Automated System for Natural Resources Management

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Annotation

The **object** of research is a system of forest management based on obtaining continuous information about the forest fund, the quantitative and qualitative state of the stands for a long time of economic activity or logging. The **subject** of the research is the technology of continuous monitoring of the forest fund with the use of radio-frequency devices remotely in automatic mode. The **purpose** of the research was to create a radio frequency information collection system for developing control actions in forest management on the basis of obtained operational data on the state of stands and forest resources flows. The **objectives** of the work were: developing methods for recording the state of the stand, forest inventory, accounting for wood in logging, measurement of harvested wood, control of wood transportation. As a **result**, a structural model for collecting data on stands on a given space has been developed. A theoretical description of the functioning of the system is given on the basis of the theoretical positions of propagation of radio waves in the forest environment. The implementation of a forest fund monitoring system based on radio frequency devices is proposed. The functional dependence of radio wave energy attenuation in a forest environment is obtained. The implementation of an automated control system allows you to remotely receive information about the status of stands, transportation of timber and make the best decision. A new approach is suggested that allows to reduce the task of traditional, manual forest management to a remote automated process. The obtained results will find application in theoretical studies of the forest fund and the practice of accounting for wood.

Keywords: radio-frequency monitoring of the forest fund; dispersion of radio waves in the forest environment; complex dielectric permeability of the forest area; parameters of the forest environment; control of timber transportation.

1 Introduction

In the forest management system, two areas can be distinguished: manual and in the near future automated, which differ in the processes (subjects) of decision making. Both systems can exist independently, but a combined version is also possible. One of the combined options is an expert management system in which the final solution is assigned to the operator, and the technical means provide the operator with information in an automatic mode. When using intelligent systems, it is possible to develop some recommendations for the operator. Decision-making by a person is the development of a control influence on a forest fund object, individual works or procedures, for example, as in [1, 2]. The control action can also be developed by the automated device according to the algorithm incorporated in it [3,4].

With manual control, the control effect is produced by a person or a group of specialists. The individual decision-making by the person is developed on the basis of theoretical knowledge, practical skills and information from the object. This willful decision-making, such as driving a car, when the driver changes speed on his own, is rebuilt into another series and other actions based on road rules and his experience. By analogy in forest management, a person develops solutions and generates work plans on the forest site: which trees to cut, where to produce sanitary felling, where to plant the seedlings of the necessary species. Such solutions are developed and applied for long-term lease of the forest area, on the basis of legislation and development strategy. But most often, individual decision-making is carried out in emergency cases, for example, in the event of a forest fire, illegal logging by a third party, etc.

In the case of a group decision-making system, it is taken on the basis of the weightedness of the sum of all sentences, i.e. a decision is taken on the basis of consensus. The difficulty lies in the fact that if an equal number of contradictions does not lead to a correct decision-making. The number of contradictions may be from two to the total number of the group of participants (the number of votes). At first glance it seems that in such a situation it is impossible to make any decision at all, but the world practice of collective management has experience in solving typical problems, for example, with the priority of the voice of the leader who takes responsibility. In this case we arrive at the first variant, i.e. the sole decision-making. For successful optimal solution of the problem, it is necessary to have experience of specialists who develop control action. In solving typical problems, the most effective will be the use of an automated decision-making system based on the analysis of the received data.

The **purpose** of the present studies was to develop the concept of information support for an automated forest management system, and to implement it, the theoretical justification and development of a network of radio frequency devices for monitoring the forest environment with the possibility of remote collection of information on the state of stands and transportation of timber.

2 Materials and methodology

The automated control system is based on the algorithm and control laws. There are open (command) and closed (closed) automatic control systems. Automated systems include the autonomous collection of information based on measuring sensors that are located on the site.

