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MODIFICATIONS OF THE MOBILE ROBOTIC SYSTEM CRAWLER

ÚPRAVY MOBILNÍHO ROBOTICKÉHO SYSTÉMU CRAWLER

Abstract

The paper describes modifications of an inspection mobile robotic system. Those were carried out in order to increase the functional value of the current mobile robot. Fulfilling the required functions of the current system was evaluated in its functional tests. The acquired parameters of fulfilling the functions were compared with similar existing systems. Next, concepts of solutions for individual robot subsystems were designed and mutually compared. When designing the concepts of the subsystem for image processing from individual cameras, it was necessary to experimentally evaluate the speed of image digitalization by existing video converters. The paper also describes the used methodology of evaluation of image transmission delay from the robot camera to operator's station. The final part of the paper focuses on evaluation of the achieved results and further suggestions for modifications of the robotic system which arose during the performed modifications.

Abstrakt

Článek popisuje provedené úpravy inspekčního mobilního robotického systému. Tyto byly provedeny za účelem zvýšení funkční hodnoty stávajícího mobilního robotu. Plnění požadovaných funkcí stávajícím systémem bylo vyhodnoceno při jeho funkčních testech. Dosažené parametry plnění funkcí byly srovnány s obdobnými realizovanými systémy. Následně byly navrhovány a vzájemně posuzovány koncepty řešení jednotlivých subsystémů robotu. Při sestavování koncepcí subsystému pro zpracování obrazu z kamer bylo nutno experimentálně vyhodnotit rychlost digitalizace obrazu dostupnými video převodníky. V článku je popsána použitá metodika vyhodnocení zpoždění v přenosu obrazu z kamery robotu na stanoviště operátora. V závěru článku je uvedeno zhodnocení dosažených výsledků a další náměty na úpravy robotického systému, které vyvstaly v průběhu realizace úprav.

Keywords

Mobile robot, teleoperator, monitoring, image transmission, control application

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1 INTRODUCTION

There are more and more applications of mobile robots for monitoring and initial surveillance in areas of emergency events. Primarily in armed and security forces, there has been a significant increase in the number of such systems. Service robotics undergoes a tremendous development and interferes into new areas of service activities. The market has more and more producers offering professional as well as hobby solutions of monitoring and surveillance robots [1 - 4]. Such applications of robotic systems are also a subject of university research [5, 6].

The key factor for those robotic systems is the subsystem securing image transmission. Remotely controlled hybrid robot [7] uses a CCD camera for image recording. Its analog signal is then transmitted by an RF transmitter. The operator has an RF receiver and the analog signal is converted to a digital form. The signal is then processed by a web server. Another used way is an RF analog transmission from cameras to the operator's station without digital conversion. The RF transmitter on the robot sends analog signal from cameras. It is received by operator's receiver and the analog signal is then processed by operator's display [8]. This way poses issues with subsequent processing of the image or with inserting additional data or status parameters of the robot (augmented reality). The newest teleoperation system already digitalizes the signal from CCD cameras on operator's side. The transmission between the robot and the operator is ensured by a radio-video transmitter [9].

Remote Surveillance Robot System [10] acquires image from cameras through a web browser. The robot contains a PC with a web server. It receives real-time uploaded image from cameras. The operator accesses the image though a web browser. Robots described in paper Parent-child Robot System for Rescue Missions [11] use Wireless Access Points for wireless transmission. The signal from a USB camera is then processed by robot's computer. The image is sent from the robot to the operator using Wireless Access Points. One-wheel robot from the University of Tokyo records the scene in from of the robot using a CMOS camera. The signal is digitalized by a video server and processed by a computer. The operator receives the processed image through a WLAN [12]. The same principle of processing and transmitting image is used by a teleoperating robot from the University of Japan [13]. A robotic vehicle from the University of India uses a wireless camera with night vision. The camera is equipped with a transmitter and sends the signal to operator's receiver [14]. Another applied way of image transmission is connecting a USB camera into a USB WLAN Access Point. The operator's LAN Access Point is connected to a computer [15]. In order to display the transmitted image from cameras, it is possible to use smart phones or tablets. The signal from the USB camera is processed by a Raspberry Pi which resends it to the operator using a Wi-Fi module. There is an application on the tablet to display the image from the cameras and to control the robot [16].

