Robotic systems in forestry

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Abstract. The article presents review of modern robotic system technologies implemented in forestry. This study shows the importance of partly and fully automated robotechnic complexes specifically designed for forest management in Russia. The research provides characteristics of goals in forestry and their solutions based on designing technologies of robotechnic systems. The article contains the review of management methods with various partly and fully automated systems that are already used in the areas close to forestry. This study shows technological aspects of development of these systems in terms of their implementation in forest sector. The research contains review of existing models, technologies and prototypes presented abroad. Active prototypes have a detailed description and their current implementation in forest sector. The analogue systems that are used in agriculture and mining have a good potential of usage in forest sector. The provided study highlights the possibility of robotechnic systems use in terms of forest planting and fighting forest fires.

1. Introduction

Forestry technological development. Systematic approach serves as basis in reaching goal of the sustainable use of forest resources. Nowadays, we should find the balanced model between logging volumes and minimized negative environmental impact. The Previous stages of forest sector development had 2 main technological periods: manual (physical) wood harvesting and mechanical harvesting with wide use of machinery (from 50-es in XX c. till present day). Development of the computing and IT in general led to intensive automatization of technological processes. Many spheres of our life change from partly automated processes to a complete automatization or is getting ready for such improvement. General level of informatization and computing capacity reveals new opportunities for use and implementation of machines and separate elements in the forest sector. Robotechnic systems are one of the perspective technologies, which can find their wide use in forestry. According to the agreed upon definition robotechnic complex is an assembly of software algorithms and hardware providing complex automatization of accomplishing the group of assigned tasks.

The main purpose of this work was to conduct research of modern robotics development in the field of forestry. Grouping robotic systems by type, description of their capabilities and applications in forest sector, automation degree of different robotic systems groups and its assessment. This article is its authors initial work cycle on this topic.
Argumentation for the development of the complex robotechnic systems. Work in the forest sector is traditionally considered as physically hard and potentially dangerous, especially in terms of wood harvesting. Logging is a long and unsafe process. During the first technological period (manual) there used to be a need of a special logging crew consisting of a logger and supporting logger. Once cut, a tree needed to be trimmed from branches and removed its top. This task usually was fulfilled by a group of workers. After that the trimmed trunk got cross-cut into logs. For this goal there was required another specialized team presented by: marker, cross-cutter and 2-3 dragmen. Such manual logging method is still used in our days, though much less than before, due to high energetic and time costs and high level of danger for workers. The described process demands working experience and strictly abidance of the safety process.

At first glance, the described logging process is hard to upgrade into partly or fully automated mode. Nonetheless, we need to point out - forest sector keeps on developing and many challenges already founds their solutions by implementing new technological processes, e.g. harvesters are capable of fulfilling 4 and more operations (felling, debranching, skidding, cross-cut and sorting). Such machinery allowed to significantly increase efficiency, improve working facilities and reduce number of operations during the difficult manual stage. Among the advantages of such method are both safety and comfort of the operator who operates the harvester. Worker’s cabin is designed for comfortable use during whole year and by using harvester we get decreased life risks for worker during logging. Due to removing of a whole chain of technological process debranching workers were replaced with a skidding tractor.

One of the challenges faced by the engineers is to increase the number of operations fulfilled by one machine, this example was followed by developers from New Zealand [1]. The implementation of the robotechnic systems in the forestry has a vast amount of advantages and perspectives. Also, it can significantly speed up not only harvesting but planting process, which follows it. This is why scientists and engineers have the common goal of upgrading from mechanized to fully robotechnized forestry by taking into account the high level of computing machines and technological solutions in general.

2. Methods and Materials
As objects of research, due to analysis of public scientific literature and thematic reviews, were analyzed several developed robotic systems. The research was conducted in 2018. It is worth noting that some types of observed robotic systems have quite limited application. In Russia, most automated robots developments from the presented ones are little known. Asessing the general segment of robotics (figure 1), according to the data of the Industrial Federation of Robotics (IFR), the world’s demand for robotics is increasing. However, in forest sector, robotics has not found extensive application to date. Most of the considered prototypes of robotic systems developed abroad.