Open (open) automatic control systems operate according to a strict algorithm, for example, by a timer or another parameter. In this case, the control effect is produced predictably, since the algorithm was developed by the person (designer, designer) on the basis of data obtained, as a rule, experimentally. Open systems are widely used in many industries, although they are classified as simple or elementary systems. Without such systems can not do, so their use in forest management is possible, for example, when collecting information on the state of the forest (humidity, temperature, etc.) from meteorological sensors and developing a control effect on the fire hazard in the forest. Another example is the system of automatic collection of data on the growth of trees, with the gauges of the girth (diameter) of the tree installed on them. Such a system runs periodically on a timer, for example, once a year. In this case, the information comes to the operator, who makes a decision on the need for cutting.

Closed automatic control systems necessarily have a feedback from the object in the form of information about the change of any parameter and the effect on the object until this parameter takes the original value. These are dynamic, operational systems that process signals immediately. As an information source about changing the value of the object parameter is an automatic measuring device located on it. The measuring device (measuring sensor, sensor) can have contact or non-contact communication with the object.

In addition, closed automatic control systems have an actuating device or an impact mechanism. For the management of forests, actuators can be, for example, robots, machinery in a protected area of the forest, unmanned aerial vehicles that perform certain functions. Unlike other areas, there are still few such functions in the forest (monitoring fire hazards in the forest, logging processes, illegal and illegal timber movements), and with the development of new technologies such functions will appear a lot, and they will be performed automatically. At the same time, the above-mentioned actuators themselves need an autonomous automated control system, for example, a transport robot patrolling forest areas must go around, overcome obstacles, which complicates the overall control system.

To date, closed automated control systems are used in the management of forest machines and other related equipment. You can plan that in future the forest machine can work without an operator or the operator will remotely control several machines at the same time. Today such machines are used in quarry mining technologies, where operations are mostly monotonous and well studied by specialists. The logging machine performs many simple operations, so the harvesting process can be fully automated or use an expert remote control system for the operator, for example, as shown in [5].

An important role in the automated management system of the forest fund is played by obtaining information on the forest, on wood stocks and other parameters, which is a very labor-intensive process. At present, information is received selectively, using computational models, where many forest workers are involved. So in preliminary studies [6, 7] it is noted that the information task can not be carried out with the help of only paper carriers. A new, more developed system with the use of electronic means is needed.

Currently, the main way to obtain information about the forest fund is to use permanent and temporary trial plots where measurements of forest parameters are made during a certain period. Disadvantages of this method are high labor costs, time costs, which are calculated by years, seasons, and data collection is carried out by expeditions. At the same time, low efficiency is observed, the human factor affects the accuracy of measuring indicators. The obtained data on the main parameters of the forest (diameter and height of the trunk, phytomass, humidity, temperature, etc.), are periodic in a separate area of the forest. Then, based on these limited data, not representative samples, the characteristics of the whole forest massif, where the studies are made, are evaluated. Such a system can not be operative and generally available, as required in the framework of the state policy of forest management of the RF [8]. The information on the state of the stand can be obtained by various methods and means:

- remote and contact;
- aircraft and ground vehicles.

The proposed model of information support for the forest fund management system is shown in Figure 1.

