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PRINCIPLES OF CYBER-PHYSICAL SYSTEMS CONSTRUCTION FOR THE NEEDS OF CROPS CULTIVATION

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***Abstract*: On the basis of the hierarchical structure of a typical cyber-physical system and main stages of crops cultivation, the list of the subsystems necessary for the creation of such a system is considered. The structures and recommendations for these systems are expounded, and the generalized structural scheme of the given cyber-physical system is described issuing from the four main objects of the research: seeding material, soil, intermediate harvest benefits, harvesting, stocking or primary processing. The application of the matrix method for the assessment of production processes quality as well as final products, which is realized at different hierarchical levels of a cyber-physical system, is proposed. The approach to the analysis of system functioning at all stages of crops cultivation is represented. The principles of data matrices forming at hierarchical levels of a cyber-physical system in combination with the applied subsystem types are presented.**

Key words: **cyber-physical system, subsystem, crop (culture), matrix, information.**

INTRODUCTION

Agriculture with its export dominance is one of the most perspective trends of the technological development nowadays in Ukraine. The main task of our agricultural economies is necessity to provide the high style of farming, owing to which the high crop capacity and appropriate quality of agricultural production are guaranteed.

These results, as a rule, are reached by means of modern systems of food product industry management. Nowadays one of the variants of developing management systems are cyber-physical systems (CPhS) [1], which in their turn are realized with the help of advanced measurement, informational and other technologies.

SETTING OF CPHS REALIZATION PROBLEM

CPhS represents the combination of measuring, calculating, managing and other technical means, intended for the technological process organization, experiment, diagnostics or phenomenon research that are realized as closed structure on the basis of collecting the measurement information, its preprocessing, analysis and formation of the necessary influences on the object. According to [1], CPhS the following should be regarded in the form of a hierarchical structure:

- research object;
- means of interaction with the object;
- means of information collection and delivery;
- means of data analysis;
- means of decision making;
- means of personal service.

In order to adapt this structure to the needs of crop cultivation (wheat, rye, barley, maize, buckwheat, potatoes etc.) the following production stages should be outlined [2]:

- identification of the place of crops in rotation;
- soil procession;
- fertilizing;
- preparing of seeding material;
- sowing and planting;
- care of plantations;
- harvesting;
- control of the brought-in harvest quality indices;
- harvest stocking or primary processing.

Thus, the main tasks for the CPhS realization by means of which the efficient technology of crop cultivation could be put into effect is the creation of the relevant CPhS apparatus structure, as well as theoretical principles for developing the program software to fulfill the mentioned production stages.

PECULIARITIES OF THE MAIN CPHS TIES IMPLEMENTATION

Even the superficial analysis of the agricultural production stages mentioned above shows that it is necessary to use the principles of management systems theory for the CPhS construction. Thus, at first we should single out the types of the main structural knots with the help of which such system will be implemented. The construction of these structural ties will be based on the peculiarities and tasks of agricultural industry stages mentioned above.

For the practical realization of any CPhS the following list of subsystems should be used:

- measurement;
- data collection;
- informational;
- primary preprocessing of information;
- state estimation;
- managing;
- additional.

In the future these subsystems will be used directly in CPhS realization for crop cultivation.

According to Fig. 1, the measurement subsystem contains a certain set of measuring transducers $MT_1,\ldots,MT_b,\ldots,MT_B$, owing to which the immediate information in the form of electrical signal (voltage, current, frequency) or certain succession of codes could be extracted.

