A SYSTEM FOR DETECTION, LOCALIZATION AND IDENTIFICATION OF IONIZING RADIATION SOURCES BASED ON AN INTERNET OF THINGS GROUND UNMANNED VEHICLE

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Abstract: *Ionizing radiation sources on our planet are either naturally occurring or artificially created. In both cases, if disseminated in the environment they would pose health hazards for the population. Certain scenarios of disasters with nuclear facilities establish a threat to public health and security. Systems for detection of ionizing radiation sources, preferably unmanned, are required.*

The current paper focuses on a novel system employed in radiation sources detection operations by means of carrying an ionizing radiation sensor as payload on a mobile ground-based platform. The platform consists of a wheeled vehicle that is remotely controlled and has no crew. The solution aims at detection, tracking and identification of different ionizing radiation sources. Possible scenarios of implementation of the system include nuclear facility disasters and catastrophes, radioactive material smuggling through borders, research and maintenance of uranium mines, management of nuclear waste depots, etc.

СИСТЕМА ЗА ОТКРИВАНЕ, ЛОКАЛИЗАЦИЯ И ИДЕНТИФИКАЦИЯ НА ИЗТОЧНИЦИ НА ЙОНИЗИРАЩО ЛЪЧЕНИЕ БАЗИРАНА НА IOT НАЗЕМНА ПЛАТФОРМА С ДИСТАНЦИОНЕН КОНТРОЛ

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Ключови думи: *Наземно превозно средство за откриване на йонизиращо лъчение, Управление на ядрени катастрофи, Системи и платформи за пренасяне на сензори за йонизиращо лъчение като полезен товар.*

Резюме: *Източниците на йонизиращо лъчение са естествени или изкуствено създадени. И в двата случая, ако бъдат разпръснати в околната среда биха представлявали риск за здравето на хората. Определени сценарии на бедствия с ядрени съоръжения представляват заплаха за общественото здраве и сигурност. В такива ситуации са нужни системи за откриване на източници на йонизиращо лъчение, за предпочитане без хора на борда.*

Настоящата публикация се фокусира върху иновативна система, която се използва за откриване на източници на йонизиращо лъчение. Това става чрез пренасяне като полезен товар на сензор за йонизиращо лъчение върху мобилна наземна платформа. Платформата се състои от колесно превозно средство, което се управлява дистанционно и няма хора на борда. Решението цели откриване, следене и идентификация на различни източници на радиация. Възможни сценарии на приложение включват ядрени катастрофи, контрабанда на радиоактивни материали през граница, изследвания и поддръжка на уранови мини, управление на депа с ядрени отпадъци и др.

Introduction

The ionization radiation sources are ubiquitous. They have natural origin or have been artificially created by humans through technological processes. For example, nuclear power plants are one of the largest "laboratories" creating nuclear byproducts being non-existent in nature as natural elements. On the other hand, we find a lot of natural radioactive substance in the environment some of which are used to create nuclear fuel for nuclear plants and their mining is an important industrial niche. The utilization of all these radioactive products poses risks to the environment and humans and requires adequate technology for radiation dosimetry and surveying. Possible scenarios requiring a ground-based unmanned platform carrying a dosimetry sensor are disaster management of nuclear accidents such as the Fukushima Daiichi nuclear disaster from 2011 and the Chernobyl disaster from 1986. Other cases to employ the system are the management of natural resources and mines of radioactive ores, smuggling counteraction, nuclear waste maintenance, etc.