![Figure 1. Statistics on demand for industrial robots according to IFR data from 2005 to 2022.](image-url)
Formally, the goals of complex robotization in forestry we can divide into specific subgroups characterizing the technology, which will be used in this robotization process. (table 1).

| System group | Name                                                                 | Robotization technologies                                        |
|--------------|----------------------------------------------------------------------|------------------------------------------------------------------|
| Group 1      | Robotized systems for analysis of forest-covered areas               | Automated UAV (drones) systems                                   |
| Group 2      | Autonomous robootechnic systems for executing harvesting tasks in forest lands | Automated Portable machines with partly remote control           |
| Group 3      | Robotechnic systems for forest planting                             | Automated controlling systems of forest planting machines         |
| Group 4      | Robotechnic systems of forest fire extinguishing                     | UAV complexes with the forest fire extinguishing ACS             |

Forestry Mechanization process became a first step on the way to the automatization of forestry. The main demand was in need of both increase of production and work safety conditions. As a result, forestry activities changed and became more intensive. After implementing such process harvesting cycle needs seconds instead of minutes as it used to be before. Swedish researchers revealed that with increase of production capacity, operators continue being the main slowdown source as human can’t work like a machine [2]. Man can operate joysticks with a required speed but needs regular breaks during work, whereas, machine is limited only with a fuel tank and maintenance. When comparing required time costs for the work duties in forest we can exclude the time that operator doesn’t use during the work process. Therefore, this time will be used by a machine without any overwork issue because robotized complex can be more efficient by several times.

Due to the change of working conditions old and more experienced workers can fulfill their duties longer. This became possible after moving them into a comfortable cabin of a machine, excluding need of hard physical labour. Such change we can reckon among the advantages of mechanization stage in forestry. In fact, with full robotization of harvesting process the need of human presence on the clear-cut will disappear. This robotization process doesn’t exclude human from the working area because this system still needs remote control presided by the operators.

Let’s analyze the basic management types of robotechnic systems which should be used in the modern forestry. Today, we have different methods of robotechnic systems controlling. They have already showed remarkable results in the similar industries (agriculture, mining and military industries). They can be grouped by the control method as following:

- Manual control - requires presence of operator directly in a machine. Operation is completed with a joystick placed in a cabin of machine. Most of modern machines have such controlling system. As a good example we can name feller-buncher machine LP-19 and its LP-19A and LP-19B modifications [3].
- Remote controlling doesn’t need physical presence of operator in the cabin but is limited with the radio-wave signal distance. In order to perform operation without any problems operator needs to be in a fixed visibility distance. Light machinery of such operation type are widespread in the New Zealand [1]. Such machines are used for housebreaking and soil packing [4].
- Tele-operational control - controlling method similar to remote controlling, though control and operation processes are managed with transmitting video-signal and use of various sensory systems (LiDAR, sonar, radar, StarFire receiver) [5]. Doesn’t require to keep operator in a fixed distance line, operator can be located thousands km away from a machine. Such machinery is less popular due to its difficult maintenance. Such examples we can find in the military industry (special UAV units) and in mining industry where can be used special cargo haulers (figure 2) [6].
- Automated control system - completely AI-controlled operation process. No operator needed, human control is also possible. Such method became widely used in mining industry.

The machinery in forest sector are equipped mainly with manual control system and requires presence of operator. However, manual operation was replaced with more modern systems in the majority of other industries. Modernization process and use of innovative technologies in forest sector meet difficulties due to the legislation and organization systems. This becomes a reason for delay in technological improvement compared with other industries. Absence of scientific test plots of such systems creates an obstacle in the way of approbation of designed solutions.

We propose to describe presented processes with scaling of automatization level where 1 is the lowest rank relating to manual operation and 5 is the maximum rank relating to full automatization that doesn’t require any permanent operator activities and presence during working processes (table 2).

