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Remote Control of a Mobile Robot for Inspection and Engineering Work in Ductwork

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Abstract. Inspection and engineering work inside ducts are a serious challenge in terms of logistics and processing. Processing-wise, a major obstacle is the remote control over a modular mobile unit with a variable cinematic configuration and intended to manage complex operating processes. This paper presents the results of the development of a mobile robot for inspection and engineering work. The items of a specific focus of the development work were the remote-control system structure and the control algorithms for the propulsion module control and the operating module control.
Keywords: automation, robotics, mobile robot, ductwork, control, optical fibre pulling

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1. INTRODUCTION

The use of remote-controlled mobile robots for inspection and engineering work inside ductwork is not a novel idea. Designs of this type have multiple examples discussed in reference sources [1]. During the execution of an EU-funded project commissioned by KARTEL s.c. (Warsaw, Poland), the Military University of Technology in Warsaw (Poland) developed a modular mobile robot intended for the inspection and repair of ductwork and installation (pulling) of optical cabling inside ductwork. The project requirement decisive to the shape and design of individual robot modules and remote control was the inner diameter range of ductwork for the robot to work in. KARTEL s.c. specified that the mobile robot should be capable of operation in ductwork with an inner diameter ranging between 200 and 800 mm, and with a maximum ductwork ingress length of 100 m. The specified requirements for the ductwork diameter, especially those of 200 mm, were critical to the development of the mobile robot solutions. The necessity of placing the power supply, data communication and remote control modules onboard the mobile robot simultaneous with the necessary reconfigurability of robot modules (by swapping the inspection module with the operating module and vice versa) forced the development of a distributed data communication and remote control structure. The solution thus developed was divided into several independent modules the design engineering processes of which could go forward independently; the only requirement at this stage was to assure continuous data transmission and power supply [2].

Fig. 1. 3D and physical models of the propulsion module

Given the remote control and multi-role capability (inspection, repair, and installation/pulling of optical cables) of the mobile robot design, the following functional modules were classified:

- propulsion module
- operating module
- power supply & data communication module
- software module

The carrier deck module was not included in the foregoing list due to its passive role in the mobile robot performance [4].

Due to a specific processing method carried out by the inspection and engineering mobile robot inside ductwork, the retention of correct processing parameters was important to the mission of the mobile robot. For the process of optical cable preparation and installation (pulling) in the ductwork, the mandatory key parameters of the remote control system included a correct control sequence of the actuation components (the motor of the propulsion module and the operating module reconfiguration servos) and the duration of individual operations done by the mobile robot.

2. STRUCTURE OF THE POWER SUPPLY, DATA COMMUNICATION AND REMOTE-CONTROL SYSTEM OF THE MOBILE ROBOT MODULES

As highlighted in the Introduction, the mobile robot solution adopted a distributed remote-control system structure. The entire mobile robot and its additional power supply modules are fed from 2300 V / 50 Hz mains and a compressed air unit which provides the correct pressure required by the operating specifications of the actuators installed aboard the propulsion and operating modules. From the perspective of an operator of the mobile robot, the primary component of the mobile robot system is the operator's control desk with the software intended for superordinate (master priority) remote control over the mobile robot and the modules installed onboard. The control desk is connected to a junction box with an Ethernet cable. The primary use of the junction box is to provide power supply and data communication for the propulsion module. Key:

- K1 – Junction box 230 V AC cable
- K2 – 230 V AC + DATA cable
- K3 – Operating module 230 V AC cable
- K4 – Operating module power and data cable
- K_eth – Control desk data cable with an Ethernet RJ45 port at the control desk
- SR ZK1 – Cable K1 port at the junction box
- SR ZK_eth – Cable K_eth (control desk data cable) at the junction box
- SR ZK2 – Cable K2 port at the junction box
- SR ZK2 – Cable K2 port at the propulsion module
- SR ZK3 – Cable K3 port at the propulsion module
- SR ZK4 – Cable K4 port at the propulsion module
- SR ZK3 – Cable K3 port at the operating module
- SR ZK4 – Cable K4 port at the operating module