2 DESCRIPTION OF THE INITIAL STATE OF THE ROBOT

The mobile robot Crawler is designed for initial surveillance in the area of an emergency event. The design and implementation was part of a diploma thesis of a student at the VŠB-TUO at the Department of Robotics. The robotic system had to meet the following requirements:

- image transmission from robot cameras to the operator's station in real time,
- camera head with two degrees of freedom,
- remote control of the robot using a gamepad,
- overcoming a cross-barrier with a min. height of robot wheel radius (80 mm),
- climbing a slope of max. 30°,
- symmetry of axles.

The robot is built on a purchased four-wheel chassis for RC models, where all wheels are driven and independently suspended. The kinematic chassis structure enables good terrain passability. The robot is remotely controlled from operator's box, where the robot is controlled by a gamepad. The wireless transmission of the control signal is ensured by a radio module [17].

The robot's body contains two cameras mounted in the orientation system with two degrees of freedom. The cameras location and their ability of turning in two axes enable to record video of the entire surroundings. The cameras signal is transmitted wirelessly into the operator's box.

The robot is powered by Li-pol rechargeable batteries and its action time is approximately 2 hours. The robot's covers and head for cameras are produced by additive technology FDM (3D printing).

2.1 Mechanical construction

The robot is built on a purchased chassis. This chassis stands out for its good passability and it is suitable for any terrain. The chassis dimensions are: 420 x 210 x 590 mm (width x height x length). The clearance in axle point is 40 mm, wheel diameter 160 mm, wheelbase 420 mm and track 200 mm. Both axles are symmetrical, independently driven and turned. Fig. 1 shows the chassis of the mobile robot before modifications.

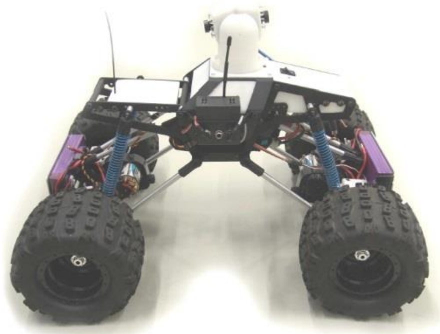

Fig. 1 Chassis of the mobile robot before modifications [17]

2.2 Hardware

The control subsystem contains three modules with microcontrollers ATMEL. Each microcontroller controls one servo and one regulator (for speed control). The third microcontroller also controls camera lighting by LED diodes.

Wireless communication goes on a serial line RS232 using a radio module, which works on frequency of 868 MHz. The signal range given by the producer is up to 6 km. The system uses only the receiver part of the line on the robot's part as the robot does not send any data to the operator through this line.

The robot power supply is ensured by three Li-pol batteries. Each axle carries one battery of 5000 mAh and 7.2 V. The third battery of 4100 mAh and 14.4 V placed on robot's body powers the control and camera subsystem. This divides the control part from the motion one, which prevents voltage fluctuation due to voltage peaks from the motion part. It could negatively influence correct functioning of the control system.

Image recording is ensured by two analog cameras. Camera signals in PAL format are processed by analog radio transmitters with an integrated all-direction aerial. The transmitter works on frequency 2.4 to 2.7835 GHz, wirelessly transmits the signal to operator's station and its range in direct visibility is up to 300 m. The operator's station is equipped with a receiver and the display with an analog input.

2.3 Software

In order to control the robot, a control application for PC was created in Microsoft Visual Studio and written in language Visual Basic. The application communicates with the robot using serial communication.

The robot's part contains three microcontrollers which receive data from a serial line, control camera lighting, and using a PWM control regulators (robot drive), one servo for turning the axles and one servo for turning the orientation cameras system.

2.4 Identified problems of the current solution and objectives of system modifications

When testing the system, the following drawbacks have been identified:

1. The big weight of the battery for power supply of the control unit sensors and communication elements caused overbalancing the robot when turning and the suspension was not able to get the robot into its straight position when returned to a straight movement. Failing to meet the instructions for battery system maintenance, they were irretrievably damaged and had to be replaced.
2. When direct visibility between the robot and the camera signal receivers was lost, there were frequent drop-outs. These image drop-outs were so frequent and long that it was almost impossible to control the robot only by the image from the cameras.
3. The control SW is designed in two programming languages. The SW is difficult to enlarge and the control application is, in fact, uncontrollable without using a gamepad or joystick.

