Improving a device for identifying and marking parts of territory with chemical and radioactive contamination

M Msallam and V I Syryamkin
Faculty of Innovative Technologies, Tomsk State University, Tomsk, Russia
E-mail: majdi.f.msallam@gmail.com

Abstract. There is an urgent need to conduct a survey of areas exposed to chemical and radioactive contamination, assess the level of risk in these areas, and work on cleansing them of their remnants. Hence the need for advanced robots arises, where they should be capable of carrying out all hard tasks in different environments in all weather conditions and around the clock. In this article, we detail the components of an advanced device that consists of a robot capable of terrestrial-aerial movement and wirelessly connected with computerized workstations. Here we show the multiple advantages that the robot has compared to other previous models. We pay special attention to the technical vision system in the robot, and offer some proposals for the purpose of developing this system.

1. Introduction

There are many dangerous areas on the earth that have been exposed to chemical and radioactive contamination. Other areas contain remnants resulted from military conflicts, such as bombs and minefields. There is an urgent need to assess the danger of these areas and work hard to cleanse them of remnants. This is very important for several reasons: firstly, it is possible to make these areas available again for living or investment, in agriculture for example. Secondly, the existence of these remnants leads to the death of many innocent people, so removing them will reduce such accidents. And thirdly, the danger of these areas may also spread to neighboring areas due to many factors (weather, animals, ... etc.) especially in the case of radioactive and chemical pollution. The problem when performing such a difficult task lies in the extreme risk to the lives of experts and other workers who come into direct contact with the dangerous materials. Any little mistake may lead to serious injuries or even death. For example, some statistical studies indicate that the number of victims of the Chernobyl disaster ranges from 4,000 to 16,000 people because of the radioactive pollution resulted from this disaster [1]. Although there is controversy about the exact number of victims, it cannot be denied that there are many harmful effects on environment and people in the vicinity of the infected area.

Hence, there is a need to create developed robots that are capable of carrying out all the tasks required in dangerous areas such as: making various measurements, processing the measured data, assessing the level of risk in areas based on data processing, marking dangerous areas, and even removing remnants. Consequently, these robots replace the human factor in performing dangerous tasks, thus contributing to reducing human losses. The robot that we are interested in is a device that is able to move completely freely in dangerous areas, whether in the air (aerial movement) or on the surface of the ground (terrestrial movement), and able to perform the required tasks around the clock and in all weather conditions.
Many attempts have been made to design a robot with the aforementioned specifications. In [2] a robot that is capable of terrestrial-aerial movement is designed and experimentally validated. It consists mainly of a quadcopter that enables the robot to fly in the air. In addition, a cylindrical cage has been added to the robot. This cage surrounds the quadcopter, so it provides protection in case of accidents, and on the other hand it works as wheels capable of movement on the ground. This robot has been called hybrid terrestrial and aerial quadrotor (HyTAQ). To obtain the required thrust during terrestrial movement, the same quadcopter drives are used. This wonderful design has many advantages: 1) Saving energy consumption. In the case of terrestrial movement, the robot requires energy only to overcome the rolling resistance, which is much less than the energy required to fly in the air, and thus one of the most important problems of aerial robots is partially overcome, which is short working period. 2) Very simple design in terms of control and mechanical design compared to other solutions. The robot can move in the air and also on the ground without adding any additional movement drivers to it, rather the same actuators are used to perform these two types of movement. 3) The ability to avoid ground obstacles which is a major problem in robots that are not able to fly. HyTAQ can do that simply by flying over these obstacles. The experimental results show that the proposed design enables a significant increase in the working period of the robot.