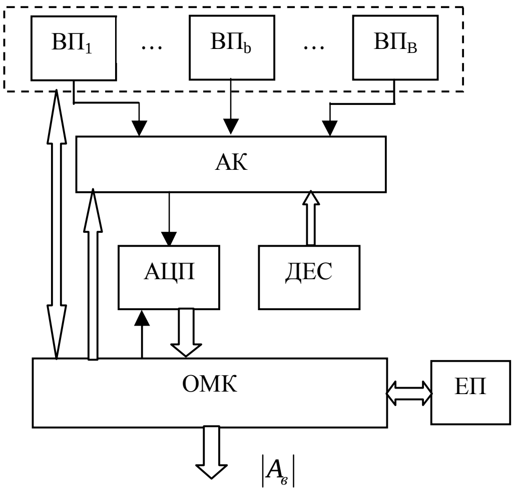

Fig. 1. Structural scheme of a typical measuring subsystem

Following the last variant of presentation, the monocrystal microcontroller MMC supplies the data in the form, needed for further application, by means of turning the digital codes into the necessary format. Otherwise, after the successive MT_b questioning by the analogue commuter AC the electrical signals are converted with the help of an analogue-digital transducer ADT into successions of the relevant digital codes. Thus, as a result, the vector of appropriate parameters $|A_в|$ is gained. If it is necessary, the measurement data codes are stored in nonvolatile memory EM. The examples of these MT_b could be the transducers of temperature, humidity and air pressure, soil humidity, the intensity level of plant illumination etc. As a rule the measurement subsystem normally contains the etalon signal source ESS, apt to test MT_b and minimizing the errors while measuring.

However, sometimes there is no possibility to get the immediate result of the transducer measurement, and sometimes there is a need of additional procedures or calculations in order to receive the final data. Such tasks are usually solved by data collection subsystems (Fig. 2).

The preliminary probe of the researched material (soil, plant patterns, and so on) is taken herewith, and the relevant pattern (solution, plant patterns and etc.) is prepared manually, half-automation and automation modes.

If the data collection subsystem is implemented in the form of a modern specialized analyzer [3], the probe is prepared in the special experimental medium SEM, which is characterized by the stable parameters – temperature, humidity and pressure. A solution of the probe placed in SEM could be one of the variants of pattern preparing. According to certain physical chemical regularities, the vector of related parameters characterizing the placed probe $|A_з|$ is defined under the management of microcontroller MC in a special measuring structure MS. The specialized analyzers for identifying the content of nitrates, nitrites, proteins, etc., could be an example of such subsystems. The devices for operation with ion-selective electrodes are also referred to the group.

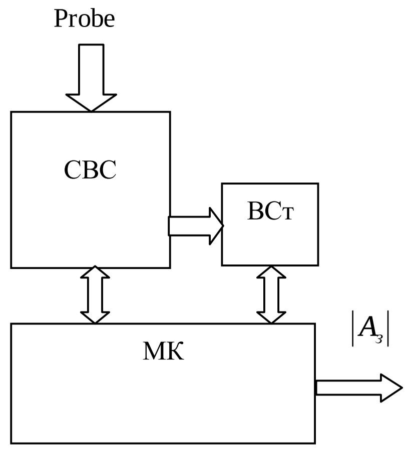

Fig. 2. Structure of the specialized analyzer as the example of data collection subsystem

The specialized structure of the micro-EOM (electro-calculating machine) is sometimes used as a MC instead of the OMC. The examples are MCs family of ADSP 2100 or ADuCM4050 by Analog Devices [4].

Speaking about informational subsystems we mean generally known structures based on OMC or MC, meant for transmission of information between different CPhS levels with its probable sorting depending on type and designation.

Sometimes it is necessary to apply certain algorithms to the gained measuring data with the purpose of defining the extended characteristics – energetic meaning of parameters or functions, described by comparatively complicated laws or mathematical models (the content of organic compositions, radioactive particles in soil or plants and etc.). With the aim of solving such problems, primary information processing subsystems are regularly applied (Fig. 3).

In order to build these subsystems, MC with traditional 8 digit and 16 digit data buses are normally used. The measuring information on the data bus DB is accompanied by relevant data through the control bus CB, which helps with the correct addressing and managing. To realize calculations with comparatively difficult analytical computations, the structure contains the additional processor (Co-processor) CP that helps to realize the needed calculations speedily. Sometimes it is sufficient to use the specialized multipliers of digital codes as CP, similar to microcontrollers of MSP family by Texas Instruments [5].