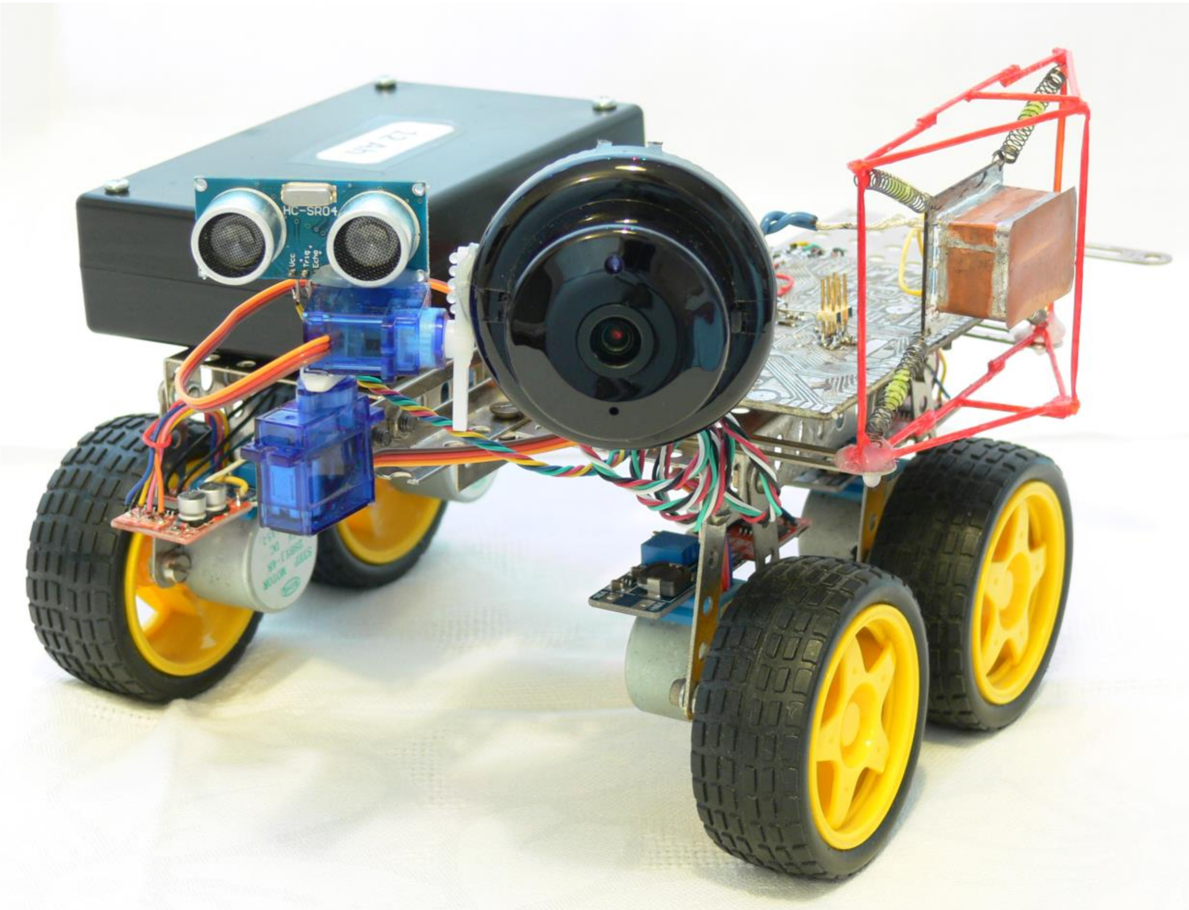

Fig. 1. The novel ground-based wheeled platform carries a spectrometric ionizing radiation sensor as payload

We have directed our research work towards the design and development of an unmanned ground-based platform used to carry an ionizing radiation sensor as its payload (see Fig. 1). The sensor was also developed for the project and is briefly described herein. The framework of this project is defined by several prerequisites that were to be met. First of all, the ground-based platform should be lightweight and cheap to manufacture and maintain. It has to be maneuverable and with off-road capabilities. The vehicle must be able to carry a sensor that is used not only for dosimetry, but also to generate spectral analysis of the radioactive sources with the goal of identifying them. Finally, in order not to risk exposing humans to radiation, the mobile platform should be unmanned.

This article discusses a novel design of a ground-based vehicle system for radiation dosimetry and radioactive source identification (Fig. 1). The article starts with overview of existing work in the field of ground-based dosimetry unmanned vehicles. The general construction of the vehicle is disclosed along with details of its design, electrical part, power source, propulsion, suspension, payload platform, auxiliary electronics, navigation camera and radio communications modules. A brief description of the employed radioactive sensor is illustrated.

In conclusion, future work is outlined with ideas of improving the system and its parts.