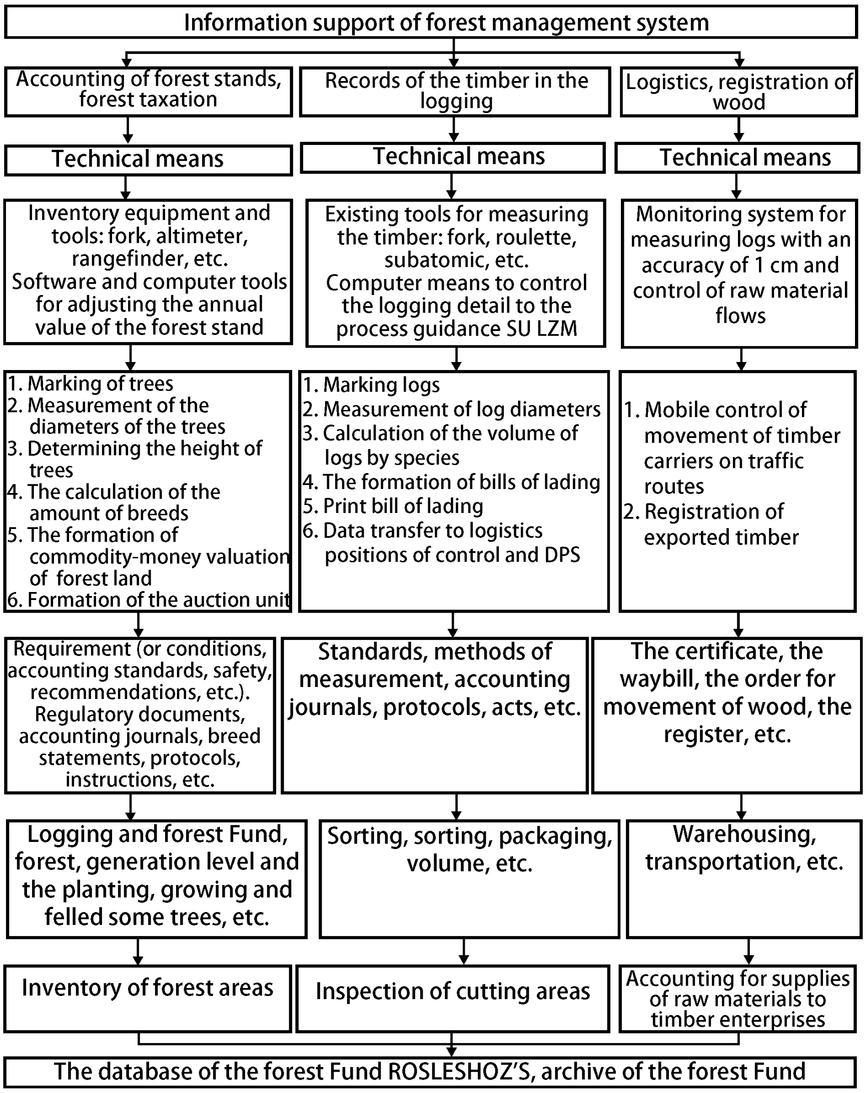


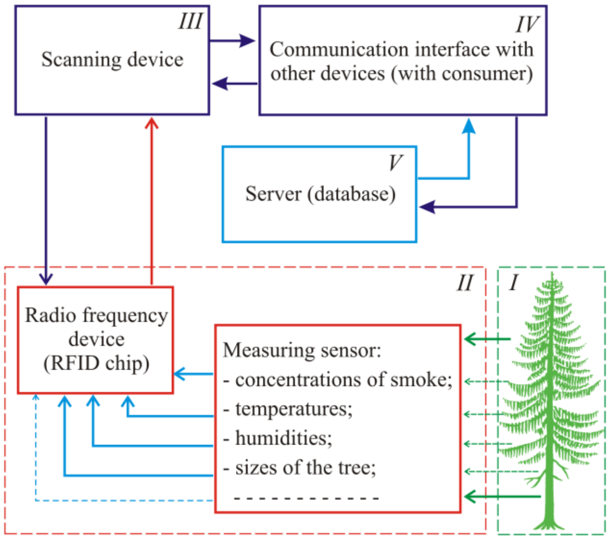
Figure 1: Information support model for the forest fund management system

In the forest management system presented in Figure 1, three directions are identified, which are interrelated in terms of functional characteristics in the database of the forest fund of the Federal Agency for Forestry:

- tree stand and forest taxation;
- accounting of wood during logging;
- Supply logistics and logging of timber when moving.

Each group of information is formed using technical means, including computer systems with software, communication channels for data collection and transmission. Access to databases increases the efficiency in the management of the forest fund. Figure 1 does not conditionally show feedback from consumers, which are not only buyers in the timber market, but also foresters in the forestries, taxologists, loggers in the plots and other specialists.

To obtain information about the status of stands, operational information is needed. This requires measuring devices located in the forest environment. The measuring devices must operate in the autonomous mode. The provision of this requirement and the development of special technical means must be solved in the near future, and the basic solution for implementing the information system based on RFID devices is shown in Figure 2.



