MULTIAGENT ROBOTIC SYSTEM APPLICATION IN CONDITIONS OF FOREST FIREFIGHTING

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ABSTRACT
Forest fires become the most frequent large-scale natural disasters, the protection from which is a complex, labor-consuming and expensive process. The extent of the damage from fires in Russia amounts to 20-110 billion rubles annually. Forest fires that raged in October 2017, Northern California, caused damage of $9 billion dollars. Today the most effective and safe means of firefighting are fire-prevention robotic systems.

Research-and-production Enterprise «Tenzosensor» with the support of the Russian Federation Ministry of education and science and in collaboration with FBI «Avialesokhrana» develops the multiagent robotic system for forest firefighting.

The scientific objectives of the study are: justification of the composition of the light multiagent robotic system for forest firefighting; justification of the structure of the multiagent remote control system; justification of the unified control interface composition based on polijoysticks.

The set tasks were solved by the methods of experimental modeling and theoretical analysis of the obtained results.

As a result of the research the following results were received: the new composition of multiagent robotic system for forest firefighting was developed including: the structure of hierarchical multiagent remote control system was developed; the unified polijoysticks-based interface for the control of the multiagent robotic system elements.

It is expected that by its performance and efficiency the developed robotic system will be able to replace a brigade of firemen of 40-60 people.

Key words: Forest fires, Fire control technique, Robotic systems, Multiagent Control software, Human-machine interface.
1. INTRODUCTION

1.1. Background

Forest fires, more frequent due to global warming, become the most frequent large-scale natural disasters, the protection from which is a complex, labor-consuming and expensive process.

In Russia, the forest damage from fires in 2011-2013 amounted to 4.32 million ha, in Canada (2.45 million ha), Brazil (2.16 million ha), United States (1.74 million ha) and Indonesia (1.61 million ha). Forest fires that raged in October 2017, Northern California, caused damage of $9 billion dollars. The extent of the damage from fires in Russia amounts to 20-110 billion rubles annually. Forest fires are a big problem for our country.

The total amount of funds allocated under the state program “Forestry development” in Russia for 2013-2014 exceeded 12 billion rubles. However, the area of fires is not reduced. This is due to the high complexity, danger and labor intensiveness of forest fire extinguishing, their dimensions and dynamism. The dimensions of fires and vast amounts of burning material are factors that drastically reduce the effectiveness of traditional fire extinguishing equipment adapted for control of local fires.

Forest firefighting is one of the biggest challenges for forestry in Russia. More than 90% of forest fires are ground fires. Crowning and peat-bog fires also begin with ground fires, in this regard, the development of new technologies of extinguishing and localization of ground fires of varying intensity increases the effectiveness of the forest protection system and therefore is highly relevant.

1.2. Technologies and technical means for the creation of artificial fire-prevention barriers

There are a large number of technologies and technical means for the creation of artificial fire-prevention barriers:

- mineralized stripes;
- fire breaks and barriers;
- fireproof borders, gutter trenches;
- barrage and supporting stripes. They are laid in the forest in the process of fighting the forest fire, which has already broken out.

1.3. Forest firefighting equipment

- *Earthmoving equipment.* Forest firefighting with the use of earthmoving equipment is quite common. Traditionally different earthmoving equipment is used to lay the mineralized stripes: bulldozers, tractors, motor blocks with dozer equipment, plows, wedges, ground throwing tools, tools for clearing from stumps and other special equipment. However, this equipment requires considerable power inputs and its operators are exposed to all the dangers of the forest fire.

- *Harvesters* (They are used for felling trees, but are quite expensive and not adapted for the work in conditions of forest fires, smoke and flame activity.)
Fire trucks, motor pumps, portable fire extinguishers etc. are used to extinguish the burning forest.

Fire-prevention robotic systems today are the most effective and safe means of firefighting [2-4].

1.4. Fire-prevention robotic systems

There are several robotic systems produced in Russia, such as RCM "KEDR" [5], YEL-4, YEL-10 (developed by FSBI Scientific-Research Institute of the Russian Ministry for Emergency Situations) [6], RTC "Pelican" (developed by scientific-production Association “SIBIRSKIY ARSENAL”, Novosibirsk) [7], "Uran-14 "(developed by "766 UPTK" OJSC) [8] and others. These are the expensive and heavy firefighting robots weighing from 3.5 to 20 tons, fitted with dozer blade.

Foreign firefighter robots are in general analogous to the described above. To such robots there can be attributed a small-sized mobile fire-extinguishing installation LUF-30, a firefighter robot Magirus TAF 20, a multi-functional robotic fire truck MVF-5 of the Croatian company DOK-ING, a firefighter robot “Thermite RS1-T2” of the company Howe and Howe Technologies, a Chinese firefighter robot RXR-M40D-1, a mobile firefighter robot Firerob, developed by the German firm Telerob, a robot-fireman FirerobFireremote 4800 of the company Ryland Research Limited (United Kingdom), a robot for firefighting JMX LT50, developed by the Research Institute of the Ministry of public security “Shanghai firefighting research institute” (China).