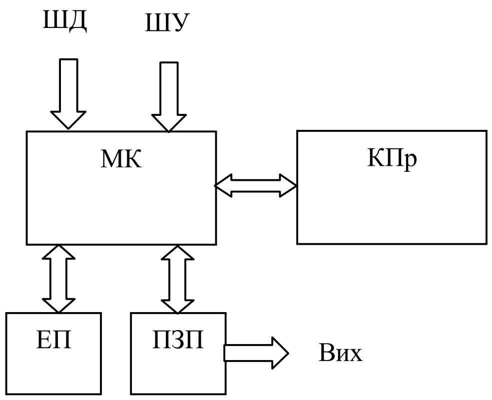

Fig. 3. Structural scheme of a typical information processing subsystem

As it was mentioned above, EM is employed to store the gained data. The transmission of output data is carried out with the help of an exchange protocol support device PSD.

When the need to analyse and research the certain stage of agricultural industry appears, the state evaluation subsystem is used. It is based on the use of personal computer as a powerful means of processing different data on the subject. Evidently, the main achievements of realized technological operations and actions concerning the given type of agricultural industry are developed.

In case of performing some actions, manipulations or procedures on the basis of the received information, the necessity to manage some external devices could appear, which is performed by the managing subsystems (Fig. 4).

Similar to the previous subsystem (Fig. 3), in this structure the necessary data come through DB accompanied by the additional ones running through CB. According to the data, OMC ensures the needed principles of management or regulation of the relevant executive devices

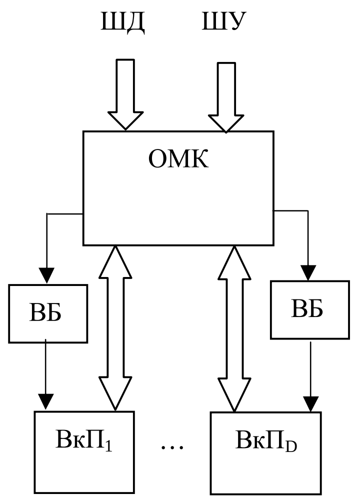

Fig. 4. Structural scheme of the typical managing subsystem

$МкТ_1$, …, $МкТ_D$ (power switches, mechanisms, technical means etc.) through the output buffers of OB (output block). The structure of any МкТ may contain different devices (measuring and control), following their output signals, the work modes of the given МкТ could be traced. These functions are carried out by OMC.