Table 2. Scale of automatization level of different operation types.

| Operation type                      | Rank | Automatization level |
|------------------------------------|------|----------------------|
| Manual control                     | 1    | low                  |
| Remote control                     | 2    | medium               |
| Tele-operational control           | 3    | medium               |
| Automatic Control Systems (ACS)    | 4    | high                 |
| Robotized complex                  | 5    | high                 |

Having analyzed robotechnic systems in terms of the operation type in different areas, we need to choose such industries where working processes are most similar to forest sector. In the developed countries there is a tendency for implementation of tele- and radio-controlled machines in forestry. It is considered that these 2 systems will be actively used in harvesting because it allows removing human from the potentially dangerous area. However, taking into account environmental conditions such operational systems can have the following disadvantages:

1. in the images received from the cameras we can hardly define the depth and soil density that may lead to bogging down,
2. limited visibility zone operator can see only what camera shows,
3. there are possible delays in receiving images from cameras due to network issues,
4. absence of thorough understanding of what actually happens in the working area.

Such issues are not crucial if to compare them with the advantages which we can get by using robotechnic systems. They can be solved by upgrading used machinery. In particular, it is possible to...
start using wide-angle cameras and develop real movement mechanics for cameras in order to upgrade their remote vision range. Outfitting automated machine with sensors and vibration pickups will allow operator to fill the movements of the machine. This will help define working depth perception on different soil types. Such types of systems are already presented in other industries (e.g., remote control systems, operational supporting medical devices).

3. Results and Discussion

Technological aspects of robotechnic systems development in forest sector. We need to mention that all robotechnic complexes which are already implemented or planned to be used in forest sector have analogues in mining and military industries. These 2 industries are considered as leaders in decreasing the human labour share because of their potential dangerous technogenic conditions. Also, they enjoy the significant financing from state and private enterprises.

The use of robots in mining industry became regular. For instance, they are used in establishing the mines’ air-cooling systems in order to reduce costs because it is dangerous for human. Robots can withstand much higher temperatures than human so in some working conditions cooling systems are useless.

Robotechnic turns into a fast-growing industry. It includes IT, sensor networks, Augmented Reality (AR), tactile control and vast number of multidisciplinary sectors. Excluding such perspective technologies from the economically unfeasible forest management in Russia is highly non-efficient approach. Development of these technologies will boost forest sector. In 2015 Canada hosted a conference devoted to robotechnics in forest sector [7]. It was stated that robotechnic development in forestry should be combined from innovations in forest, mining and space industries.

Among speakers, there was Robert Hall, international expert in mining machinery automatization who presented University of British Colombia. They discussed the following issues: use of large driverless cargo RC trucks equipped with GPS system. Implementation of remote RC systems in mining industry led to a significant changes in approaches and mindset. As an example, highly accurate GPS navigation will allow designing more narrow roads for cargo traffic than a standard one. It will reduce total cost of road maintenance and traffic network construction.

Implementing in forestry any gained experience of robotechnics’ use in mining industry we need to take into account some specifics of this sector. Automatization of separate technological process is not enough due to the multitask working conditions of the forest machinery. We need to consider the ecological impact. Data collection and detailed analysis of environment should be obligatory requirements. This work should be done in several fields simultaneously and fulfill other functions of a technological process as well.

In addition, national forest science knows some successful examples of implementation of different IT and automated methods in forest management data collection and its analysis [8, 9].

3.1. Foreign experience of the robotechnic systems design

Excavator John Deere 909 is the first radio controlled harvester and one of the latest semiautomatic machines designed for New Zealand forestry fits for working on steep areas [10]. Currently, Paul Malliken, chief designer of this machine works upon upgrading tele-operational controlling systems. It will allow operator to control harvesting process remotely by observing surrounding area on the screen screen.