When modifying the robot, the objective was not only to eliminate the problems identified during testing, but its modernization using currently available components as well.

Objectives set for robot modification:

1. To decrease robot's body weight, to move the center of gravity.
2. To eliminate camera signal drop-outs.
3. To design a produce covers for electronics.
4. To replace of the damaged components.
5. To unify the SW into one programming language.

3 IMPLEMENTED SYSTEM MODIFICATIONS

Based on the performed analyses and identified system drawbacks during functional tests, implementation of the below-described modifications has been carried out.

3.1 Decrease of robot body weight

In order to decrease robot body weight and having considered other possibilities, it was decided to remove the battery for power supply of the electronics, which was mounted in the central part of the robot.

The current version of the robot powers all the performance parts by one battery and the second battery powers all the remaining components. There will be a drop in the maximum run time to a half, but laboratory measurements showed that the run time would not drop below one hour, which can be considered satisfactory with respect to the anticipated use of the robot. Laboratory tests also provided the minimum capacity and current consumption which must be provided by the batteries. Considering those parameters and the minimum weight, we used for the performance part a Li-pol battery, which provided voltage 7.4 V at 5 700 mAh and weight 150 g. The connection scheme is depicted in Fig. 2.

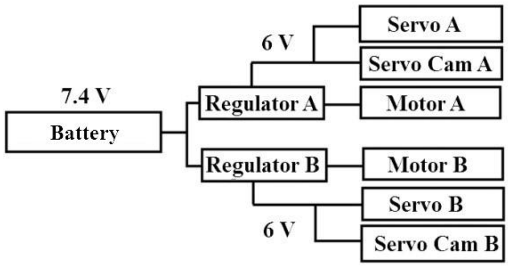

Fig. 2 Power supply of the performance part

In order to power the control part and cameras, the same way of selection was used for battery, which provides voltage 14.8 V at capacity 4 200 mAh and weight 381 g. The connection scheme remains the same as for the original variant.

Both batteries will be mounted on robot axles. Each axis has a mounting place with cover for the battery. New batteries lower the chassis weight by 0.4 kg. Important is that the weight of the original heaviest battery, mounted on robot suspended body, was moved to robot axle.

Further tests showed that when turning, the robot body tilted only a bit and suspension springs managed to return the robot into an almost upright position when moving straight again.

Removing batteries from the suspended chassis part of the robot and changing the batteries on robots axles brought the decrease in the weight and significantly eliminated the problem with tilting the robot’s body when turning.

3.2 Digital image transmission

The used analog wireless image transmission showed to be unstable for robot control in real time using robot camera images. One of solutions of this problem is image digitalization and its transmission by a Wi-Fi router. Image transmission from two analog cameras at the same time requires two video encoders, a switch, and a Wi-Fi router, as depicted in Fig. 3.

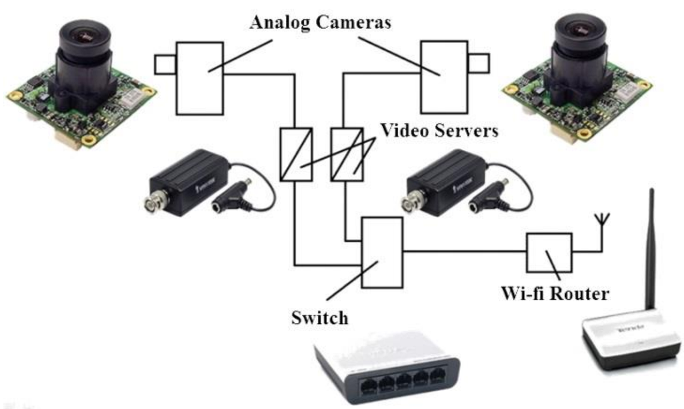

Fig. 3 Image digitalization

Hardware components for implementation of camera image transmission to operator's station were selected with respect to the minimum values of parameters as weight, dimensions, current consumption, voltage, and price. The selected components are:

- analog camera,
- Wi-Fi router,
- video encoder,
- switch.

Before implementation of the new camera subsystem, it was necessary to find out the delay time of the camera signal because producers of video encoders do not provide the analog-to-digital conversion time. A too long delay would hamper effective control of the robot in real time using camera image.

