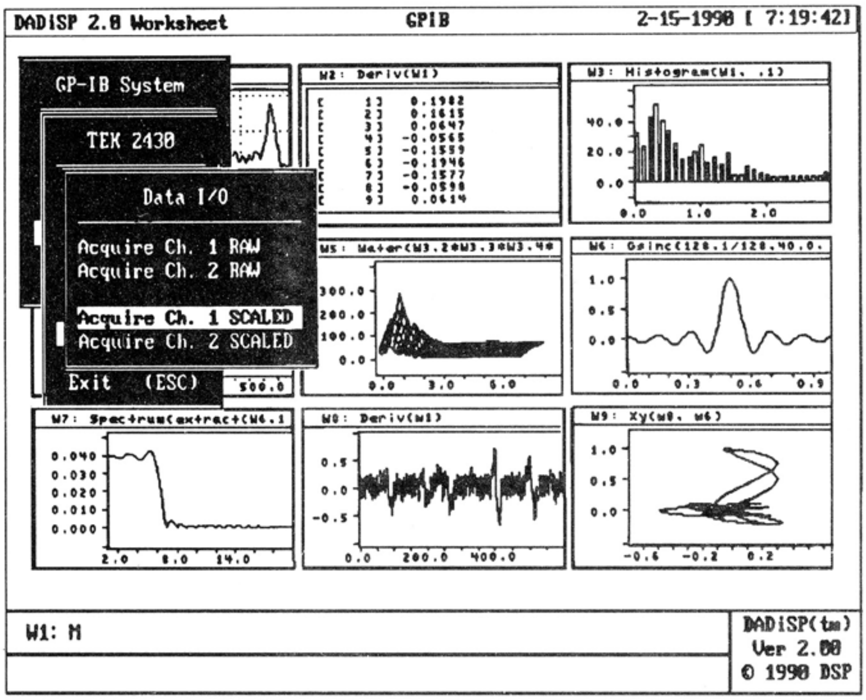

FIG. 3.

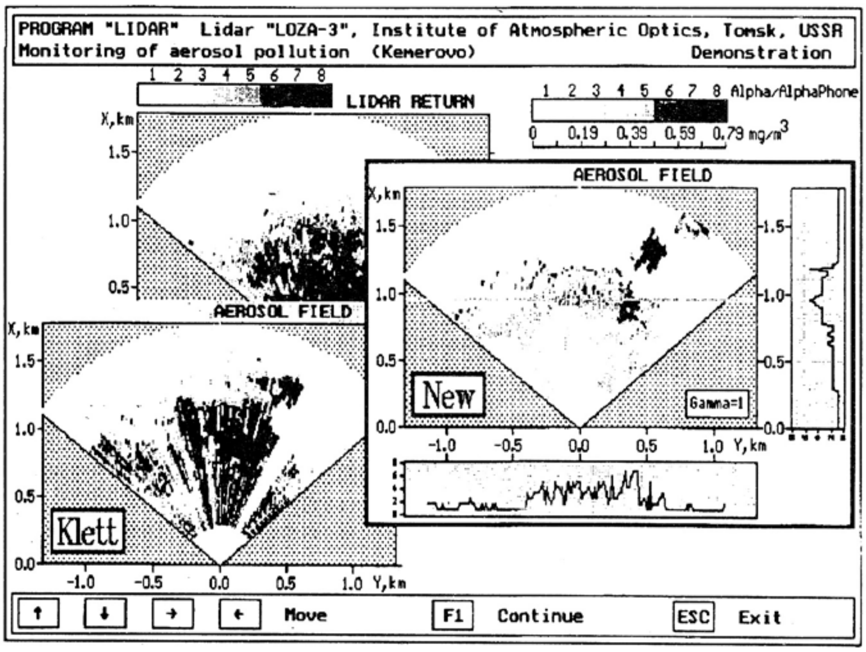

FIG.4.

The "Mouse" remote console serves as an index finder with which the user can directly control the front panels of the devices. By testing the validity of the data any incorrect actions on the part of the user are forbidden by the computer and corresponding information is given on the display screen. It was shown in Ref. 5 that the time required for learning the operation of the device is minimized in this case. This makes it possible for the user to concentrate his efforts on solving the measurement problem without being distracted by problems of servicing of the program. The work Station for an Engineer (WSE) is intended for doing design work and performing various calculations in atmospheric optics research. The scientific device for solving this problem consists of four parts (optical and mechanical channel, processor block for control and manipulation, and power supply block), for which the corresponding software is required. These may include PCAD, AUTOCAD, OPTiCAD, RAY TRACE, and AUTO ROUTER ELECTRICAL. Integration of this software provides their interconnection and enables one to use peripheral devices (plotters, scanners, digitizers, etc.). The requirements for the computational power are the same as for the work station for a theoretician. The central computer is intended for detailed data processing in the SRDE loop, therefore, research in atmospheric optics requires more powerful computers. The CRAY computer, which provides access to the laboratory with the help of the fast INTER NET interface system, is used at WPL. The fast development of hardware and software has made it possible to do without expensive computers. Therefore, an alternative way of solving the problem may be to use a complex system consisting of a great number of loosely–coupled independent co–processors operating simultaneously with different segments of the single problem (for example, the Intel "Hypercube"[11]). The number of co–processors may be increased successively from 32 to 64 and even up to 128. These co–processors are directly linked with each other.

In conclusion it should be noted that introduction of integrated computer systems in atmospheric optics research makes it possible to concentrate the user's efforts on solving the problem without being distracted by problems of servicing, i.e., to use high–power computer facilities for intelligence amplification as well as to create the conditions for acceleration of information exchange among the participants of scientific research. This provides acceleration of scientific research itself.

REFERENCES

1. E.I. Gromakov, V.T. Kalaida, and G.M. Krekov, in: *Methodological problems of Scientific–Technical Progress* (Novosibirsk, Nauka, 1986), 54–65.
2. B.T. Kalaida, Atm. Opt. **3**, No. 8, 721–733 (1990).
3. J. Wahrer, in: *Visual Data Analysis into the '90s*, Presicion Visual, Boulder, Colo., 1990, pp. 1–5.
4. *Data Analysis and Digital Signal Processing*, DADiSP—488. Ver. 2.00. DSP, Development Corporation, Aug. 1990.
5. A. Preuss, Elektronik, No. 20, 102–110 (1989).
6. S. Wohlgemuth, Elektronik. No. 20, 120–123 (1989).
7. W.R. Ashbu, in: Automata Studies, Princeton Univ. Press, 1956, pp. 215–234.
8. V.S. Komarov, A.A. Mitsel', S.A. Michailov, et al., Opt. Atm. **1**, No. 5, 84–89 (1988).
9. O.K. Voitsechovskaya, V.E. Zuev, and V.G. Tyuterev, Opt. Atm. **1**, No. 3, 3–15 (1988).
10. Yu.S. Balin, S.I. Kavkyanov, I.A. Rasenkov, in: *Abstract of Reports at the Fifteenth International Laser Radar Conference*, Vol. 2, 1990, pp. 92.
11. R. Asburru, G. Trison, T. Roth, Comput. Des. **24**, No. 11, 99–102, 104, 106–107(1985).