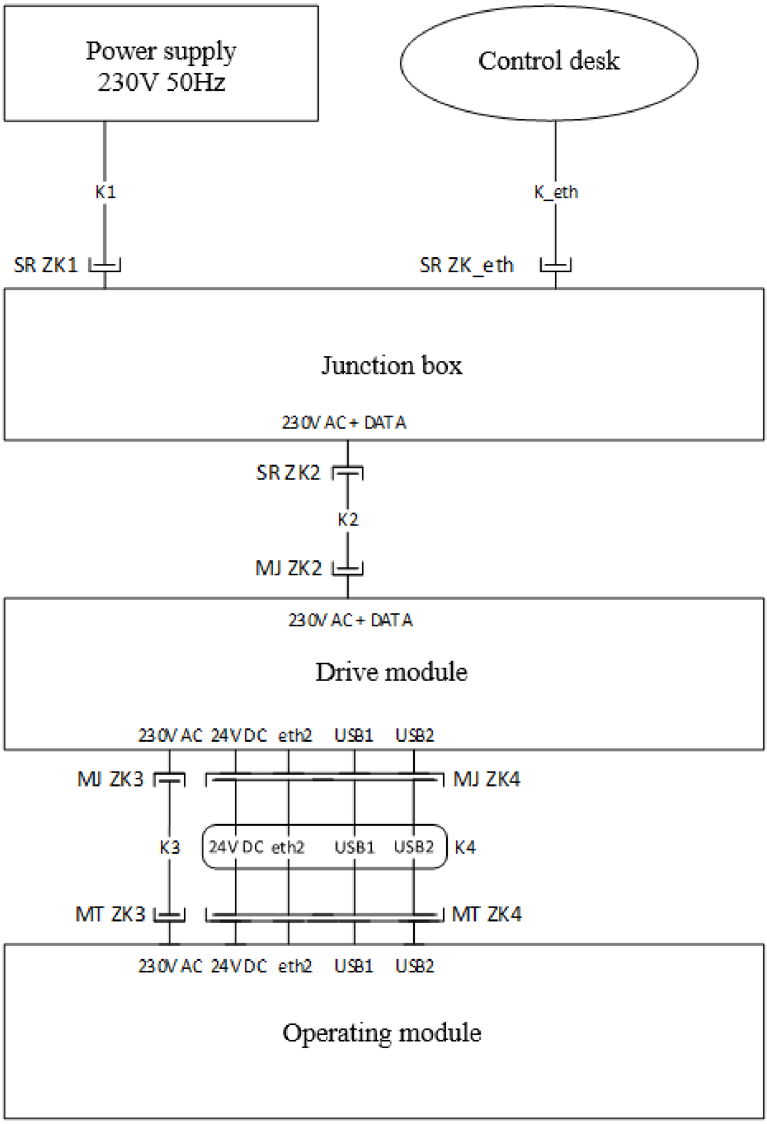

Fig. 2. Interconnection diagram of the mobile robot system modules

The data communication exchange between the junction box and the propulsion module is based on PoE, which minimised the number of data cables.