The delay time of camera signal transmission was found out experimentally. The connection scheme of the experiment is depicted in Fig. 4.

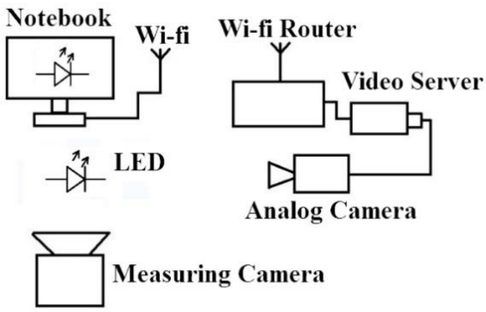

Fig. 4 Principle of measuring the camera signal

The video encoder receives the signal from an analog board camera. The Ethernet output from the video server is connected to a Wi-Fi router, which wirelessly sends data to a notebook. In order to assess the image transmission delay, a simple methodology was used. The methodology takes its base from the known time interval between individual video frames. The time interval between the frames is the parameter of the used measuring camera. This camera records a video from the camera images displayed on a monitor and a LED diode. The LED diode turns on and off in predefined intervals. Thus, the image transmission delay is the time interval between the diode turn-on in front of the camera and the turn-on of the diode on the monitor. The video recording from the camera is divided to individual frames using program Free Video to JPG Converter. According to the length of the video and the number of the frames, the time between the frames is calculated.

$$t_s = \frac{t_v}{(n_c - 1)}, \quad (1)$$

where:

t_s – time between frames $[\mathrm{s}]$,

t_v – length of the video $[\mathrm{s}]$,

n_c – total number of frames $[-]$.

Knowing the time between the frames, frames can be viewed one by one and when the LED diode on the camera lights up, the number of the frames until the LED diode lights up on the monitor is counted. The number of the frames is then multiplied by the time between the frames and the camera image transmission delay is then calculated.

$$t_z = t_s \cdot n_s, \qquad (2)$$

where:

t_z – camera transmission delay time $[\mathrm{s}]$,

t_s – time between the frames $[\mathrm{s}]$,

n_s – number of frames $[-]$.

The used camera for measuring the delays measures with accuracy of ± 0.03 s. The experiment revealed that the delay is 0.33 s. When testing the robot control, the delay time was satisfactory for performing all required functions of the robot. The digital image transmission was stable and there was not a single signal drop-out during testing.

3.3 Change of shock absorbers and elimination of further mechanical damage of the robot

The change of the shock absorbers increased axles' hardness. New shock absorbers are shorter, but their overall construction is much harder and more rigid than of the original ones. The absorbers have configurable stiffness.

When testing, higher stiffness of the shock absorbers proved to be necessary as it completely eliminated the problem with a slight deviance in the chassis tilting on the suspended part from the initial position after turning.

Individual HW components had to be suitable for mounting on the robot. With respect to a limited mounting area on the robot body, a CAD system was used to design covers and fixtures of individual components on the robot body, as depicted in Fig. 5. Covers and fixtures of components for image transmission were designed with respect to the use of additive technology FDM (3D printing).

This solution exists only in a 3D model for now and has not been implemented yet. Additional HW components and their covering will increase the weight of the chassis by approximately 0.5 kg. It will probably be necessary to adjust stiffness of the shock absorbers after this modification.

In order to prevent further mechanical damage, it was decided to prepare a sensory subsystem with ultrasound sensors to detect obstacles in robot surroundings. This modification of the system requiring significant changes in the control software is ready for next period and it is not integrated in the currently implemented modifications.

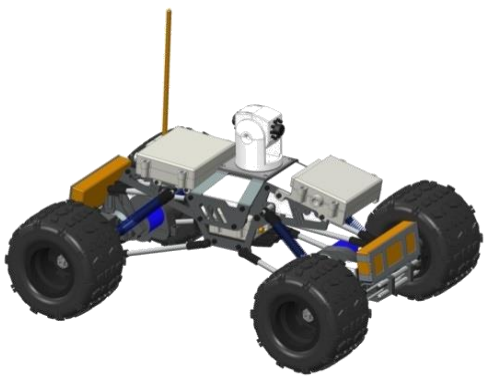

Fig. 5 Covers of component for camera image signal transmission

3.4 Change of the robot control subsystem

The original robot control subsystem was based on microprocessors Atmel. For easier implementation of sensors which would extend robot functionality those microprocessors will be replaced with a single Netduino 2 Plus. The Netduino 2 Plus has small dimensions, low weight, supports serial communication on UART and contains a sufficient number of input/output ports for communication with sensors and the rest of the robot.

