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MULTI-ROBOT GROUP FOR INSPECTING LARGE AREA OBJECTS

Key words

Multi-robot group, autonomous mobile robot, inspection, behaviour-based control system.

Summary

The paper deals with concepts and an implementation of a multi-robot group that is capable of inspecting large areas of technical objects. With the group of autonomous robots it is possible to register video images and the values of characteristic quantities (temperature, concentration of any gas etc.) in the open area of the technical object. Robots are able to travel to any place of the inspected area and acquire relevant data, which could be sent to the control unit to allow its careful examination by the experienced human operator. The group of robots consists of one autonomous transport robot and four autonomous inspection robots. In this paper, primary systems of robots (e.g. control, detection, communication, and self-localisation systems) and their functioning are briefly described.

Introduction

Recent technical systems are increasingly complex. In the same time, there are numerous hazards that may affect the operation of these systems. Large-area objects such as airfields, open-air stores, country borders, drink water bodies, and many others, can require the supervising of their vital functions. This supervision can include intrusion and the presence of unauthorised persons, detecting leakage of fuels, harmful gases, fire hazards, etc. To allow supervision of these objects, mobile robots are even more and more frequently used.

The paper deals with a project whose goal has been to develop a prototype group of mobile robots capable of carrying out flexible supervision tasks. The main idea consists in sharing tasks among different members of the group. There are two distinct classes of robots: a transport robot and robots-scouts that are flexible enough to carry out different supervision tasks. In order to give an overview of the complex work, the paper is composed of the following: In the next section the research problem is formulated. Then several conceptions are presented. Section 3 deals with the implementation of chosen conceptions, taking into consideration mechanical carriers of the robot types, the architectures of control systems, a communication system, and a system of the self-location of the group. The paper ends with conclusions.

1. Research problem

The main problem addressed by this project was to build non-commercial prototypes of robots that are capable of inspecting large areas of technical objects. A group of robots consists of one autonomous transport robot and four autonomous inspection robots. Inspection robots are transported to the workplace with the use of an autonomous transport robot. Next, the small robot makes an inspection. The group of robots should allow substituting traditional human patrol groups during the inspection of technical objects, especially in such places and situations where the operation of humans is dangerous, arduous or even impossible [4].

The main problem was to ensure that robots will be capable of operating in various terrain and weather conditions. The group of robots should be able to keep mobility during movement on snow, mud, gravel, sand, tarmac, grass, etc. Moreover, the robot should be able to operate on rainy days and in a wide range of ambient temperatures (-20^{O}C ÷ +50^{O}C). Main requirements for transport and inspection robots are contained in Table 1.

Table 1. Main requirements for transport and inspection robots

Requirement	Transport robot	Inspection robots
Minimal velocity (during rectilin-ear movement)	1 m/s	0,1 m/s
Ability to movement on slope	min. 15%	min. 20%,
Minimal time of autonomous running	2 h	0,3 h in case of continuous running and 4 h in case of interrupted one
Minimal useful lifting capacity of platform	200 N	10 N
Maximal mass	not defined	5 kg

The other problems addressed within this project concerned the elaboration of some important systems: a detection system to assure autonomous operation in unknown environment, a communication system between the robots and the user, and a self-localisation system during a mission.

2. Development of conceptions

The research group made an attempt at the analysis of some important issues. The following issues are analysed: the type of drive, the type of power supply, the method of positioning in unknown environment, and the selection of necessary electronic components. Many conceptions of transport and inspection robots were formulated.

Based on the brief pre-design requirements and the analysis of the specified problems, 6 conceptions of transport robot were formulated (Fig. 1). The conceptions [7] are characterised by a high level of shape generalities. The common features of all conceptions are a wheel chassis, the type of electric motors, reserved space for inspection robots, the size and kind of wheels, the arrangement of batteries, etc. The main differences between the conceptions consist in numbers of wheels, the placement of inspection robots (top or middle part of the main body), the arrangement of incursion platform for the inspection robots, the placement of engines and batteries, the method of transferring propulsion into wheels, etc. All the conceptions were carefully evaluated using the respective system of criteria. The conception t-6 was accepted as an optimal conception and then further developed.