The robotechnic systems specially designed for the specific space researches can also be used in forest industry. MDA (MacDonald, Dettwiler and Associates) is an american company that specializes in space technologies production. The remote manipulator Canadarm 2 developed by this company has been used in the last 4 flight missions to the Mars and is now used and operated on the International Space Station (ISS). Main destination of this system is running different tasks in the open space remotely or during astronauts’ work outside the ISS. Machinery in forest industry can be equipped with systems of similar design specification of different scale. Such systems have higher contact and calculation accuracy due to their specially programmed elements of intellectual data analysis. Such systems can be
used on the clear-cuts. John Deere Forestry used Canadarm 2 as analogue and developed controlling system for knuckled arm. Knuckled arm is the main gripping element on the grapple that automatically controls hydraulic cylinders. It allows operator to move gripping element in the required direction. The main disadvantage of ordinary systems is impossibility of controlling each cylinder separately that leads to decrease of their operating mass. Innovative system is called intelligent knuckled arm management. This system allowed not only reducing learning curve of operators but also speed up the production cycle and lowered fuel consumption. Compared to the human-controlled process, automatic grapple operating allowed for smoother moves of knuckled arm.

Besides robotization of grapple system there is a developed concept of walking robots for forest industry. It is planned to replace current tracked and wheeled forest machines which cause negative impact on the forest soils considered as one of the main and important components of a forest biosphere with such robots. Such advantages of these robots as lightened construction and lifting legs minimize harm to the forest soils (table 3). Programming algorithms based on phase training allow reaching acceptable moving speed. Boston Dynamic tested many similar technologies. The equipment of robotized forest machines with sensors will allow choosing the best placing of the leg in advance. The Finnish Plustech Oy, serves as successful example of such harvesting excavator [11]. This machine has automatic gripping mechanism and 6 mechanic legs instead of regular wheels or tracks [12]. It is the first partly robotized machine specially designed for forestry needs that can step over the obstacles and work on different type of forest soils.

Table 3. General characteristics of walking harvester excavator by Plustech Oy.

| Length, cm | Width, cm | Height in a vertical position, cm | Clearance, cm | Diameter of the foot’s base, cm | Step length, cm | Weight, kg |
|------------|-----------|----------------------------------|--------------|-------------------------------|----------------|-----------|
| 575        | 275       | About 450                        | 0-120 (depending on position) | About 54                     | 30-90 (depending on terrain) | About 13000 |

Another group of robotechnic systems that can find implementation in forest industry belong to the technical systems for debranching. They help to get high quality wood. Japanese engineers developed Woody for such purpose. It is a robot that can move up and down the tree stem and cut branches [9]. Main characteristics of this tree climbing robot mentioned in table 4. Similar machines with mechanic saws were developed in the USSR, though they didn’t find wide practical use.

Table 4. Characteristics of tree climbing robot “Woody”.

| Length, mm | Width, mm | Height, mm | Adaptable tree diameter, mm | Workspace | Weight, kg |
|------------|-----------|------------|-----------------------------|-----------|-----------|
| 750        | 310       | 310        | 100-150                     | Straight trunk | 13.8      |

One of the most innovative ideas or the robotechnic systems is use of robots in the over ground area, providing full absence of contact with the forest soils. It can completely change forestry. Perhaps, one can find use of such technologies as difficult at first. Yet, every year the technologies get smarter and more complex. Scion scientific research institute, New Zealand leads active experiments in this area [13]. They offered as one of possible solutions using such machines in the areas with difficult access where regular forest machines can’t reach, e.g. mountain regions, steep slopes. The above-ground wood processing machine was designed with the financial support of Scion Institute, Ministry of primary industry of the New Zealand and Levy Trust Forest Fund (FGLT) [14]. Students of the Canterbury University created working RC machine in 2013 that could move from tree to tree.