In order to control robot Crawler, it is necessary to control 4 digital outputs for camera lighting, receive serial communication signals from radio module and generate 6 PWM signals for 6 motors (two servos for axle turning, two servos for turning the orientation camera system, two regulators to control drive motors, which are also controlled as a regular servo using a PWM signal).

Due to the need to generate a higher number of PWM signals, it was decided to use Servo controller. This unit allows to control up to 12 servos and communicates using serial communication. The Netduino 2 Plus will communicate through one serial communication with the radio module and through the second serial communication with the Servo controller it will control robot drives.

The code for Netduino 2 is written in C#. Packets with commands for all positions, velocities and LED lighting are sent from the operator PC every 20 ms via a radio communication line. Every accepted packet on Netduino raises and event which performs data checking. Checked is length of the packet and starting and ending byte. Wrong packets are ignored; correct packets are processed to get the individual values. Values for required LED lighting are set to digital outputs of Netduino. Motors are controlled by a Servo controller which get commands by a second serial line. If no valid packet form the operator PC is received during 1 second, a watchdog is activated and all motors are stopped.

The connection of the control subsystem both on the operator and mobile robot CRAWLER side is depicted on Fig. 6.

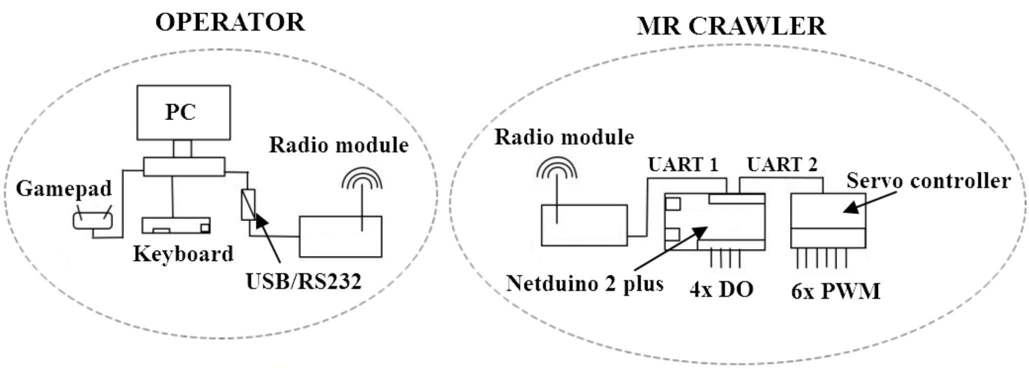

Fig. 6 Scheme of signal transmission

Having written the program for Netduino 2 Plus, the whole connection was tested and its functionality was proved. Tested was control of all motors and LED lighting by gamepad, joystick, keyboard and mouse. Fig. 7 shows the testing of the control subsystem. Implementation of robot Crawler required modifications in chassis covers with new elements and adjustment of the energy system in a way that it would be able to power all the used components at the required voltage.

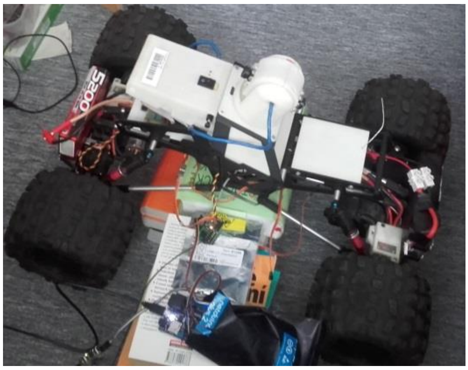

Fig. 7 Testing of the control subsystem

3.5 Modification of the control application

The original control application for the PC operator was written in Visual Basic and it was necessary to replace it. The main reason was that it did not enable to control the robot using a keyboard, which would prevent using the robot in the case of gamepad failure (e.g. discharged batteries).