In [3], an improvement on the previous design was made by using a hexacopter instead of quadcopter, whereby two of the six propellers were installed directly on the horizontal axis on which the hexacopter is fixed. The new design was called RP-1R, and the introduced modifications have contributed to solving many problems of the design in [2] as follows: 1) In order to obtain the necessary thrust for terrestrial movement, only the two drivers installed on the horizontal axis are used instead of using four drivers. This reduces the energy required for this type of movement and thus increases the working period of the robot. 2) The modification added to the robot enables it to make a rotation in the same spot by moving the two propellers installed on the horizontal axis in opposite directions. This rotation is not possible to achieve in HyTAQ. Thus, the modification that introduced to the robot increases its ability to maneuver in narrow places. 3) During the terrestrial movement the drone remains in a horizontal position parallel to the ground surface, where it is sufficient to tilt the propellers installed on the axis at a certain angle to obtain the required movement, while in HyTAQ, the whole quadcopter needs to be tilted. 4) Stability is maintained in the horizontal position of the hexacopter by equipping the robot with a microprocessor stabilization system, this reduces the swing and provides better control. 5) In the case that one of the propellers fails to work during flight, it is possible to use the other propellers to land the robot smoothly, which increases its safety and reliability.

In this paper, we describe a device that consists of workstations connected wirelessly with a robot that is an upgraded version of the robot in [3]. The device we consider in this paper is described in the patent in [4] under the name "A device for identifying and marking parts of territory with chemical and radioactive contamination". Our aim is to get to know the structure of the device and how it works, with a focus on the technical vision system in it. We also aim to present a set of proposals regarding the development of this device.

The paper is organized as follows: In Section 2 we present a description of the components of the device. In Section 3 we describe in some details the technical vision system of the robot. In Section 4 we offer some suggestions for the development of the technical vision system. Finally, we conclude in Section 5.

2. Description of the device
The device mainly consists of a robot and computerized workstations connected with each other wirelessly. The robot in turn consists of a hexacopter and a cylindrical aerodynamic grille surrounding it. The hexacopter has been fixed on the horizontal axis within the grille in a similar way to the design in [3], which enables the robot to move on the ground and in the air as well. In addition, a lot of other equipment is installed on the hexacopter platform, such as measuring and communication devices. The main goal of the robot is the ability to move in different areas with high maneuverability in all weather conditions.
conditions and around the clock. It is able to make various measurements using the many measuring devices attached to it. It can also process the measured data to determine the level of risk in areas contaminated with chemical, radioactive materials and other remnants, and mark the high-risk parts of the area.

By comparing the robot with the previous models in [2, 3], we find that it has the following characteristics: 1) the ability to work for a long period of time by providing it with a rechargeable battery using solar energy and wind energy, 2) the ability to receive and process visual information. It is equipped with a color 3D video camera with two optical sensors capable of building three-dimensional images of the working environment. It is also equipped with a camera that works in the infrared range, and another thermal camera that enables thermal imaging. It contains an advanced image processing and pattern recognition unit, in addition to a sound analyzer, 3) increased maneuverability by providing the robot with a device to measure the direction and speed of the wind and then to change the direction and speed of the propellers accordingly, 4) increased accuracy and speed of coordinate determination by providing the robot with a GPS/GLONASS coordinate finder and an altimeter, in addition to the ability to compare the captured images of the working area with reference images stored in its memory, 5) the ability to implement automated and automatic modes of operation, where in automated mode, the work of the robot can be controlled through computerized workstations, while in automatic mode, an automatic work program is stored in its microcontroller memory and then an autopilot in the robot is activated. In automatic mode, obstacles can be avoided using the captured images and the recognition unit, which ensures the safety of the device, 6) the ability to detect areas contaminated with chemical and radioactive materials, and the ability to detect mines using a magnetometer, 7) the ability to mark dangerous areas contaminated with chemical and radioactive remnants, where the device contains a mechanism for installing specific modules in the required locations, 8) The ability to move on different surfaces (earth, snow, water, marshland, loose soil, ... etc.) by modifying the composition of the external grille, it contains multi-layered rims that are unsinkable with high permeability. The rims contain an inner power polymer frame, an outer layer of carbon and a lightweight foam filler. This solution allows the device to reduce the pressure on the ground (this is useful for example, when working in minefields), 9) The ability to protect information through the use of an encryption unit.