The tests of such machine showed that independence from the ground makes it easier to operate the machine. It excludes necessity of taking into account soil conditions, e.g. holes in the ground, rocks, fragile soils, etc. However, operating process is rather different comparing with the traditional one. It is
planned to implement series of such over-ground machines that can use trees for their movements. They will fulfill economically important tasks such as tree measurements, debranching, thinnings of the young stands and selective felling of mature stems. Each designed machine will be able to work autonomously and perform specific tasks collectively, transmitting received data among each other. In terms of forest industry robotechnic designs should be compact and small-sized. The whole technological cycle can be divided by categories of the machines, which execute required operations.

Foreign forest robotechnic development is not limited only by harvesting goals. There are existing concepts of robots for such important tasks as forest restoration and forest fire extinguishing. There are designs of the robots for forest planting in the University of Victoria, Canada. Such machine can automatically plant seedlings and firm the soil.

Development of the robotechnic machinery for forest fire extinguishing has great importance as for our country specifically and for the world in general. There are registered 10 000 – 35 000 forest fires each year in Russia, with total cover area of 500 000 – 2.5 mln ha [15].

One of the presented forest fire registration methods is based on the use of CCTV monitoring with thermic sensors. Though, this method requires full-time presence of the operator. Its main disadvantage in the registration of forest fires caused by the operator’s concentration loss. Satellite monitoring also faces challenges in registration caused by the limitation of image resolution. In order to register a forest fire with such method at least 900 m² needs to be affected

The designs of the American company Insight Robotics are specialized in creating robotechnic systems for early registration of forest fires. Automated system of early registration is presented by a highly accurate robot with panoramic imaging and heatwave sensors combined with AI visualization technology. This robot is equipped with infrared sensors, which are able to register fire on a tree from the distance up to 200 km² [16]. According to the developers, detecting fire spot and it fast utilization will prevent the catastrophic outcomes and lower the CO₂ emissions produced during the fire.

The main functional and running characteristics on the developed robots are presented in table 5. For innovative development of the forest industry in the Russian Federation, within digital transformation of economy, application of robotic systems will allow to automate processes of hard manual work. Robotization is gradual transition process, the following scientific and technological breakthrough of society which will make impact on all types of the industry. In this context forestry in Russia has to not only develop the direction of robotization, but also look for evidence-based paths of use of the hi-tech equipment for the forest sector.

### Table 5. The main characteristics of the considered robots.

| №  | Robot name                          | Applied application   | Functional achievement                        | Types of technological operations | Degree of automation on a scale |
|----|------------------------------------|-----------------------|---------------------------------------------|-----------------------------------|-------------------------------|
| 1  | Walking tractor by John Degree     | Timber harvesting     | Movement on a surface without harming the soil | 1. Movement, saw cut of a trunk, 2. Scrap of boughs | 3                             |
| 2  | Woody robot                        | Tree care operations  | Pruning                                      | 1. Moving along a tree trunk, 2. Pruning | 4                             |
| 3  | Robot with wood-to-wood movement technology | Timber harvesting | Technology moving from tree to tree without contact the ground | 1. Moving along a tree trunk, 2. Trunk sawing | 4                             |
| 4  | Robot on detection of the fires from the company Insight Robotics | Fire detection | Early fire detection                          | 1. Moving, 2. Thermal data processing | 5                             |
4. Conclusion
Technological changes that currently take place in each economical field can be considered as natural process. Development and further implementation of modern technologies not only allow optimizing human resources but also, they become economically efficient. Forest industry needs its own technological development that implies the use of robotechnics. Nonetheless, the process of moving from mechanization to automatization is at starting point. The majority of technological changes in specific processes are always associated with certain anxiety. Here we can name decreasing participation of human in the decision-making process and decreasing share of work duties that can lead to disappearance of some professions. The use and implementation of robotechnics doesn’t exclude human from the working process.

There will be all-time need of a person who will operate, provide maintenance, set the software. The constant demand of service operators will create new professions and need of specialists. We need to mention that robotechnic systems potentially change the forestry approach and will allow finding new opportunities in forest studies, especially in the remote areas, forests planting and multi-scale data analysis gained from its observation. The robotics market is rapidly expanding and new machines are emerging every year.

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