The new application is written in C#. The application can be controlled using a keyboard, gamepad, joystick, or a mouse. The USB port only requires a USB/RS232 converter as the radio module communicates through RS232 bus. Fig. 8 shows the view of the user interface of the PC operator's control application.

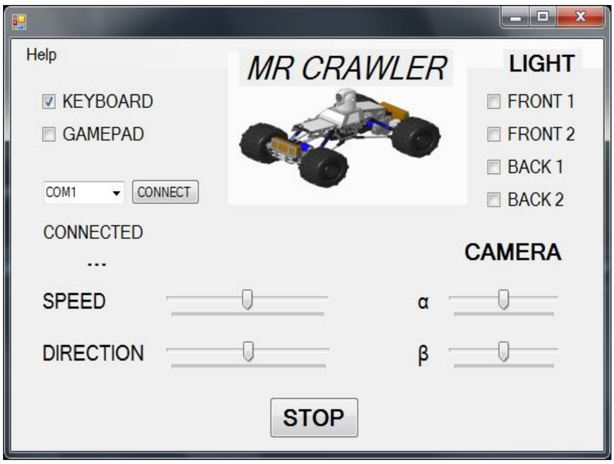

Fig. 8 View of the user interface of the PC operator's control application

4 CONCLUSIONS

The inspection mobile robot marked as Crawler was built in 2009 as part of a diploma thesis. It is designed for initial surveillance in areas of emergency events. When testing its functionality, there were identified several problems in fulfilling the required functions. It was necessary to solve robot chassis tilting influenced by the position of the center of gravity. It was also necessary to modify the image transmission subsystem due to frequent drop-outs, which in certain situations hampered robot's control by camera image in real time. The need to increase the system functionality led to a complete substitution of the control subsystem containing microcontrollers Atmel with newly created control application for the PC operator.

Having determined the objectives of robot modernization, modifications were initialized. First, one battery was removed and shock absorbers were replaced. These modifications successfully solved problems with chassis tilting when turning. Additional HW components and their covering will increase the weight of the chassis by approximately 0.5 kg. It will probably be necessary to adjust stiffness of the shock absorbers after this modification. Next, the analog wireless signal transmission was replaced by a digital one. The digital transmission was experimentally tested for the delay of the transmitted video at the operator's station. The delay is 0.33 s, which is satisfactory for the control of Crawler. The two main differences between the previous analog and new digital image transmission are stability and lag. Analog transmission caused frequent drop-outs, which made remote control of the robot in real time almost impossible. Lag was however non-perceptible. Digital transmission is completely stable, but there is a noticeable lag. It is difficult to specify an acceptable value of image lag for a given application. It is thus necessary to make practical tests.

The control subsystem was also modified with the use of Netduino 2 Plus and Servo controller. New hardware components were added with new mounting and covers on the chassis. The new control system allows simple connection of additional sensors. Just a common USB cable is needed to upload new programme from PC to the robot, while the previous solution with Atmel microcontroller required a special programming HW. Next, the control application for the PC operator and the SW for the robot were rewritten to programming language C#. Testing proved functionality of the control subsystem and the created SW applications.

The robot will be later extended with a sensory subsystem for monitoring of the batteries status and collision prevention. Covers will also be extended and the position of batteries optimized. The stated modifications are subject to further research under the project of students' grant competition 2016 and they are currently in progress.

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REFERENCES

[1] ECA Robotics. *NIDES* [online]. Brno: NIDES, 2015 [cit. 2016-07-06]. Available at: http://www.nides.cz/eca-robotics/

[2] I SPY TANK WHITE. *I SPY TANK* [online]. Sweden: I SPY TANK, 2015 [cit. 2016-07-12]. Available at: http://ispytank.com/index.php/i-spy-tank-white.html

[3] 4WD Enclosed Robot with Scissor Lift and PTZ Camera. *RobotShop* [online]. Canada: RobotShop, 2016 [cit. 2016-07-12]. Available at: http://www.robotshop.com/en/4wd-enclosed-robot-scissor-lift-ptz-camera.html

[4] Inspectorbots 4WD FPV Spider Mite Robot. *RobotShop* [online]. Canada: RobotShop, 2016 [cit. 2016-07-12]. Available at: http://www.robotshop.com/en/inspectorbots-4wd-fpv-spider-mite-robot.html