I is the object; *II* - radio frequency device; *III* - scanning device; *IV* - communication interface; *V* - server
Figure 2: RFID Device Information System for Collecting Forest Fund Data

The scanning device (see Figure 2), as shown by experiments, can simultaneously receive information from at least 200 RFID devices and this is not the limit. In fact, the RFID device is the "passport" of the tree. Such a system will allow for full control over the state of the forest fund, preservation of trees from unauthorized cuttings, forest fires, concentration of oxygen, smoke, etc. In the experiments, a sensor developed on the basis of an RFID chip (μ-chip) with non-volatile EEPROM memory. At present, the chips produced by many well-known firms can not be operated in the temperature range from minus 20 to 70 ^{o}C. According to these parameters, the RFID chips available on the market are not suitable for winter use in the middle and northern latitudes of Russia and the Urals. Special RFID chips for forest inventory today are not produced by industry. For them, severe operating conditions are given: a long service life (for example, due to the lease term of forest tracts up to 50 years); possibility to work at low temperatures (the lower limit should be lowered to -45 ^{o}C), high humidity of the air, in the absence of power supply or have an autonomous power source capable of generating power at the installation site of RFID devices.

To conduct experimental studies, a monitoring system was developed based on the RFID device network. During experiments in the forest environment, the main devices of the radio frequency monitoring system were tested, the possibility of their application for monitoring the stand, moving timber and forest fires was proved, and rational distances between receivers and transmitters were determined to assure the reception of the signal in the forest. At the same time, the characteristics of the selected devices met many of the requirements formulated above. To meet all the requirements of the state system for regulating environmental protection and nature management, [8] a functional diagram of the automated system of accounting records has been developed, into which the proposed forest monitoring system fits (figure 3).

The assessment of forest resources in the management system is based on the accounting records, so the automation of processes and individual operations (works) is an important condition in the decision making, in the development of optimal control actions. The State Forest Cadastre contains information on quantitative, qualitative, ecological, economic and other indicators of the forest fund. The data stored in the state forest cadastre are used in the state forestry management, in assessing the economic activities of forest users and forest managers.

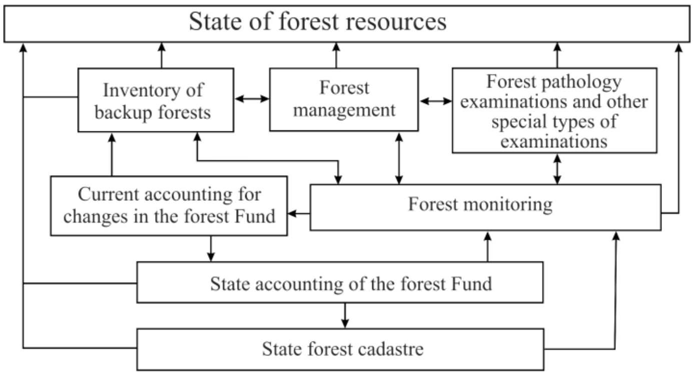


Figure 3: Functional diagram of an automated system of accounting records

Consider a system for collecting information on the state of stands from the standpoint of its synergistic properties. Suppose that it can consist of the *n*-th number of RFID sensors and the *k*-th number of readers. The number of readers and sensors depends on the design of the system for monitoring the accounting of wood and the specific task performed. The whole procedure is reduced to monitoring the status of all RFID sensors in the monitoring system. Monitoring of the forest is carried out at any time of the year in any weather and for a long period of operation. In this case, the number of devices in the system can change during the entire operation period. Self-organizing systems with their synergetic capabilities are suitable for these purposes. Information about events that varies randomly in the RFID system can be divided into private information and general. A mathematical model of private information "from event to event" is described in [9]

$$J(B \to A) = Log_2 \frac{p(A \mid B)}{p(A)},$$

where $J(B \to A)$ is the particular information about event A contained in event B;

$p(A|B)$ is the conditional (a posteriori) probability of the occurrence of event A at the occurrence of event B;

$p(A)$ is the a priori probability of occurrence of the event A.

