Development of a robotic vehicle complex for wildfire-fighting by means of fire-protection roll screens

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Abstract. Fighting wildfires is one of the most important missions of Russian forest management. The most promising and safe means of fire-fighting are now the robotic firefighting vehicle complexes. The NPP “Tenzosensor” is developing a multi-agent robotic vehicle complex for wildfire-fighting by means of fire-protection roll screens, supported by the Ministry of Education and Science of Russia and in cooperation with SPbNIILH and “Avialesohrana” Federal Budget Entities. The scientific missions of the paper are: substantiation of the fleet of the multi-agent robotic complex for wildfire-fighting by means of fire-protection roll screens; substantiation of the structure of the multi-agent remote control system; substantiation of the structure of the poly-joystick based remote control interface. The set goals were achieved by experimental modelling and a theoretical analysis of the results obtained. It is supposed that the performance of the robotic vehicle complex for wildfire-fighting could be equivalent to that of a brigade of 40-60 firemen.

1. Introduction

Wildfires are growing to a most frequent natural catastrophe requiring sophisticated, labour-intensive and expensive protection measures.

In 2011-2013 4.32 million ha of forest were lost in Russia, 2.45 million ha in Canada, 2.16 million ha in Brazil, 1.74 million ha in the USA, 0.94 million ha in the Europe, and 1.61 million ha in Indonesia. Wildfires which raged in October, 2017 in the North of California brought damages in amount of US $ 9 billion. The annual wildfire damage in Russia reaches RUB 20 to 110 billion. Forest fires pose a major problem for the whole world.

Total cost of funds to be spent for the State programme “Forestry Development” in Russia during 2013-2014 was above 12 billion rubles [1], though the area of forest fires has not decreased. The reasons for it are the high complexity, high risks and labour intensity of fighting of wildfires, their vast scale and high dynamics. The vast scales of wildfires and enormous quantities of burning materials are the factors which drastically reduce the efficiency of conventional means of fire-fighting, which are suitable mostly for fighting of confined local fires.

Over 90% of wildfires are creeping fires [1]. Crowning and peat fires are also ignited by creeping fires; that is why the development of new fighting and localization techniques against creeping fires of
different intensity will improve the efficiency of the forest protection system, thus being absolutely urgent matter.

There is a large number methods and technical means of creating artificial fire barriers. Fire barriers are mineralized stripes, fire gaps and barrages, fire trenches, barrier and support stripes. The latter are made during fighting of already burning wildfires. Fighting of wildfires using heavy-duty earth moving machinery is rather common. It is traditionally used for making mineralized stripes. Bulldozers and tractors with ploughs are generally used. However, such machinery requires much energy for operation. More frequent is the use of motor cultivators combined with soil-throwing mounted implements. Engineed tools used by firemen (e.g. petrol-powered chain saws) are intensively exposed to hazardous wildfire factors: a high-temperature environment in working area, smoke and burning particles of inflammable forest materials.

For the fighting of wildfires, fire trucks, petrol-powered pumps, backpack fire-extinguishers, etc. are currently used.

Currently, the most promising and safe means of fire-fighting are the robotic fire-fighting vehicle complexes [2-4]. They let people stay outside the danger area of the fire, thus reducing the hazards of the fire-fighting process.

There are robotic vehicle complexes (hereinafter RVC) of domestic makes, such as MRC “KEDR”, YEL’–4, YEL’–10, RVC “Pelikan”, “Uran-14” and others [5-8]. These are expensive and heavy fire-fighting robots of 3.5 to 20 t weight with bulldozer blades.

Foreign-made fire-fighting robots, such as RXR-M40D-1, Thermite RS1-T2, Magirus TAF 20, FirerobFireremote 4800, JMX-LT50 are mostly similar to the domestic units with the functionality of fire-fighting, removal of fire barricades, reconnaissance of catastrophe area, searching and saving suffering people.

There are no foreign-made multi-agent systems combining interaction of several different robotic vehicles in a single team controlled by a hierarchic multi-agent remote control system.

A creation and introduction of multi-agent RVCs deploying roll fire-protection screens will considerably improve the efficiency of fighting wildfires and drastically reduce death and injury risks of rescue team personnel.