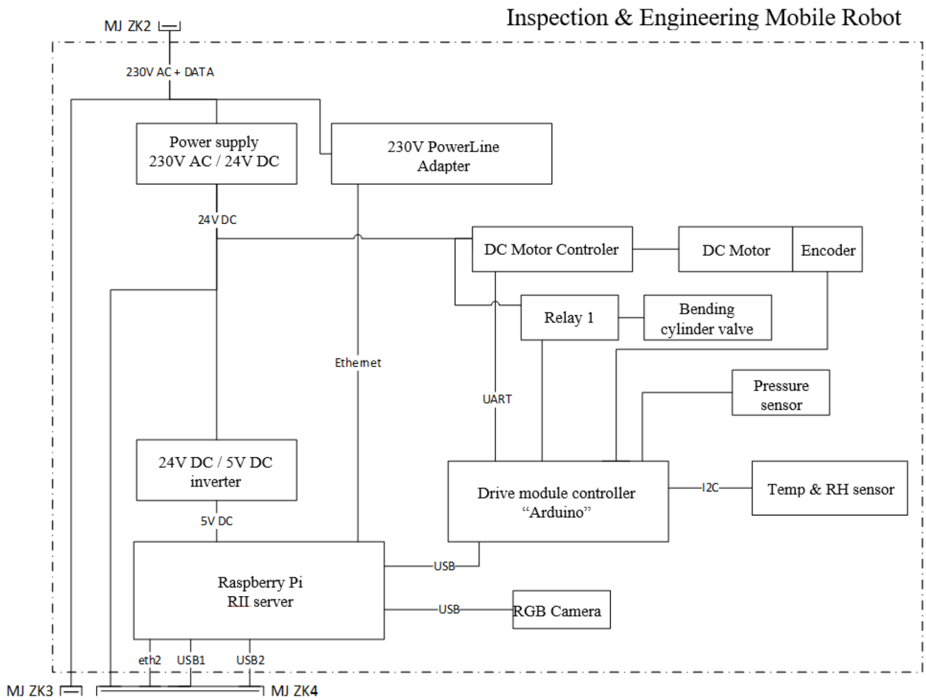

Fig. 3. Diagram of the propulsion module

The IER (*Inspection and Engineering mobile Robot*) server in the propulsion module structure and based on a Raspberry Pi microcomputer handles data communication between the control desk and the propulsion module and between the propulsion module and the operating module [3]. The pre-installed USB ports of Raspberry Pi were used to install a fish-eye video camera on the propulsion module. The video camera can support inspection in its basic operating mode. The propulsion module controller is based on an Arduino microchip controller and manages the propulsion motor control and the control over the positioning valves of the actuators installed in the propulsion module. The Arduino propulsion module controller collects the data from the sensors installed aboard the propulsion module.

For the operating module, the number of controlled components is much higher than in the propulsion module. This is a result of the number of functions handled by the operating module.

According to the project design conditions, the operating module software is required to handle the operating process of preparation and adhesive bonding of HDPE tubes to the top inner surface of ductwork. This operating process requires a specific control strategy of the operating module components. The process is handled automatically and requires no intervention of the operator, whose task is limited to launching the process in the control desk application.

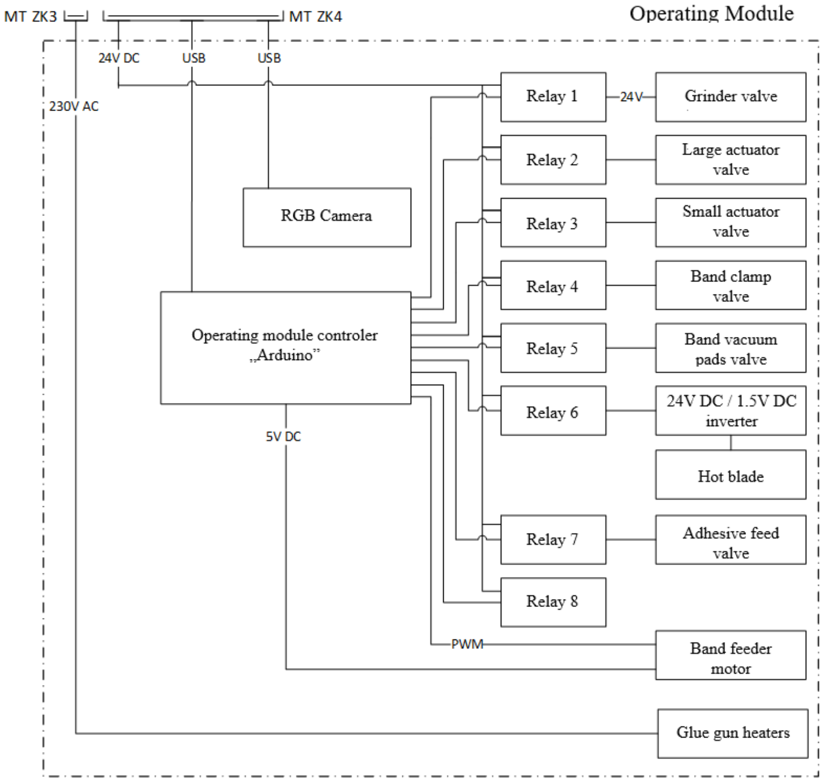

Fig. 4. Diagram of the operating module area

The following cyclogram depicts the operating process of a single fastening installation handled by the operating module:

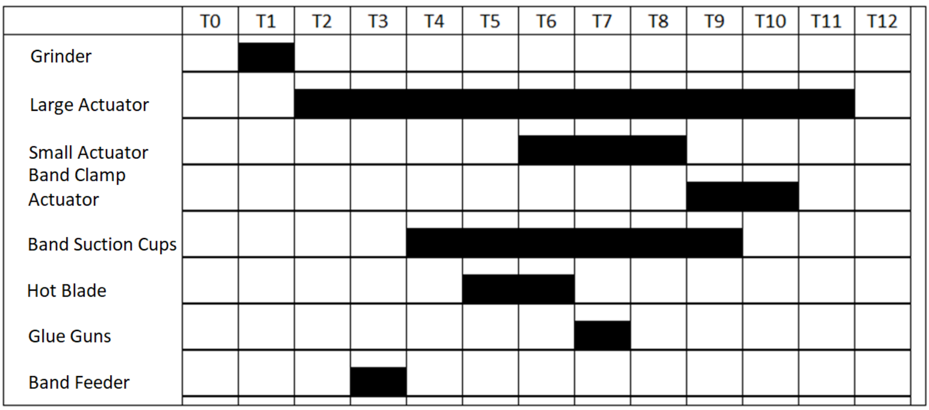

Fig. 5. Operating process cyclogram

Key to the cycles:

- T1: Surface cleaning
- T2: Large cylinder withdrawn
- T3: Band fed to the shoe
- T4: Band held on the shoe
- T5: Hot blade powered on
- T6: Small cylinder extended
- T7: Glue applied on the band + hot blade powered off
- T8: Small cylinder withdrawn
- T9: Band clamp cylinder extended
- T10: Band hold disabled
- T11: Band clamp cylinder withdrawn
- T12: Large cylinder extended

The first step is to achieve the required system parameters. The system receives compressed air which switches the individual parts of components to their home positions. The supply voltage is switched on for the modules which heat the glue to the processing temperature. Once the mobile robot is in the operating position, the grinding disc is placed in the operating position and cleans the pipe surface (to prepare it for the installation process).

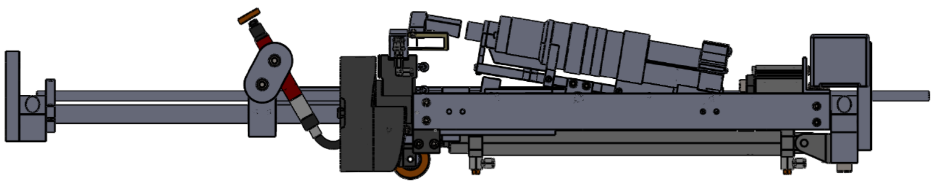

Fig. 6. Positioning of the operating module components in position for cleaning the ductwork surface.

Once the surface is clean, the next step begins by moving the glue module to the installation standby position, followed by feeding out a stretch of the band, which is then held over the shoe and cut to length with the hot blade. The third step is to move the glue feeding and application subsystem into position. Next, the glue feeding subsystem is withdrawn, and the HDPE tube holder is clamped down. Finally, the band clamp is released, and the large cylinder positions the operating module home.

The onboard operating system of the inspection and engineering mobile robot features an application dedicated to managing the status data collected from the Arduino actuation modules which are located in:

- the propulsion module (PM) of the mobile robot;
- the operating module (OM);

and the control data transmitted from the control desk (CD). The application associates the data exchanged with the CD with the data exchanged between the Arduino actuation modules.

3. REMOTE CONTROL SOFTWARE: THE CONTROL DESK

The remote-control software installed on the control desk is a GUI (*Graphical User Interface*) by which the operator controls the mobile robot. With the remote-control software, the operator can issue commands to the mobile robot, and monitor the video camera feed from the mobile robot's propulsion or operating module (depending on the actual configuration). The operator can archive the data incoming from the installation process by saving the still frames from the video camera feed to a file path specified in the application [5].

The software module developed to handle the data communication and remote control of the inspection and engineering mobile robot provides:

- reliable and fail-safe transmission of binary and bit-stream control data to the robot and the reception of binary and bit-stream monitoring data from the robot;
- reliable and fail-safe transmission of binary and bit-stream control data to the robot winch controller (RWC) and the reception of binary and bit-stream monitoring data from the RWC;
- automatic indication of data communication session initiation (over TCP) and communication link losses independent from the data exchange between CD and IER and between CD and RWC;
- reception of two video feeds transmitted by IER at a minimum resolution of 1024x768;
- visualisation of the video feed and numerical data transmitted by IER;
- saving of the numerical data transmitted by IER to text files and video feed still frames to graphic files in response to triggers generated automatically by the IER software or manually by the CD operator;
- editing and visualisation of the data transmitted to IER;
- visualisation of the numerical data transmitted by RWC;
- editing and visualisation of the data transmitted to RWC.