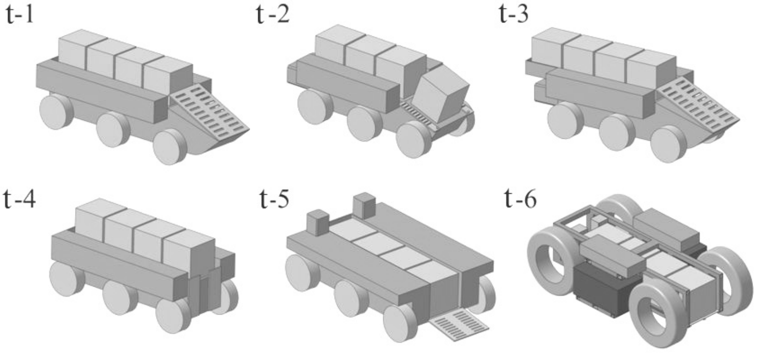

Fig. 1. Six design conceptions of the autonomous transport robot [7]

Based on the brief pre-design and analysis specified problems, 10 conceptions of inspection robots were formulated (Fig. 2). The differences between conceptions are the following, among other things: the type of drive (caterpillar, wheels), the type of motors (DC, stepper), the type of chassis (sectional, non-sectional), the arrangement of wheels and motors, the size of wheels, and the arrangement of batteries. All the conceptions were carefully evaluated using respective systems of criteria. The conception k-3 was selected as an optimal conception to final realisation.

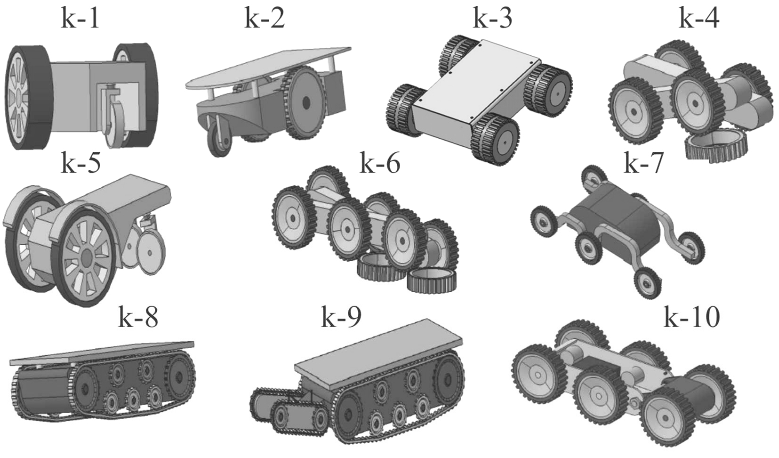

Fig. 2. Concepts of autonomous inspection robots [9]

3. Implementation

Based on optimal conceptions, a prototype group of robots was elaborated (Fig. 3). The robots consist of the following units: a mechanical system, a control system, a supply system, a detection system that allows it to work in an autonomous mode in a variable environment, a communication system between the robots and the user, and a system for self-localisation during mission. This section describes the mechanical carrier and the major systems of the final robots for inspecting large area objects.

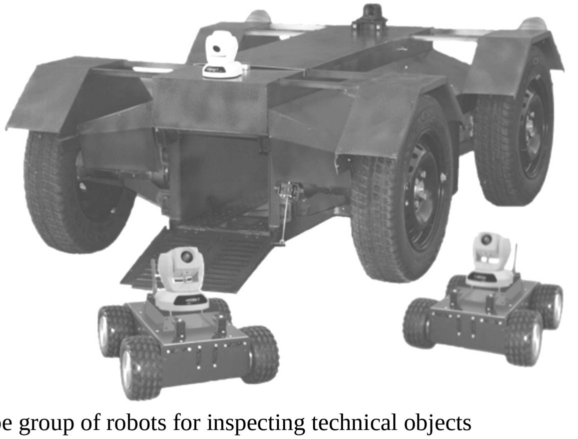

Fig. 3. The prototype group of robots for inspecting technical objects

3.1. Mechanical carrier

As an input to the realisation of design process, the optimal conception was used (see p. 2.). Virtual 3D models of robots were obtained as a result of the design process (all activities were supported by CAD/CAE/CAM system). The 3D models (and corresponding 2D drawings) were an input to the manufacturing process. Finally, the prototypes of both the transport and inspection robots were made.