[5] Inspekční pyrotechnický robot – nasazuje život za nás. *CAD* [online]. Brno: CAD, 2014 [cit. 2016-07-06]. Available at: http://www.cad.cz/strojirenstvi/38-strojirenstvi/2248-inspekcni-pyrotechnicky-robot-nasazuje-zivot-za-nas.html

[6] Mobile Robot SUMMIT XL. *Robotnik* [online]. Spain: Robotnik, 2015 [cit. 2016-07-06]. Available at: http://www.robotnik.eu/mobile-robots/summit-xl/

[7] Citace: C. h. Kuo et al., "Remote Control Based Hybrid-Structure Robot Design for Home Security Applications," 2006 IEEE/RSJ International Conference on Intelligent Robots and

Systems, Beijing, 2006, pp. 4484-4489. doi: 10.1109/IROS.2006.282085

[8] R. J. Schultz, R. Nakajima and J. Nomura, "Telepresence mobile robot for security applications," *Industrial Electronics, Control and Instrumentation, 1991. Proceedings. IECON '91., 1991 International Conference on*, Kobe, 1991, pp. 1063-1066 vol.2. doi: 10.1109/IECON.1991.239144

[9] Naoji Shiroma, Ryo Miyauchi and Fumitoshi Matsuno, "Mobile robot teleoperation through virtual robot," *RO-MAN 2008 - The 17th IEEE International Symposium on Robot and Human Interactive Communication*, Munich, 2008, pp. 477-482. doi: 10.1109/ROMAN.2008.4600712

[10] A. Sundaram, M. Gupta, V. Rathod and K. Chandrasekaran, "Remote Surveillance Robot System -- A Robust Framework Using Cloud," *2015 IEEE International Symposium on Nanoelectronic and Information Systems*, Indore, 2015, pp. 213-218. doi: 10.1109/iNIS.2015.47

[11] Y. Yang, G. Xu, X. Wu, H. Feng and Y. Xu, "Parent-child robot system for rescue missions," *Robotics and Biomimetics (ROBIO), 2009 IEEE International Conference on*, Guilin, 2009, pp. 1427-1432. doi: 10.1109/ROBIO.2009.5420753

[12] Hideo Sato, K. Kawabata, Tsuyoshi Suzuki, Hayato Kaetsu, Y. Hada and Yoshito Tobe, "Information gathering by wireless camera node with passive pendulum mechanism," *Control, Automation and Systems, 2008. ICCAS 2008. International Conference on*, Seoul, 2008, pp. 137-140. doi: 10.1109/ICCAS.2008.4694539

[13] H. Sato, K. Kawabata, T. Yugo, H. Kaetsu and T. Suzuki, "Wireless camera nodes deployment by a teleoperated mobile robot for construction of sensor network," *ICCAS-SICE, 2009*, Fukuoka, 2009, pp. 3726-3730.

[14] J. Patoliya, H. Mehta and H. Patel, "Arduino controlled war field spy robot using night vision wireless camera and Android application," *2015 5th Nirma University International Conference on Engineering (NUiCONE)*, Ahmedabad, 2015, pp. 1-5. doi: 10.1109/NUICONE.2015.7449624

[15] Gossaye Mekonnen, Sanjeev Kumar, P.M. Pathak, Wireless hybrid visual servoing of omnidirectional wheeled mobile robots, Robotics and Autonomous Systems, Volume 75, Part B, January 2016, pp. 450-462, ISSN 0921-8890, http://dx.doi.org/10.1016/j.robot.2015.08.008.

[16] Sefer Şener, Ercan Sarıdoğan, Selva Staub, Gonca Ersahin, Herman Sedef, World Conference on Technology, Innovation and EntrepreneurshipWireless Mobile Robot Control With Tablet Computer, Procedia - Social and Behavioral Sciences, Volume 195, 2015, pp. 2874-2882, ISSN 1877-0428, http://dx.doi.org/10.1016/j.sbspro.2015.06.411.

[17] JAN, Káňa. Výběr/úprava mobilního podvozku pro prvotní průzkum oblasti mimořádné události [online]. Ostrava, 2009 [cit. 2016.7.06]. Available at: http://hdl.handle.net/10084/76297. Diploma thesis. Vysoká škola báňská - Technická univerzita Ostrava. Faculty of Mechanical Engineering.