The robotic systems creation and implementation allows increasing the effectiveness of forest fire extinguishing, drastically reduces the risks of death and injury among personnel rescue units, reduces the cost of fire extinguishing.

2. METHODOLOGY

Forest fire is a difficult complex phenomenon, which effective extinguishing is possible only through the use of multiple robotic machines working simultaneously, but performing different functions and mutually reinforcing each other.

All the previously created fire systems represent a self-propelled remote-control device equipped with a set of different tools. Typically, these are fire carriages, a blade, a manipulator and a winch. When performing any separate operation all other working bodies are inactive. This system building principle leads to the potential decrease in the equipment effectiveness and increase in the system cost.

Another common drawback of robotic systems is control based on joysticks. When entering the control commands from such panels the operator is constantly distracted from visual observation of the robot. This reduces the quality of control and increases the operator’s fatigue. Traditional control elements -buttons and joysticks- are extremely hard to use in conditions of action of frequent tremors, vibrations, and in emergency situations. This decreases the effectiveness and survivability of systems, efficiency and quality of control.

2.1. Justification of the composition of the multiagent robotic system for forest firefighting

To eliminate these shortcomings the innovative compact information entry systems were developed — the unified human-machine interfaces, including the polijoysticks (left and right), a video mask and a control unit. The video mask display shows the picture from camcorders, tactical situation, as well as a variety of appliances and switches needed to manage RTC. Application of video masks allows to get rid of bulky displays, sensitive to
vibrations and tremors. Application of polijoysticks allows carrying out the reliable tactile control without eye contact with the manipulators.

During localization of forest fire extinguishing the most frequent and volumetric operations are burning forest, felling trees and creation of demineralized stripes.

To implement these functions the system composition included a firefighter robot, a robotic miniharvester and a robotic trencher, which are located on two border lines of fire extinguishing (Figure 1).

![Figure 1. Robotic system for forest firefighting](image)

Firefighter robot is designed for fire extinguishing by either pouring water on inflammation or other fire extinguishing liquid on the 1 border line.

Firefighter robot is equipped with a motor pump, a fire carriage with circular scan, hinged containers for water storage and system for switching of operating modes. Firefighter robot can work in the firefighting mode with the use of water from the tank, as well as in the working mode of fire carriage from the towed fire. Firefighter robot is capable to fill its tanks from an open water source or from the towed hose by the operator's commands.

Robotic miniharvester and trencher are designed for creating the fire and mineralized stripes on the 2nd border line for the further start of counter annealing.

Robotic miniharvester is equipped with an axle device based on the binding clamp and electric saw, allowing felling trees with a diameter up to 400 mm.

Robotic trencher is equipped with a mounted trencher with ground-blower, allowing lying demineralized stripes with a depth of trenches up to 30 cm and width of soil layer to 1.0 meters.

All robots are mounted on the unified tracked chassis with the size of 2400 x 1400 mm and have a weight of not more than 400 kg. Robots are equipped with a petrol engine and capable of working without refueling in the remote-control mode for up to 8 hours.

3. RESULTS
3.1. Detection of fire localization
In accordance with the Rules of forest fire extinguishing the starting action to extinguish a forest fire is its inspection. The inspection is carried out using the land-based, airborne and (or) space assets in order to identify the type and speed of the forest fire spread, its outline and the approximate area, etc. The most effective modern means of inspection are aerial reconnaissance drones, equipped with the regular or infrared video cameras FLIR or night
vision cameras SWIR. Therefore, the system included the aerial reconnaissance drone Fantom 4 Pro [9] equipped with the camcorder on controlled 3D-suspension.

Before forest firefighting the inspection of fire is carried out using the copter equipped with video surveillance system and/or SWIR cameras or FLIR and/or surveillance systems of robotic platforms.

After the fire inspection its localization is started by laying the barrier and supporting mineralized stripes. Previously, on the intended route of the barrier and the supporting mineralized stripes the felling trees is carried out using robotic miniharvester, then a mineralized or barrier stripe is lain using robotic trencher. In the process of creating the barrier or supporting mineralized stripes there is a constant inspection/monitoring of fire using copter and surveillance systems of robotic platforms. Video images of monitoring are transmitted into the car of mobile control center from which the copter is controlled, and are constantly analyzed.

In case of probability or the fact detection of fire flame front crossing the created mineralized and annealed stripe, the fire firefighter robot is directed to the fire breakout place, equipped with the installation for flame extinguishing with the water jet, and the flame is remotely extinguished at this site, preventing the fire breakout through the mineralized stripe.