The central component in the device is the control microcontroller which is numbered 11, and it acts as the center node that connects all the other parts of the robot to each other and provides control signals to them. Below we will show some figures that illustrate how the microcontroller 11 is connected to the other parts of the robot. In Figure 1, we show how the microcontroller 11 is linked with the computerized workstations, where we notice that there are two computerized workstations, which are the pilot's workstation 26 and the engineer's workstation 27, each containing a processor, memory, display screen and some input equipment such as a keyboard or a joystick. Workstation 26 is responsible for directing the robot within the working area, while workstation 27 is responsible for collecting and displaying the obtained information. The two computerized workstations are connected with a set of other blocks as shown in Figure 1, which are: the universal control panel of the robot 25 whose task is to prepare the work program of the robot in the preparatory stage and to control the robot in the automated mode, antenna unit with an auto tracker 22, and a digital telemetry unit 37 that is used to process and display information on the two computerized workstations 26 and 27. These units communicate with the robot via the second transceiver 24, which exchanges information wirelessly with the first transceiver 23 installed on the robot. This information is encrypted through the encryption unit 36 in order to prevent interception of information by a third party. The electrical supply to the aforementioned blocks is provided by the stationary power supply 30 which contains an alternating current rectifier, a regulator, a battery, and a recharging unit based on a complex solar unit and a mini wind power unit.
Figure 1. Connections between control microcontroller 11 and computerized workstations.

Figure 2. Connections of microcontroller 11 with movement blocks and the mechanism for marking dangerous areas.

Figure 2 shows a set of parts of the robot that are responsible for its movement, where the microcontroller 11 is connected to two other control units: the controller 9 responsible for controlling movement drives, and the controller 10 responsible for controlling flight drives. Controller 9 controls the two blocks numbered 3 and 4, where each block represents a drive with a propeller. The controller
10 controls four other blocks, numbered 5-8, and these blocks have the same composition as blocks 3 and 4.

Block 2 in Figure 2 represents the platform on which all other parts are installed, it is in turn connected with block 1 which represents the grille surrounding the hexacopter in the robot. The microcontroller 11 is also connected with the stabilization unit 14 whose function is to control both the gyroscope 12 and the accelerometer 13, which measure the navigational parameters. In addition, the microcontroller 11 is connected with other blocks, as shown in Figure 2, these blocks are the GPS/GLONASS coordinates finder 33, and the autopilot 28 whose task is to direct the robot according to a specific trajectory when working in the automatic mode.

In Figure 2 it is also shown that the microcontroller 11 is connected with a block for marking dangerous areas 38. Actually, the device contains a number of blocks similar to the block 38 and they represent devices that are installed in a specific area to indicate that this area is dangerous. The installation is done using the mechanism 39. The robot is fed with electrical energy through the mobile power supply 29 which contains a battery, and a recharging unit based on solar unit and mini wind power unit.

In Figure 3 we show the parts of the robot that are responsible for making the various measurements, they include the following: altimeter 15, mines detector magnetometer 16, chemical and radiation detector 17, color 3D video camera 18, thermal imager 19, night vision camera 20, air temperature meter 31, wind direction and speed meter 32, locator 34, and sound analyzer 40. All these equipment are connected to the block 21 responsible for controlling them and, in turn, is linked to the microcontroller 11. Altimeter 15 is used with the locator 34 and the three cameras 18, 19, and 20 to recognize and avoid obstacles. The microcontroller 11 is also connected, as shown in Figure 3, to the recognizer 35, which is the unit responsible for processing the received images and recognizing patterns in them. In Section 3 we will introduce in detail the components of the recognizer 35. Blocks 16, 17, and 31 are used to measure the necessary data to determine the level of risk in the area.