The exchange of numerical control and monitoring data (and the video feed data), and the automatic indication of communication session initiation and communication link loss were developed as processes independent from the GUI layer of input control commands and the monitoring data of actual statuses of IER and RWC.

The data communication layer of the software module features a mechanism for sharing of the numerical monitoring data received from IER to the GUI layer software.

The data communication layer of the software module features a mechanism for editing the control data sent from IER and the control over the client-server connection for the GUI layer software.

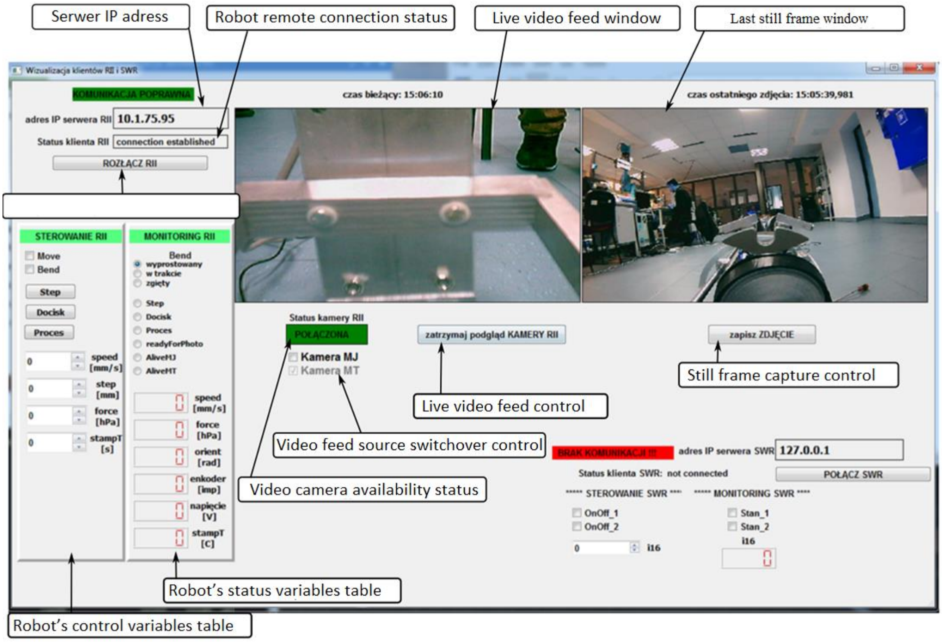

Fig. 7. Individual components of the GUI

4. CONCLUSIONS

The development of the inspection and engineering robot (IER) dedicated for the preparation and pulling of ELV cable systems (in the form of optical cables) and furnished with a distributed remote-control system ensured a modular structure of the mobile robot system. The replacement of the inspection module (which will ultimately feature an advanced opto-electronic module) with an operating module (a repair module or optical cable installation module) is fast and trouble-free and requires no additional configuration of the mobile robot system.

The application developed for the control console provides full control over the functionalities of the mobile robot and archiving of the mobile robot work performance – which is especially important for the project owner (KARTEL s.c.), a commercial contractor for optical cable installation services for end customers. The application of local control systems for the management of operation of the individual mobile robot modules enables simple diagnostics and troubleshooting of the modules.

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Sterowanie robotem mobilnym do prac inspekcyjno-inżynieryjnych w przewodach kanalizacyjnych

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Streszczenie: Realizacja prac inspekcyjno-inżynieryjnych w przewodach kanalizacyjnych stanowi poważne wyzwanie logistyczne jak i technologiczne. W aspekcie technologicznym znaczącym utrudnieniem jest sterowanie urządzeniem modułowym, o zmiennej konfiguracji kinematycznej, realizującym złożone procesy technologiczne. W artykule przedstawiono wyniki prac polegających na opracowaniu modelu robota mobilnego do prac inspekcyjno-inżynieryjnych ze szczególnym uwzględnieniem struktury systemu sterowania oraz algorytmów sterujących, odpowiadających za realizację procesu sterowania modułem jezdnym i modułem technologicznym.

Słowa kluczowe: robotyka, automatyka, robot mobilny, przewody kanalizacyjne, sterowanie, układanie światłowodów