2. Methodology. Substantiation of the fleet of a multi-agent RVC for fighting of wildfires

All known fire-fighting complexes are self-propelled remotely controlled units equipped with different tool sets [2-8]. These are mostly a fire-fighting nozzle, a bulldozer blade, an arm and a winch. When an operation is carried out, the rest of the mounted implements is usually idle. Such principle of RVC architecture will reduce the efficiency of the equipment and lead to a price growth of the RVC.

In the same time, a wildfire is a complex phenomenon efficient fighting with which is only possible by means of an RVC of several robotic vehicles of different specialized functionalities operating together and completing one another.

Another problem of the existing RVCs is the inefficient remote control units, based on industrial joysticks. The input of control commands will divert the operator from visual monitoring of the robot, making him/her look for the required controls on the remote control unit. This reduces the control quality and increases the operator’s fatigue.

Besides, the conventional joysticks are hard to manipulate in conditions of frequent jerks, vibrations and in emergency situations. This will affect the efficiency, the survivability of the RVC, increase the response time and reduce the control quality.

To eliminate the aforesaid drawbacks, a new innovative small-size data input means was developed, an all-purpose HMI including poly-joysticks (left and right), a video mask and a control unit. The uniform control HMI consists of:

- two poly-joysticks (each one with 5 optical mini-sticks);
- a video mask;
- a control system interface unit.
The optical mini-sticks of the poly-joysticks may be used as polymorphous multi-function switches like push-button, toggle switch, selector switch and miniature joystick. The functionality may be changed directly on-line, during the operation, in real time mode.

The use of poly-joysticks provides with reliable tactile control without need to see the controls. The display of the video mask will show pictures from video cams of the robots, visualize the tactical situation, as well as various instruments and switches required for RVC control. The use of a video mask makes it possible to reject bulky monitors which are sensitive to vibrations and jerks.

When fighting against forest fires, the most difficulty represents timber felling and creation of control lines for stopping the fire. For this functionality, the RVC fleet shall utilize a fire-fighting robotic vehicle, a robotic mini-harvester and a robotic trench cutting machine located in two fire-fighting lines (Fig. 1).

![Figure 1. Robotic complex for fighting of wildfires by means of fire-protection roll screens.](image)

The fire-fighting robot (Figure 2) has the functionality of fire-fighting by jets of water or any other extinguishing agent sprayed on the on-fire area edge in the first fire-fighting line.

The fire-fighting robot is equipped by a motor pump, a fire-hose nozzle and detachable extinguishing fluid tanks, as well as an operation mode switch. The fire-fighting robot can operate in the mode of filled fire-hose towing, as well as in the mode of using on-board extinguishing fluid tank. The fire-fighting robot can, on operator’s commands, tank water either from an open basin or from the towed hose.
The robotic mini-harvester and trench cutting machine have the functionality of making mineralized fire barrier stripes in the 2nd fire-fighting line for backfire.

The robotic mini-harvester (Figure 3) is equipped with a tree-falling implement based on a powerful gripper and an electric saw allowing for falling of trees up to 200 mm trunk diameter.

The robotic trench cutting machine (Figure 4) is equipped with a trench-cutting mounted implement. It may be equipped with an appliance for automated setting of roll fire-protection screens into the trench cut (Figure 5).
Figure 5. The robotic trench cutting machine with appliance for automated roll fire-protection screens setting.

The robotic setting of a fire-protection screen along any curved line will be 5 to 10 times faster than by any other methods. Studies by FBU “SPbNIILH” demonstrate [9] that the utilization of quick-set fire-protection screens is much more efficient than any other known methods of retarding and localization of wildfires. The small weight of the fire-protection screen allows for its fast setting, whereas the use of strong fire-resistant materials allows for multiple use of such barriers. The appliance for automated screen setting can also operate in the mode of extraction of the fire-protection screen from the trench and its winding back to a roll after wildfire localization.

All robots of the multi-agent complex are mounted on uniform robotic caterpillar chassis with dimensions of 2400×1400 mm and a weight of 600-700 kg. The robots are equipped with petrol motors and are capable of 8 hours continuous operation without refuelling in the remote control mode.

In accordance with the Rules of Wildfire Fighting [10], the initial action of wildfire fighting is the reconnaissance. The reconnaissance is performed by ground, airborne and/or spacecraft means, in order to clear the wildfire type and proliferation velocity, the wildfire area contours and approximate dimensions, etc.