Thus, we have described the basic components of the considered device, and now we move on to the description of the external appearance of the robot, which is shown in Figure 4, where we can see an external grille that allows the robot to move on the surface of the ground. The grille consists of two rims with spokes, a connecting grille and a horizontal axis on which the hexacopter and the other parts of the robot are attached. The spokes of the two rims are connected to the horizontal axis via bearings, allowing the movement of the external grille to be independent of the movement of the horizontal axis and the hexacopter, and this allows the hexacopter to stay in the horizontal position while the external grille is moving over the surface of the ground.
3. Technical vision system

The three cameras (color 3D camera 18, thermal camera 19, and night vision camera 20) together with the control microcontroller 11, attachment control unit 21 and the recognizer 35 form the basic components of the robot's technical vision system. In this section, we introduce the different methods used in image processing and pattern recognition.

We show in Figure 5 the basic components of the recognizer 35. It contains the following blocks: The input interface 53, a set of parallel blocks for processing input images numbered from 54 to 60. They differ from each other in the method used for processing, and are controlled by block 61 which is called the control unit for image processing subsystems, it sends control signals to the processing units via the input interface 53. The recognizer contains an intelligent unit for analyzing the results 62 whose task is to collect results from all the processing units and process them to obtain the output control signals, which are then sent through the output interface 63 to the microcontroller 11. The processing units of the recognizer are the following:

3.1. Correlation analysis unit 54

Information processing according to this method consists of three functional stages, where in the first stage reference information is generated, and in the second stage the comparison between current information and reference information is carried out using the cross-correlation function, and in the third stage the extreme values of correlation are determined. The theoretical study of this method dates back to 1885, then in 1895 Pearson's Correlation Coefficient was introduced. This method is widely used in statistical analysis, image processing, and pattern recognition. Important applications of this method in technical vision systems are: performance improvement of navigation systems in real time by calculating the correlation between successive frames, avoiding obstacles while moving in unknown dynamic environments, and an environment observer that defines the region of interest (ROI) in the working area, and that contributes to reducing energy consumption [5].

3.2. Analysis unit by neuro-fuzzy methods 55

This method is based on the combination of two technologies, namely artificial neural networks and fuzzy logic, and has become widely used in many applications in recent years, due to the fact that this method allows to benefit from the power of its two components. Fuzzy logic allows to deal with ambiguous or inaccurate data, as is the case of overlapping classes of arbitrary shapes, where the boundaries between them are not clearly defined. Neural networks have the ability to learn from data and obtain information that may be invisible to other methods, and then generalize the obtained information for new data. The neuro-fuzzy method allows classes to be distinguished from each other with high accuracy and high noise immunity [6].
3.3. Fourier analysis unit 56
The Fourier transform goes back to the French mathematician Jean-Baptiste Joseph Fourier, born in 1768, who showed that each periodic function can be represented by the sum of trigonometric functions of different frequencies and multiplied by different coefficients, and this is what is known today as Fourier series. In fact, even non-periodic functions can be represented in the frequency domain using the Fourier transform. The fast Fourier transform (FFT) algorithm which was found in the 1950s allows this transform to be performed very quickly. One of the most important features of Fourier transform is that it greatly simplifies the calculations, especially the convolution, which is converted into a simple product in the frequency domain [7]. The Fourier transform can be applied to one-dimensional signals (such as audio) as well as to two-dimensional signals (such as images). It is mainly used in filtering processes to delete noise component in signals, but it can also be used for pattern recognition as its real and imaginary parts can be used as features [8].

3.4. Wavelet analysis unit 57
In contrast to the Fourier transform, which relies on trigonometric functions as its basis, the wavelet transform is based on small functions with different frequencies and finite duration, called wavelets. This transformation allows not only to determine the signal’s frequency but also the moment in time at which the signal has this frequency. It is appeared for the first time in 1987 [7]. This transform can also be applied to both audio and image signals, and can be used for compression, noise suppression, and feature extraction.
3.5. Fractal analysis unit 58
The fractional analysis method is a very useful for understanding and characterizing complex structures such as images. The method is based on geometrically highly complex sets called fractals. Fractals have fractal dimensions, each of which determines the variations of the fractal set at a specified observational scale. Fractal dimensions are used to analyze and classify images. Usually, one fractal is not sufficient to represent real images, rather several fractals are required in the so-called multi-fractal analysis. This method requires benchmark patterns to be compared with, and they can be obtained using a software dedicated to this purpose [9].