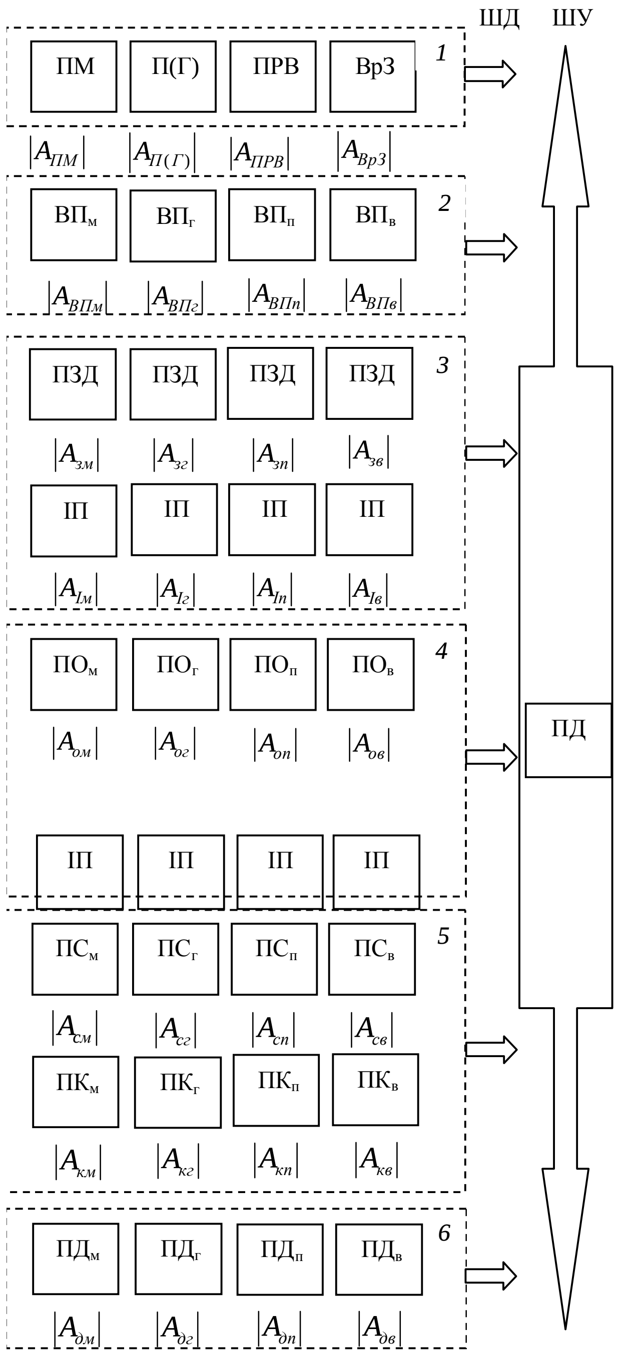

Fig. 5. The CPhS structural scheme for crop cultivation

Besides, CPhS contains the set of helping subsystems, owing to which many significant tasks are realized, we mean the soil examination before sowing and after harvesting, preparing of seeding material, control of agricultural equipment state, control of cultivation, CPhS structures powering and their protection from overloading, obstacles and external inventions.

Thus, the CPhS structure represents a particular computer system (Fig. 5) consisting of the following hierarchy levels [1].

The first level "research object" contains the following objects: seeding material SM, field (soil) F(S), the intermediate harvest results IHR, harvest and its stocking HS.

The measuring subsystems $MT_м$, $MT_г$, $MT_п$, $MT_в$ connected with the corresponding objects are located at the second level "the means of interaction with an object".

The third level "the means of information collection and delivery" consists of the following subsystems: data collection DCS and information IS.

At the forth level "the means of data processing" there are primary information processing subsystems $PPS_м$, $PPS_г$, $PPS_п$, $PPS_в$, different by designation and realization (but similar by construction principle), as well as information systems IS.

The fifth level "the means of decision making" includes the following subsystems: state evaluation $SS_м$, $SS_г$, $SS_п$, $SS_в$ and control $CS_м$, $CS_г$, $CS_п$, $CS_в$.

The sixth level "the means of personal service" consists of different helping subsystems HS, providing certain service functions that help to realize additional possibilities in this CPhS for a user while maintaining the stages of correspondent agricultural industry.

Following the recommendations [1], it is expedient to apply the common DB and CB to all the CPhS. It will facilitate the possibilities of information exchange between hierarchical CPhS levels, and also, between different ties of the same level and certain ties of different levels. Besides, in the structure of DB and CB there are HS providing access to any needed tie of the available CPhS levels with the purpose of extracting information on a running agrarian production process.

MATRIX METHOD FOR MODELING PRODUCTION PROCESSES DURING CPHS REALISATION

On the basis of the given CPhS structure, we could assert that for mathematical reflection of the given stages of that kind of agricultural industry the set theory should be applied [6]. Thus, any stage is characterized as a set of indicators describing its course and changes occurring.

It is worth mentioning that along with guarantying high crop capacity, the quality of the agricultural production should be kept decent. To our mind, we should apply the matrix method of production quality assessment at the different industry stages and particular hierarchical CPhS levels [7]. It will give an opportunity to correlate theoretical aspects of industry functioning with an apparatus part of CPhS, which will assist the construction of the optimal extended structure of the latter.

According to matrix method and postulates of the matrix calculation theory [6, 7], the general quality matrix is constructed for any research object at the fifth level of CPhS. The matrix consists of relevant matrix blocks corresponding to the levels from the first to the fifth. For example, for the object of SM the general matrix is:

$$\left|A_{ПМ\Sigma}\right| = \begin{vmatrix} A_{ПМ} & A_{ВПм} & A_{зм} \\ A_{Iм} & A_{ом} & A_{см} \\ A_{км} & A_{дм1} & A_{дм2} \end{vmatrix}, \qquad (1)$$

Any of its elements is a matrix block reflected in Fig. 5.

Considering the CPhS operation during agricultural production, it becomes evident that the objects SM and F(S) are controlled simultaneously at beginning.