In previous studies [10], [11], an example of determining the amount of information on the occurrence of forest fires (event A) contained in a forest area with measurable characteristics (event B) is described in detail, it can be interpreted as follows:

$$J(B \to A) = Log_2 \frac{\text{the probability of indication of a fire}}{\text{probability of occurrence of a sign of the investigated forest area}}.$$

The mathematical model of information evaluation (informativity) of a sign (P_i) affecting a forest fire, relative to the normal ecological situation (reference) of a forest object ($Э_э$) has the form

$$J(P_i \to Э_э) = Log_2 \frac{m(P_i^Э)/m(Э_э)}{m(P_i)/m(N)},$$

where $J(P_i \to Э_э)$ – is the value of informativeness of the i-th attribute;

$m(N)$ – the total number of recognition objects (elementary cells divided by the area of research of predicted fires);

$m(Э_э)$ – is the total number of forest recognition objects with normal ecological indicators (standard);

$m(P_i)$ – is the total number of forest recognition objects on which the i-th characteristic occurrence of a forest fire;

$m(P_i^Э)$ – is the number of reference forest recognition objects on which the i-th characteristic is manifested.

RFID devices with sensors for obtaining information about the state of the forest are most effectively implemented as a network system, as shown in Figure 4. This is only one of the possible options for the structural scheme of information collection. Therefore, in the course of experimental studies, other possible versions of the monitoring system were considered, for which time delays and other parameters ensuring the stability of the system operation were previously calculated.

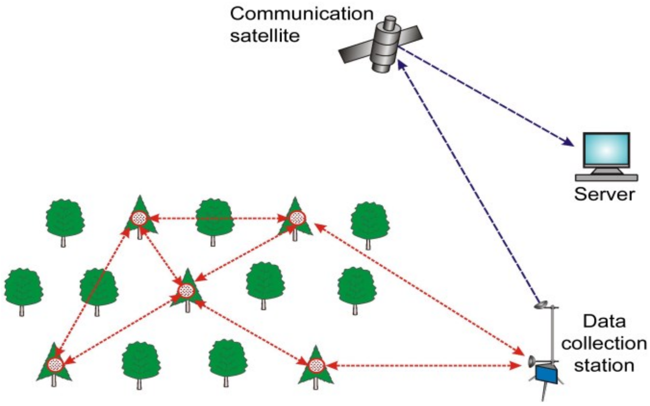


Figure 4: Structure of the Synergetic Network for Collecting Information on the Forest Fund

The number of information sources $m(P_i)$ located on a forest plot and capable of transmitting it in a probabilistic way at the same time or in a different sequence is the total amount of information *J*. The technical capability of the network will be determined by the use of communication devices for collecting information, communication protocols in the network, depending on total number of devices. In the synergetic approach, the determination of the amount of I_A information that an arbitrary system object reproduces about itself as a single whole is the following self-reproducing information of the system object *A*:

1). By the term *information*, one should understand *information about a system object as a single whole*.

2). The amount of information I_A, a self-reproducing system object *A*, is a monotonically increasing function of $m(A)$ and, accordingly, for any two system information objects *A* and *B*, we can write:

$$m(A) = X,\ m(B) = X + 1,$$

provided: $I_A < I_B$.

3). The indicator of the system information object *A*, as a unit and indivisible, is the integrative label number, which is an individual sequence of symbols (number) for each element. The length of a label (number) in digital form is a function of the total number of elements of the system object.

The amount of information I_A should be determined on the basis of modeling the processes of changing the number of elements in the system object *A* in the form of a network model of an oriented tree or graph (Figure 5).