Fractional analysis is used in images segmentation and features extraction, which are then can be used in patterns recognition [10]. This method can also be used to compress images in what is called fractal compression.

3.6. Analysis unit by structural-reconfigurable methods 59
Reconfigurable computing is a high-speed computer architecture obtained by processing a flexible computational device such as field-programmable gate arrays (FPGAs), where the hardware responsible for processing information can be changed adaptively during runtime by activating or deactivating circuits in the reconfigurable hardware. This method dates back to the 1960s, and it assumes that there is a primary processor responsible for controlling the reconfigurable hardware that performs the processing tasks such as image processing and pattern recognition, and when the current task ends, the hardware architecture can be reconfigured to fit the new task [11].

The reconfigurable hardware contains a large number of processor elements that have the ability to work in parallel, and this allows for maximum use of the computational capabilities of all these elements. To process information in modern technical vision systems, reconfigurable hardware is introduced into the functional architecture of the system.

3.7. Analysis unit by morphological methods 60
Mathematical morphology is a tool that allows to extract the components of an image that represent and describe its objects such as edges, skeleton and convex hull. Morphological operations can also be used for preprocessing and post-processing of images such as in filtering, thinning and pruning [7]. This method was originally developed for binary images (whose pixels have values of 0 or 1) and first appeared in 1964, and then the method was extended to gray images in the period between the mid-seventies and mid-eighties [12].

4. Suggestions for developing the technical vision system
Here are some suggestions for developing the technical vision system in the robot:

- We noticed in [4] that the intelligent unit (block 62 in Figure 5) that is responsible for analyzing the results of image processing units depends on a simple rule in its calculations, where the probabilities at the input of the intelligent unit are just compared with a fixed threshold (relation (1) in [4]). The performance of the intelligent unit can be improved by applying fuzzy logic to process the input probabilities in order to obtain the output control signals.

- In order to evaluate the performance of different algorithms and methods used in image processing and pattern recognition in the technical vision system, a universal dataset must be built so that it will be available on the Internet and can be used to compare the different systems. Thus, we can estimate the performance of the system and its effectiveness, whether in recognizing and avoiding obstacles or in detecting chemical and radioactive materials, before we have to test the robot in reality in dangerous areas.

- Pattern recognition algorithms can be accelerated by compressing data in images. Objects can be represented using the minimum number of bits, such as relying on their edges and centroids to represent them.
• It is possible to work on integrating the features that are obtained using different image processing methods, where these features can be grouped into a specific block such as the analysis unit using the neuro-fuzzy methods, and then a features selection process is performed before feeding them into classification stage, so that the best features are selected and the features of little importance are ignored.

• There is a wide field of work on developing the neuro-fuzzy methods, as its design can be relied upon modern high-performance artificial neural networks [13].

5. Conclusion
In this paper, we have detailed a device for identifying and marking parts of territory that is polluted with chemical and radioactive materials. The device mainly consists of an advanced robot connected with two computerized workstations, one for the pilot and the other for the engineer. The robot is able to move both on the ground and in the air, as it consists of a hexacopter surrounded by a cylindrical grille that plays the role of wheels. We described the components of device and showed how they are connected with each other. We compared the robot with two other previous models, and showed that the considered design has many characteristics and capabilities that make it able to carry out the required tasks more efficiently, as many of the drawbacks that previous designs suffer from have been overcome.

Special attention has been paid to the robot's technical vision system. We presented the details of this system and described the different methods used for image processing and pattern recognition. In addition, we proposed some suggestions with the aim of developing the technical vision system, where a lot of work can still be done to develop the robot to reach the ultimate goal, which is the ability to move completely freely in dangerous areas and perform the required tasks in all weather conditions and around the clock.

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