At the first stage, the matrices $\left|A_{ПМ}\right|$ and $\left|A_{П(Г)}\right|$ fix the data concerning normative requirements for seeding material (indices of the place of a culture in crop rotation, seeding material preparation, sort parameters), as well as those for field and soil F(S) (indices of the soil cultivation, fertilizers, soil state before or during sowing and planting). We mean the complexes of indices which should be followed.

While performing these operations, the measuring information for forming the matrices $\left|A_{ВПм}\right|$ and $\left|A_{зм}\right|$ concerning the object SM, and matrices $\left|A_{ВПг}\right|$ and $\left|A_{зг}\right|$ for the object F(S) is acquired at the second and third levels. These data reflect the course of the performed processes, but in order to make conclusions about their quality some calculations should be carried out following certain algorithms to research the efficiency of the processes as compared to an ideal model (normative requirements). To achieve that, we define the matrices $\left|A_{зм}\right|$ and $\left|A_{зг}\right|$, using DCS, and with the help of IS we form $\left|A_{Iм}\right|$ and $\left|A_{Iг}\right|$. The latter ones are transferred to the level 4, PPSм and PPSг, respectively.

As a result of data preprocessing, the content of useful (high harvesting with decent parameters) and harmful (safety and harmlessness of the grown production) substances in SW and F(S) is verified. This information is stored in the matrices $\left|A_{ом}\right|$ and $\left|A_{ог}\right|$. In the mentioned above manner, these data are transformed by means of IS into $\left|A_{Iм2}\right|$ and $\left|A_{Iг2}\right|$.

Following them, the state of SM and soil is fixed in the matrices $\left|A_{см}\right|$ and $\left|A_{сг}\right|$ (level 5) at the beginning of agricultural production. On the basis of their analysis the conclusions and further plans are formed in the matrices $\left|A_{км}\right|$ and $\left|A_{кг}\right|$. For example, to substitute SM or fulfil additional actions concerning F(S) – to water or add fertilizers, pesticides, which is realized at the level 6 (matrices $\left|A_{дм}\right|$ and $\left|A_{дг}\right|$).

The following is the correlation of objects F(S) and IHR of CPhS (level 1). The matrix $\left|A_{П(Г)}\right|$ provides the list of requirements for the content of nourishing and harmful substances and humidity in the soil, while the matrix $\left|A_{ПРВ}\right|$ gives the sets of requirements for crop capacity of the culture (selective plant height, the number of leaves, the number of buds) at the determined time intervals, i.e. during the period of crop cultivation.

Correspondently the sets MS and DCS (levels *2* and *3*) regularly gather the real data on F (S) and IHR concerning the content of useful and harmful organic and inorganic substances, radioactive particles in the soil or plants, and indices given for the objects at the level 1. Consequently, during the established time intervals the ***j***-th matrices are formed $\left|A_{ВПг-j}\right|$ and $\left|A_{зг-j}\right|$ (for F(S)) as well as $\left|A_{ВПп-j}\right|$ and $\left|A_{зп-j}\right|$ (for IHR), when we mean the j-th control selection.

These data are transformed into the matrices $\left|A_{Iг-j}\right|$ and $\left|A_{Iп-j}\right|$ with the help of IS for the following application. Practically, after preliminary processing of this data the information on the objects F(S) and IHR gained at the levels 2 and 3 is accomplished at the level 4. We mean the identification of indices on the basis of more complicated calculations using the data gained at the levels 2 and 3. For example, concerning some useful and harmful substances, whose content could be identified only by means of classical physical and chemical research and complicated mathematical calculations.

On this basis, the matrices $\left|A_{oг}\right|$ (object F(S)) and $\left|A_{oп}\right|$ (object IHR) are formed and subsequently transformed into $\left|A_{Iг2}\right|$ and $\left|A_{Iп2}\right|$ with the help of IS.