The most efficient contemporary means of wildfire reconnaissance are air drones (maximum wind speed – 10 meters per second) equipped with conventional cameras, FLIR infra-red cameras or night vision SWIR cameras. That is why the RVC includes an air reconnaissance drone of Phantom 4 Pro type, equipped with a video cam in a 3D servo suspension [11].

3. Results

The localization of wildfires by means of the developed RVC is performed as follows (Figure 1).

Prior to fire-fighting proper, the reconnaissance of the wildfire is made by means of a drone with a video monitoring system and/or monitoring systems of the robotic platforms.

After the reconnaissance, the localization of the wildfire begins by means of making a fire barrier stripe. Preliminarily, along the planned barrier stripe, trees are fallen by the robotic mini-harvester, then the fire barrier stripe is made, by means of the robotic trench cutting machine; if required, a roll fire-protection screen shall be set which can also serve as a fire barrier or a base stripe for backfire launching. While making the barrier or the backfire support stripe, the wildfire is monitored further by means of the drone and the monitoring system of the robotic platforms. The monitoring cam images are transmitted to the mobile command station vehicle from which the drone is controlled, for continuous analysis.

In case of high probability or a reported breakthrough of the barrier stripe by the wildfire edge, the fire-fighting robot is sent to the breakthrough section with a water-jet fire-fighting system for remote fire-extinguishing, in order to eliminate the breakthrough.

The mobile command station includes three off-road vehicles with robot control terminals and work places of the supervisor and the brigadier. The command station is located in a safe distance from the area on fire.

The robotic vehicles are brought to the wildfire area by helicopters or on command vehicle trailers. After unloading, the robots reach their combat areas in self-propelled mode. The multi-purpose robotic
platforms on caterpillar chassis feature high passability and swim capability. That is why the robots can overcome small water barriers and swampy areas in self-propulsion mode.

The trailers of the command vehicles are equipped with telescopic aerials which can reach up to 6 m height. The use of the telescopic aerials can increase the control range of the RVC in forest conditions. In travel position, the telescopic aerials are completely retracted. When in transit, the reconnaissance drone is carried in a command vehicle.

For RVC control, a multi-agent remote control system is used for the first time, with hierarchical architecture with an option of two-level control of the robots, that of the supervisor and that of the brigadier. The multi-agent remote control system allows for interaction of the operators, the brigadier, the supervisor and the elements of the RVC for wildfires fighting, as well as for monitoring of control and data transmission processes.

Brigadier receives fire-fighting task via the internet. Based on the assigned mission, the brigadier gives specific assignments to the robots. The brigadier has a total access control board enabling him/her to interfere with the control process of each robot, as well as to re-assign the control of each robot between control terminals.

The supervisor pilots the drone, monitors the robots and the combat situation in the mission area. The operator of the fire-fighting robot gets assignments by the brigadier and extinguishes fire with the fire-fighting robot. The operators of the robotic mini-harvester and trench cutting machine get assignments from the brigadier for erection of fire-retardant lines to prevent fire proliferation. The mini-harvester operator performs falling of trees and cutting of bushes. The trench cutting machine operator cuts the fire barrier strip preventing fire proliferation or a base strip for backfire launch.

The trailers of the command station feature sleeping places providing for round-the-clock duty of the RVC operators.

For controlling the wildfire-fighting RVC elements, a new uniform control interface is used (Figure 6), based on poly-joysticks and optical mini-sticks [12-18].

![Figure 6. Uniform control HMI (video mask and two poly-joysticks (left) and operator with poly-joysticks (right)).](image)

The use of poly-joysticks provides for reliable tactile control without need to see the controls. The display of the video mask will show pictures from video cams of the robots, visualize the tactical situation, as well as various instruments and switches required for RVC control. The use of a video mask makes it possible to reject bulky monitors which are sensitive to vibrations and jerks.

4. Conclusions and Recommendations

Annually, 200,000 wildfires occur in the world. Based on data by Greenpeace, the annual loss of the forest makes up to 1.47 million hectares or 0.5% of its total area [19, 20]. The economic losses due to wildfires in the USA makes at least US$ 25,000 per forest hectare. In Russia, based on Rosleshoz data, this value makes up to US$1.200 – 1.500 per hectare. If we take the average loss of US$ 13.100 per hectare, then the annual loss from wildfires can be assessed as US$ 19.3 billion. Potentially, this damage
forms a world market of fire-fighting equipment of US$ 1.5-2.0 billion. Thus, the problem of robotic automation of wildfire-fighting is rather urgent and efficient robotic complexes for wildfire-fighting will be in high demand in the markets of all big countries with large forest areas. The use of robotic complexes for fighting of wildfires is very promising. It is expected that a complex is capable of replacing a fire-fighting crew consisting of 40-60 persons. Thereby the firemen can keep up to 2 km distance from the wildfire core without any risk of life [21].