3.1. Usage of robotic system for forest firefighting

The robots are carried by the control cars on trailers to the place of fire. Each trailer is equipped with a retractable radio mast for lifting the control antennas to the height of 6 m. Application of retractable radio masts allows you to increase the distance of system control in the forest environment. In stowed position the radio masts are in the folded position. When moving the system in stowed position the copter with a surveillance camera is carried in a packaged form in a control car.

After arriving to the firefighting scene, the system is placed in the working position. Robots are unloaded onto the ground on the removable ramps, and the radio masts are pulled out in the working position. At that the control cars can be on the same spot or can locate in the places convenient to control robots.

For the connection and coherent robotic system control all the cars are equipped with the communication means to communicate by Wi-Fi network. For the centralized connection one of the cars has the satellite communication means with the superior leadership.

With the aim of increasing the functionality and efficiency of the robotic system its composition may include several robotic platforms as well as multiple copters, equipped with the video surveillance cameras, as well as FLIR or SWIR cameras.

Control of the robotic system elements is carried out remotely from the mobile control center (Figure 2).

The mobile control center includes three cross-country cars with the workstations for the operators of robots, as well as the supervisor and the foreman.

For the first time to control the robotic system the multiagent remote control system is used, built hierarchically, with the possibility to control the work of the operators of robots at two control levels - of the supervisor and the foreman. Multiagent remote control system provides the possibility of the interoperability of operators, the foreman, the supervisor and the robotic system elements for forest fire extinguishing, as well as to control the management and communication processes.
The foreman has a direct connection with the leadership over the Internet and receives the firefighting tasks from it. According to the task the foreman sets the specific targets to the operators of robots. The foreman has a universal remote control and the ability to intervene in the control process of any robot, and also to reassign the control of any robot onto a different remote control.

The supervisor controls the drone, monitors the robots and surroundings in the workspace.

A firefighter robot operator gets the tasks from the foreman and performs the fire extinguishing using the firefighter robot.

Operators of the robotic miniharvester and trencher receive tasks from the foreman to create the fire border line, preventing the fire spread. The miniharvester operator performs the felling trees and shrub cutting. The trencher operator performs the barrier or mineralized stripe laying, preventing the fire spread.

The trailers of the mobile control center are equipped with the recreational facilities, providing 24-hour shift work for the system operators.

All the mobile control center cars are linked to each other by the wireless network to ensure the personnel management and interaction, monitoring the state of the cars and environment.

To control the robotic system elements for forest firefighting a new unified control interface is used based on polidjoysticks [10] and optical ministicks [11, 12] (Figure 3).

**Figure 2.** Block diagram of the robotic system for forest firefighting

**Figure 3.** Unified HMI (on the right – the operator with the polidjoysticks, on the left – the video mask and two polidjoysticks)
The unified human-machine interface consists of:

- two polijoysticks (there are 5 optical ministicks on each);
- a video mask;
- the control system interface unit.

Optical ministicks on polijoysticks can be used as polymorphic switches able to perform several functions: for example, a button, a toggle switch, a selector switch and a miniature joystick. One can change the functionality directly during the operation, i.e. on a real-time basis.

Application of polijoysticks enables to carry out a reliable tactile control without eye contact with the manipulators.

The display of a video mask shows the image from video cameras, the tactical environment as well as various devices and switches necessary for control. Application of a video mask allows to get rid of bulky displays, sensitive to exposure, vibrations and tremors.

4. CONCLUSIONS AND RECOMMENDATIONS

Every year on the planet 200 000 forest fires break out. [13]. According to Greenpeace data the world annual average rate of forest loss is about 1.47 million ha or 0.5 per cent of its area [14]. The economic damage from the fires in the United States is at least 25 thous. US dollars per ha of the forest. In Russia, according to Rosleskhoz data, this rate is 1.2–1.5 thousand dollars per ha. If you take the average value of the amount of damages from the wildfires at the level of 13.1 thous. dollars, then an assessment of the damage from the forest fires in the world can be estimated at about 19.3 billion dollars. This damage potentially forms the firefighting equipment world market in the volume of 1.5-2.0 billion dollars.

Thus, the problem of forest fire fighting robotization is relevant enough and effective robotic systems for the forest fire extinguishing will be in demand on the markets of all large countries possessing the large forest spaces. The use of robotic systems for the forest fire extinguishing is very effective. By its productivity and efficiency, the developed system can replace the fire brigade in the amount of 40-60 people. At that the firefighters can be up to 2 km from the seat of fire and not to put their lives at risk.

Development of remotely operated robotic systems is the first step in creating the online-driven robotic firefighting systems, which control can be carried out via the Internet from anywhere in the world.

ACKNOWLEDGEMENTS

The research is carried out with the financial support from the state, through the Ministry of education and science of the Russian Federation in the framework of the implementation of the agreement of September 26, 2017 № 14.579.21.0151. The unique identifier of the applied scientific research and experimental development is RFMEFI57917X0151. The authors are grateful to the monitors and experts of STE Directorate for the correct and friendly discussion of the obtained results.

REFERENCES