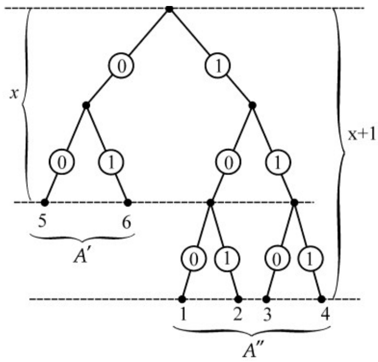


Figure 5: Fragment of the network model tree with sensor number $n = 2$ and $m(A) = 6$

The set of "hanging" vertices are mutually unambiguously correspond to the set of elements $a \in A$ in the model. The maximum number of arcs in a tree model emerging from a single vertex is equal to the number of characters (n) chosen to compose the integrative label number. For each of the adjacent arcs, a symbol is used in constructing the model. As the individual integrative number of the label of the model element, there appears a sequence of symbols that are on the path of movement from the initial vertex of the tree to the hanging vertex corresponding to this element. As an example, consider the model of the number tree of labels for the number of symbols $n = 2$ and for the "dangling" vertices $m(A) = 6$.

The model of the number tree of labels consists of the set *A* along the length of the integrative numbers of the labels of its elements, divided into two subsets *A'* and *A"*. Each group of subsets shows the number of "suspended" vertices: $U_{A'} = x$ and $U_{A''} = x+1$, where $x = [\log_n m(A)]$ is the integer part of $\log_n m(A)$. Taking into account that U_A is not a single-valued function of $m(A)$, we should consider its average length ($\bar{U}_A$) of integrative label numbers as:

$$\overline{U}_A = \frac{xm(A') + (x+1)m(A'')}{m(A)},$$

starting with the minimum number of characters $n = 2$.

From the analysis of the model of the label number tree (Figure 6) it follows that for $n = 2$ the increase of $m(A)$ per unit causes a decrease by one unit of the number of elements with the label number length x and an increase in the number of elements with label number length $x + 1$ by two elements [11], that is, it can be written:

$$m(A)+1|_{n=2} \rightarrow (U_{A'} - 1) \wedge (U_{A''} + 2).$$

From the resulting expression for $U_{A'}$ and $U_{A''}$ we formulate a system of equations

$$\begin{cases} m(A') + m(A'') = m(A) \\ 2m(A') + m(A'') = 2^{x+1}, \end{cases}$$

and when solving this system of equations, we get

$$\begin{cases} m(A') = 2^{x+1} - m(A) \\ m(A'') = 2(m(A) - 2^x). \end{cases}$$

Substituting the values of (6) into expression (5), and carrying out simple transformations, we arrive at the following formula for the average length of integrative codes for $n = 2$:

$$\overline{U}_A|_{n=2} = x + 2 - \frac{2^{x+1}}{m(A)}.$$

The obtained expression satisfies the accepted conditions and can serve as a measure of the amount of information I_A, self-reproducing finite set A. Examples of models of trees with label numbers for $n> 2$ are considered in Figure 6 for a tree with parameters for the number of symbols $n = 3$ and "hanging" vertices $m(A) = 2, 3, 8$ and 9.

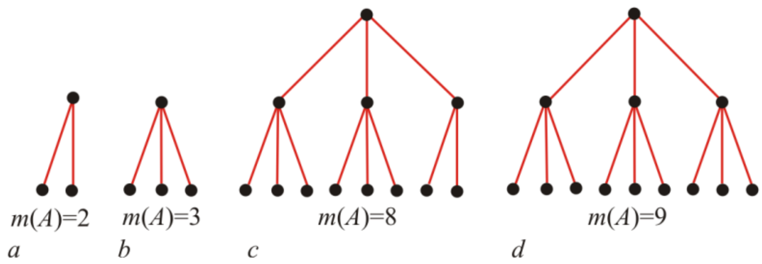


Figure 6: The model of the number tree of the labels $n = 3$ and $m(A) = 2, 3, 8, 9$ (a, b, c, d, respectively)