Then, the state of soil and harvest of crop is estimated (level 5) at every stage of the control selection. Primarily state matrices $\left|A_{cг-j}\right|$ (object F(S)) and $\left|A_{cп-j}\right|$ (object IHR) are formed at the j-th interval. Then their comparison is made with matrices of etalon (normative) values of the corresponding indices $\left|A_{cг-je}\right|$ and $\left|A_{cп-je}\right|$, which reveal the corresponding level of technological operations' performance at all stages of harvest monitoring (here the j-th one). Thus, the following operations are fulfilled

$$\begin{bmatrix} \left|A_{cг-j}\right| \to \text{var} \\ \left|A_{cг-je}\right| \\ \left|A_{cг-jnop}\right| \to \text{var} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{порушення, якщо} \left|A_{cг-j}\right| - \left|A_{cг-je}\right| \rangle 0 \\ \text{норма, якщо } \left|A_{cг-j}\right| - \left|A_{cг-je}\right| \le 0 \\ \text{відхилення, якщо } \left|A_{cг-j}\right| - \left|A_{cг-jnop}\right| \ge 0 \\ \text{нехтування, якщо } \left|A_{cг-j}\right| - \left|A_{cг-jnop}\right| \langle 0 \end{bmatrix}, \quad (2)$$

$$\begin{bmatrix} \left|A_{cп-j}\right| \to \text{var} \\ \left|A_{cп-je}\right| \\ \left|A_{cп-jnop}\right| \to \text{var} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{порушення, якщо} \left|A_{cп-j}\right| - \left|A_{cп-je}\right| \rangle 0 \\ \text{норма, якщо } \left|A_{cп-j}\right| - \left|A_{cп-je}\right| \le 0 \\ \text{відхилення, якщо } \left|A_{cп-j}\right| - \left|A_{cп-jnop}\right| \ge 0 \\ \text{нехтування, якщо } \left|A_{cп-j}\right| - \left|A_{cп-jnop}\right| \langle 0 \end{bmatrix}, \quad (3)$$

here $\left|A_{cг-jnno}\right|$ and $\left|A_{cп-jnno}\right|$ − matrices of threshold values of the researched indices F(S), owing to which some information could be ignored.

It allows us to optimize the set of indices, characterizing the researched object. Using the received data, the necessary actions concerning the improvement of technological processes of crop cultivation, for example, soil watering; additional application of necessary fertilizers or herbicides in order to fight pests, are worked out. It is fixed in the matrices of level 5 $\left|A_{кг}\right|$ (object F(S), $CS_г$) and $\left|A_{кп}\right|$ (object IHR, $CS_п$).

Then these actions are performed with the help of $HP_г$ and $HS_п$, which is described by corresponding matrices $\left|A_{дг}\right|$ and $\left|A_{дп}\right|$.

Finally, the last object of CPhS research is HS. Similarly, as mentioned above, the normative requirements for the process of harvesting, stocking and primary processing are stored in the matrix $\left|A_{Врз}\right|$.

Correspondingly, the measuring information gained at the levels 2 and 3 is reflected in matrices $\left|A_{ВПв}\right|$ ($MS_в$) and $\left|A_{зв}\right|$ (DCS). By means of IS given in $\left|A_{Iв}\right|$ these data are transferred to the level 4 at $PPS_в$, where $\left|A_{ов}\right|$ is formed, and subsequently through IS – $\left|A_{Iв2}\right|$.

On the basis of this, the harvesting process quality is estimated, as well as the state of harvest and the quality of processed material.

The complex of the necessary actions for improving the collected or processed material stored in $\left|A_{кв}\right|$ (in $CS_в$), is regarded subsequently, e.g. drying for humidity reducing, refining and sorting the material due to main indices, packing; flour, semi-manufacture and forage making. These actions are performed at the level 6 by means of $HS_в$ and based on matrix $\left|A_{дв}\right|$.

In order to provide information exchange and perform some service actions, in DB and CB structures there are HS, by means of which additional control of crop cultivation, soil state after harvesting, agricultural equipment state, CPhS structure powering and their protection from overloading, obstacles and external interventions can be implemented.

CONCLUSIONS

Application of modern informational and technical means provides an opportunity to form new approaches to organization and control of technologies of agricultural production with the help of CPhS. The main stages of crop cultivation technologies, on the basis of which the general CPhS structure is composed, have been defined. It will enable the producing of high quality national goods, which could be certified following the requirements of international normative documents.

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