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References

[1] Rosleshoz Federal Forest Management Agency, available at: http://www.rosleshoz.gov.ru
[2] Magirus AirCore TAF20 Datasheet, available at: http://robotrends.ru/images/1549/80463/Magirus_AirCore_TAF20_Datasheet.pdf
[3] MVF-5 Multifunctional, remotely controlled, firefighting robotic vehicle for hazardous environments, available at: http://dok-ing.hr/products/ Firefighting/mvf_5
[4] World's First Purpose Built Robotic Fire Fighting Solution, available at: http://www.roboticfirefighters.com
[5] Fire-fighting robot. KEDR, LUF-60: Spravka 01, Fire safety portal, available at: https://spravka01.pdj/articles/technics/pozharnyj_robot_kedr_luf-60/
[6] Robotic complex RTS YEL’-4 (10), available at: http://fire-truck.ru/pozharnyie-avtomobili/robototechnicheskiy-kompleks-rts-el-4.html
[7] “Pelikan” Fire-Fighting Robot, available at: https://arsenal-sib.ru/pozharnyj_robot/pozharnyj_robot/pelikan/
[8] “Uran” Robotic Complexes: Mission Success Guarantee. National Defence Journal, available at: http://www.oborona.ru/includes/periodics/defense/2015/0526/161615808/detail.shtml
[9] Gusev V G, Yeritsov A M, Stepanov V A and Fomin G Ye 2015 Result of research tests and approval of new fighting technique of creeping fires Tr. of St-Petersburg Scientific Research Institute of Forest Management 2 pp 71-83
[10] Fighting Rules of Wildfires, approved by the Ministry of natural Resources and Ecology of the Russian Federation, available at: http://www.rosleshoz.gov.ru/ activity/forestConserv/docs/21/IV-19_Pravila_tusheniya_lesnyh_pozharov.pdf
[11] DJI Phantom 4 Pro Quadrocopter, available at: https://kvadrokoptery.pro/kvadrokopter-phantom-4-pro/
[12] Nikitin V S and Belov R B, RF Patent No. 2,497,177 (2013)
[13] DMR4I-Ch Digital Optical Mini-stick datasheet, available at: http://www.tenzosensor.ru/images/DMR4I-Ch%20Data%20Sheet.pdf
[14] Golubin S A, Lomanov A N, Nikitin V S and Komarov V M 2015 Experimental research on the performance of optical ministicks with a common receiver Light&Engineering 23 (4) 81
[15] Golubin S A, Lomanov A N, Nikitin V S, Komarov V M and Semenov E I 2016 Experimental study of how lighting patterns affect optical ministicks characteristics Light&Engineering 24 (4) 105
[16] Golubin S A, Lomanov A N, Nikitin V S, Komarov V M and Semenov E I 2016 Study of Characteristics of VCSEL-based Optical Ministicks Light&Engineering 24 (4) 111
[17] Golubin S A 2017 Digital optical mini-sticks based on elastically stressed polymer elements PhD thesis, FGBOU VO Moscow State Technical University named after N E Bauman (national
research university), available at: http://www.dslib.net/vychislitel-texnika/cifrovye-opticheskie-ministiki-na-osnove-uprugodeformuemyh-polimernyh-jelementov.html

[18] PD-002 Poly-joystick Datasheet, available at: http://www.tenzosensor.ru/images/PD-002%20Data%20Sheet.pdf

[19] Nature of Russia: National Portal, available at: http://www.priroda.ru.

[20] Greenpressa: Forest management forum, available at: http://greenpressa.ru/viewtopic.php?f=3&t=1756

[21] Nikitin V S and Belov R B 2017 Robotic automated complex for fighting of wildfires Scientific Manufacturing Enterprise Materials of the XIII Int. scientific and practical Conf. (Robotics vol 3) p 24, available at: http://www.rusnauka.com/books/2017-10-28-A4-tom-3.pdf