The main mechanical and electromechanical elements of the transport robot are as follows: a) a lightweight frame built as a welded truss (welding material: aluminium alloy PA-38), b) an entry ramp for the inspection robots (top/down movement realised by a mechanism powered by the linear actuator type L40, 3,5V, 50N), c) suspension (partially amortizable by rubber units) as a compact unit with integrated drives (electrical engine type 65/67PF 24V, rated torque 1.8Nm and compatible planetary gear type RE 80, reduction ratio 1:80), d) separately powered car running wheels (size 145/80R13 T75), e) battery bins (contains two gel batteries 12V, 200ah), and f) the body of the vehicle (main material: thin and light sheet aluminium – shown in the central part of Fig. 4).

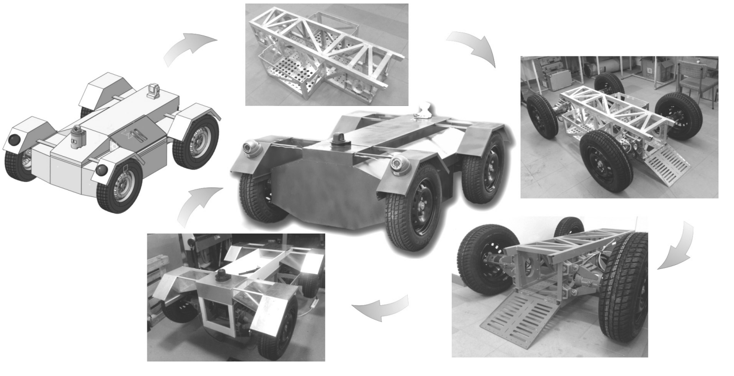

Fig. 4. The prototype of the transport robot – development of mechanical parts

The research group decided to use in inspection robots a nonholonomic driving system [6] that is often introduced into mobile robots and tracklaying vehicles. The driving system used allows driving forward and backward in straight line, driving forward and backward according to a certain curve, and turning round on the spot. The main mechanical systems and parts are presented in Fig. 5.

The drive system of the inspection robot consists of four independently controlled 12 V DC motors with planetary gears. Special exchangeable tyres are put on wheel's hubs, which are attached directly to the shafts of motors. It is possible to change a tyre, if required. Each inspection robot is supplied by two 12 V gel batteries. The batteries are mounted inside the frame. The chassis and frame of each inspection robot was made of aluminium by laser cutting and bending. Aluminium was used because of its low mass and relatively high durability features.

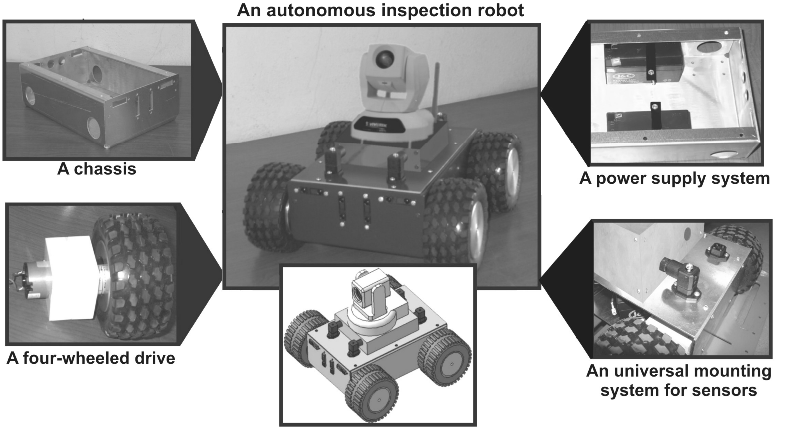

Fig. 5. Mechanical parts of the prototype of the autonomous inspection robot [4]

The construction of the robot also allows the efficient and fast changing of sensors (motion, smoke, gas sensor, microphone) and cameras (vision, night-vision), as required. The obtained system is based on four special industrial connectors protecting the connection against moisture and other medium that can penetrate inside the connection. Each connector allows sending a signal by four pins. Operation of the universal mounting system was described in [4].

3.2. Control system architecture

This section describes the major parts of the control systems for both the transport and inspection robots. The control system consists of hardware and software components: a main control computer, motors, sensors, data acquisition boards, Wi-Fi based communication protocols, high/low-level controllers, real-time operating system, user interface, etc.