From the analysis of the graph in Fig. 6, it is clear that when the outgoing arcs of the starting point of the number tree of the marks are filled with outgoing arcs (Fig. 6, *a*, *b*) and the last of the "hanging" vertices (Fig. 6 *c*, *d*), the average code length $\bar{U}_A$ does not change [11]:

$$n = 3 \rightarrow \begin{cases} \bar{U}_A|_{m(A)=2} = \bar{U}_A|_{m(A)=3} = 1 \\ \bar{U}_A|_{m(A)=8} = \bar{U}_A|_{m(A)=9} = 2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \bar{U}_A|_{m(A)=3^{y-1}} = \bar{U}_A|_{m(A)=3^y} = y \end{cases},$$

where $y - 1, 2, \ldots$

With increasing n, we arrive at the general expression for the cases of constancy of the values of $\bar{U}_A$ when filling out the outgoing arcs of the last of the "hanging" vertices:

$$n > 2 \rightarrow \bar{U}_A|_{m(A)=n^y-n+2} = \bar{U}_A|_{m(A)=n^y-n+3} = \ldots = \bar{U}_A|_{m(A)=n^y} = y.$$

It follows from the expression that $\bar{U}_A$ for $n> 2$ and $\bar{U}_A \geq n^y$ in at least $(n - 2)y$ cases contradicts the expression from [12] of the monotonic increase of the information I_A. This allows us to make a fundamentally important conclusion: *the average length of the integrative number of elements can act as a measure of the amount of information only when the integrative numbers of the sensor are compiled using a binary sequence of symbols* [12].

Thus, we come to the fact that the amount of information is defined as $I_A = \bar{U}_A|n = 2$, therefore we will consider the examples with respect to $n = 2$.

From formula

$$\overline{U}_A|_{n=2} = x + 2 - \frac{2^{x+1}}{m(A)},$$

It can be seen that if $m(A) = 2^x$, then the amount of information is calculated by the formula $\bar{U}_A = \log_2 m(A)$.

According to [12], in cases where the curve $\bar{U}_A$ is defined by the parameters $2^x < m(A) < 2^{x+1}$, it slightly exceeds the $\log_2 m(A)$ curve, which can be observed in Fig. 7. The amount of information I_A at each moment of time carries a random character caused by events occurring in the forest area where RFID sensors are installed. The organization of a local, self-organizing network of RFID devices in the forest to ensure the collection of information about the state of the forest requires further development and priority tasks should be to solve the power problem for dozens of years, justify the standards for data exchange protocols, and refine the model of radio signal attenuation in the forest environment.

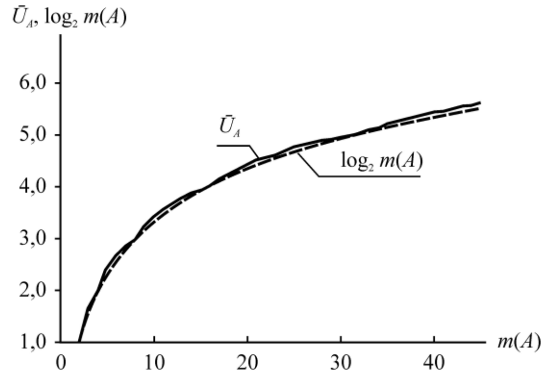


Figure 7: The graph of the functions $\bar{U}_A$ and $\log_2 m(A)$

In the proposed version of the synergetic network to collect information on the state of the forest in the event of failures, it is planned to restore the network's operability through other operating devices [13,14]. Failures occur for various reasons, for example, if damaged by forest fires. In this case, the transfer of information will take place in a different way and the information in any case will get to the server in the database. This ensures the reliability of the network, which is an important factor in the conditions of the forest.

Conclusions

1. Further improvement of forest management processes in the Russian Federation is practically possible only with the use of information technologies, and for this purpose a model of a conceptual automated forest management system based on a synergetic system for transferring information to the database was proposed.
2. For the most effective implementation of the model of automated forest management, a system of radio frequency monitoring in the form of a network of RFID devices has been developed.
3. A mathematical device has been created that describes the information flows in the RFID device network and the synergetic properties of the monitoring system.
4. A model with a description of the algorithm for transmission, reception, storage and use of autonomous sensors in the network is presented. Comparison with the known logarithmic curve of the model dependence shows sufficient adequacy of the model.

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