Hardware layout

A hardware controller for the transport robot is based on an embedded computer made by AAEON model AEC-6910. The AEC-6910 BOXER is an advanced embedded control system that focuses on the highly expandable function and compact size combined with fan-less design and highly efficient heat conduction mechanism. The controller is based on a 1.8 GHz Intel Pentium M processor with low power consumption and relatively high performance. The computer is equipped with four USB ports, Ethernet, and four Serial ports that are able to communicate with diverse devices with a high transfer rate. Furthermore, AEC-6910 can concurrently support PCI and PCMCIA expansion interfaces.

The communication between the transport robot and an operator's station is carried out via Wi-Fi local area network (hardware controller is connected to a Wi-Fi router). The Wi-Fi router is also used for sending video signal from a stereovision camera, rotary observation camera, and cameras mounted on the inspection robot.

The transport robot motors are driven by a high frequency MOSFET controller with regenerative braking for permanent magnet motors. The MOSFET controller is connected with an Input/Outputs module (Janbit model USB-1208FS) to the main controller. The I/O module is also used for measuring analogue and digital signals form all the sensors of the robot.

The inspection robot is controlled by an ARM9 - based, Linux-ready System on Module - the M-501 from Artila Electronics. M-501, powered by a 180MHz ATMEL AT91RM9200 RISC, comes with onboard 32MB SDRAM and a 16MB Flash memory that contains a Linux 2.6 kernel. The controller module is equipped with dual 2x25 Dual-In-Line connectors designed for I/O peripheral expansion, one 10/100M Ethernet, four UART serial communication ports, two USB 2.0 hosts, a Secure Data Card (SD) Interface, and a Serial Peripheral Interface (SPI). All the sensors are connected directly to the SoM. The motors that drive the wheels are supplied and controlled with the use of power H bridges, also connected to the System on Module. ZigBee communication modules are used for assuring communication between the transport robot and the inspection robot(s).

Software

The authors decided to apply the behaviour-based approach [1, 2, 5] for developing the control systems of the robots. Such a control system uses a collection of "behaviours" allowing the robot(s) to obtain a predefined goal or to accomplish some task. Examples: elementary (*go-straight*, *turn-right/left*, *etc.*), more complex (*line-following*, *wall-following*, *avoid-obstacle*, *flocking*, *maintain-formation*, *etc.*) or the task/mission oriented (*go-point-to-point*, *go-back-home*, *watch-the-area*, *cruise*, *etc.*) behaviours. All of these behaviours may be applied for one or a few robots. It was assumed that there is the possibility of connecting behaviours, e.g. *go-point-to-point* and *obstacle-avoidance* behaviours for the robot(s) moving between two points in the presence of an obstacle.

The control system of the robots was elaborated with the help of the Microsoft Robotics Developer Studio (MRDS) [9]. It provides the user with two basic technologies: Decentralized Software Services (*DSS*) and Coordination and Concurrency Runtime (*CCR*), allowing writing multi-threading applications (control systems) able to operate on many computers which are manageable using a Web browser. Moreover, the MRDS provides the user with two basic tools facilitating the development of the control system: Visual Programming Language (*VPL*) and Visual Simulation Environment (*VSE*). VPL allows programming using the drag-and-drop method. VSE, which is based on AGEIA PhysX libraries used for computer games, takes into account both the kinematic and dynamic properties of objects and physical phenomena such as gravity, friction, inertia, etc. Since VSE allows testing algorithms in simulation, it is a very convenient tool for the system verification. Furthermore, MRDS gives access to the source code of many pieces of hardware (sensors, motors, encoders, etc.) and software (direction dialog boxes, etc.) services.

3.3. System for environment detecting and recognising

Each robot from the group of robots is equipped with variety of sensors that can detect obstacles, identify location and direction, and more. Sensors of robots allow the active operating of the robots in an unknown environment during the given mission [3]. The detection system delivers data to the control system.

The front of the transport robot is equipped with a laser scanning sensor, 3 ultrasonic sensors and 5 infrared (IR) sensors. The robot additionally has a stereovision camera mounted on it. The rear part of the robot is equipped with 4 ultrasonic sensors. All these sensors of the transport robot are used for measuring the distance to obstacles. The robots also have sensors for self-localisation, such as a compass, acceleration sensor, speed sensor, and a gyroscope. The robots also have sensors for self–diagnostics, such as temperature and current sensors.

To measure the distance to obstacles, infrared (IR) and ultrasonic sensors were selected for the described detection system of the inspection robots. Each inspection robot is equipped with 6 IR sensors (4 sensors with measurement range: 40-300 mm and 2 sensors with measurement range: 10-800 mm), and one ultrasonic sensor (measurement distance: 1-3500mm). The two types of sensors applied are supplementary to each other. The inspection robots are also equipped with an acceleration sensor and a gyroscope, which allow it to identify its position and orientation in an absolute co-ordinate system.

3.4. System for self-localisation

The multi-robot group is equipped with a self-localisation system. The system is used for two types of tasks. The first task is concerned with localising the robots at a large scale on a topological map of terrain. The accuracy needed for this task is a medium one, and it is possible to use the standard GPS system. The transport robot has a deferential GPS (dGPS) module from NovAtel model SuperStar II, whose accuracy is not worse than ±0.5 meters. All the inspection robots have also standard GPS modules from NovAtel.

The second task is concerned with positioning the inspection robots during entering the cargo space of the transport robot. The accuracy needed for this task is very demanding. The realisation of this task forced the development of a radio-ultrasonic system. The system gives very high accuracy, about ±0.015 meters, while its operation range is up to 9 meters.

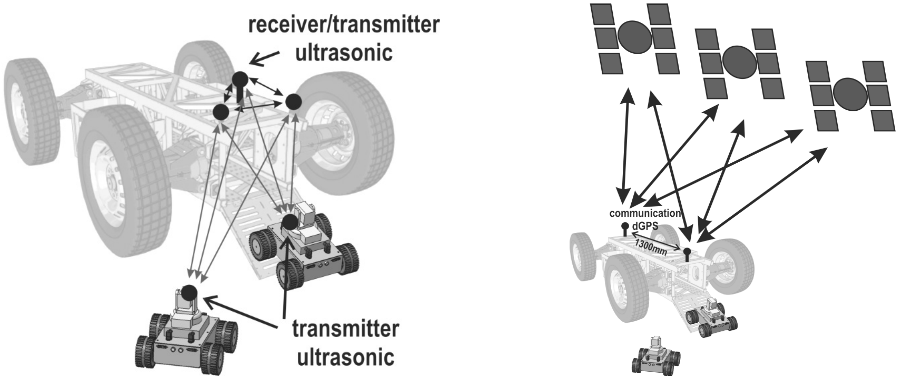

Fig. 5. Radio – ultrasonic and dGPS self localisation systems of autonomous robots

Conclusions

In the paper, a group of autonomous mobile robots was described, consisting of the transport unit that simultaneously operates as the communication centre, a unit of absolute location, and the resource of more extensive computations. This group has been implemented in the Department of Fundamentals of Machinery Design, Silesian University of Technology at Gliwice. During the implementation, it was possible to verify many conceptions and develop original solutions. Both the classes of robots satisfy requirements that have been set at the very beginning of the project.

After carrying out the project, several conclusions can be drawn. An important issue of the project has been the application of MS Robotics Studio for developing algorithms and software modules used in the control system and sensor drivers. The system of the self-localisation of the group should be further developed in order to allow location of the group that would not require direct visibility between inspection robots and the transport robot. Furthermore, there is the need to develop the control system of the complete group, based on the behaviours of the group. This system should take advantage of group operation of all the robots.

The authors are going to continue the work with special attention paid to industrial implementation of the group.

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Grupa robotów do inspekcji wielkopowierzchniowych obiektów technicznych

Słowa kluczowe

Autonomiczne roboty mobilne, grupa robotów, inspekcja, system sterowania oparty o zachowania.

Streszczenie

W niniejszym artykule przedstawiono opracowane koncepcje oraz implementację grupy autonomicznych robotów zdolnych do inspekcji dużych obszarów obiektów technicznych. Dzięki wykorzystaniu grupy robotów możliwa jest

rejestracja obrazów wideo oraz akwizycja danych dotyczących wybranych wielkości fizycznych (np. temperatura, stężenie wybranego gazu), z dowolnego miejsca kontrolowanego obszaru. Roboty mają możliwość dotarcia w dowolne miejsce kontrolowanego obszaru obiektu technicznego, pozyskania odpowiednich danych, a następnie przesłania tych danych do operatora w celu dokonania ich analizy i interpretacji. Opisywana w niniejszym artykule grupa robotów składa się z jednego robota transportowego oraz czterech robotów inspekcyjnych. W artykule opisane zostały podstawowe systemy robotów (m.in. sterowania, detekcji otoczenia, komunikacji, samolokalizacji) oraz ich działanie.