Related work

Existing ground-based unmanned systems having the same purpose of ionizing radiation dosimetry and spectrometry are found in the scientific literature.

The CARMA 2 ground-based vehicle is a large wheel platform used for ionizing radiation surveying. It has dimensions of 830x440x1030 mm but a ground clearance of only 65 mm. The battery life of this vehicle is 4 hours maximum. It is interesting to note that the CARMA 2 creators estimate high probability of catastrophic failure in γ-environments having the intensity of the Fukushima Daiichi disaster site. It is obvious that systems with high failure rates and at the same time being costly like the CARMA 2 platform are inefficient.

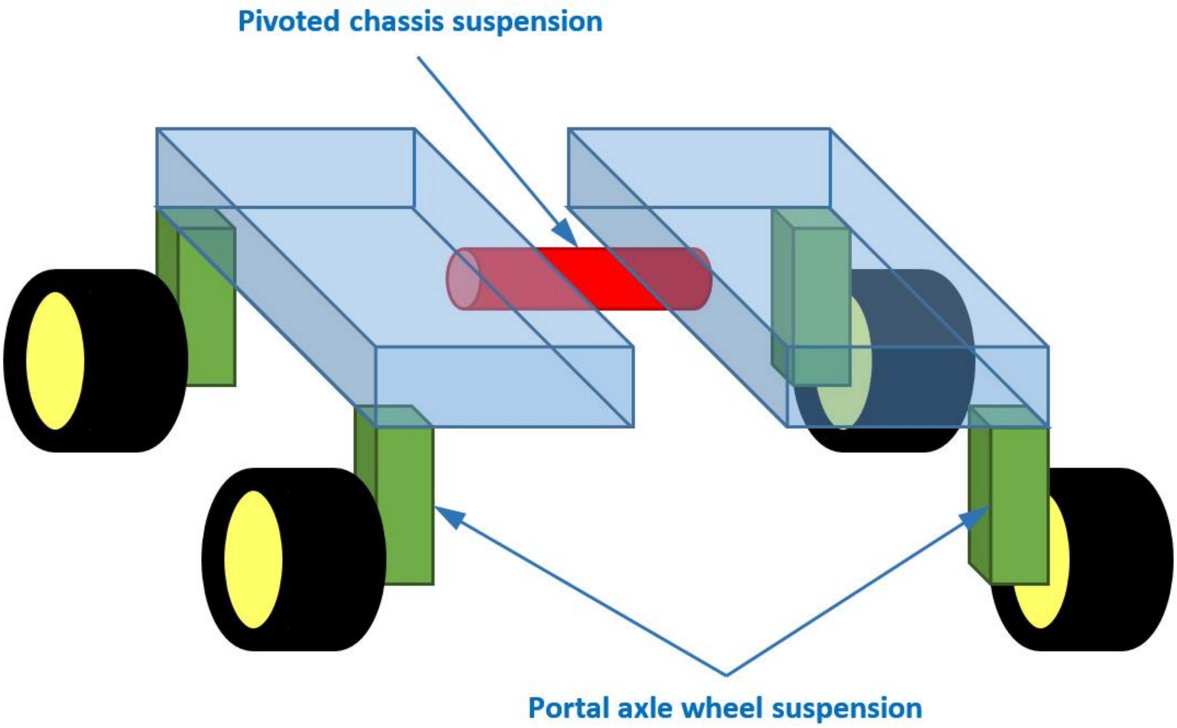

Fig. 2. The pivoted suspension of the ground-based platform and the portal axles ensure high ground clearance and uninterrupted contact with the ground of all four wheels

There are other systems that have been grounded at the Fukushima Daiichi site used specifically for γ-surveying such as JAEA-3 and Quince. The former is a four wheeled platform equipped with gamma ray imaging sensor called Gamma Eye. This system including both the platform and the instrument weighs 70 kg. Quince, on the other hand, is a tracked vehicle having a little less weight of 50 kg. The instrument on board is the dosimeter CPXANRFA-30 manufactured by Fuji Electric Co., Ltd.

There are still other developments most of which are wheeled and some – tracked. The majority of utilized sensors are Geiger Müller tubes for γ- and β-surveying, but there are modern solid state sensors also.

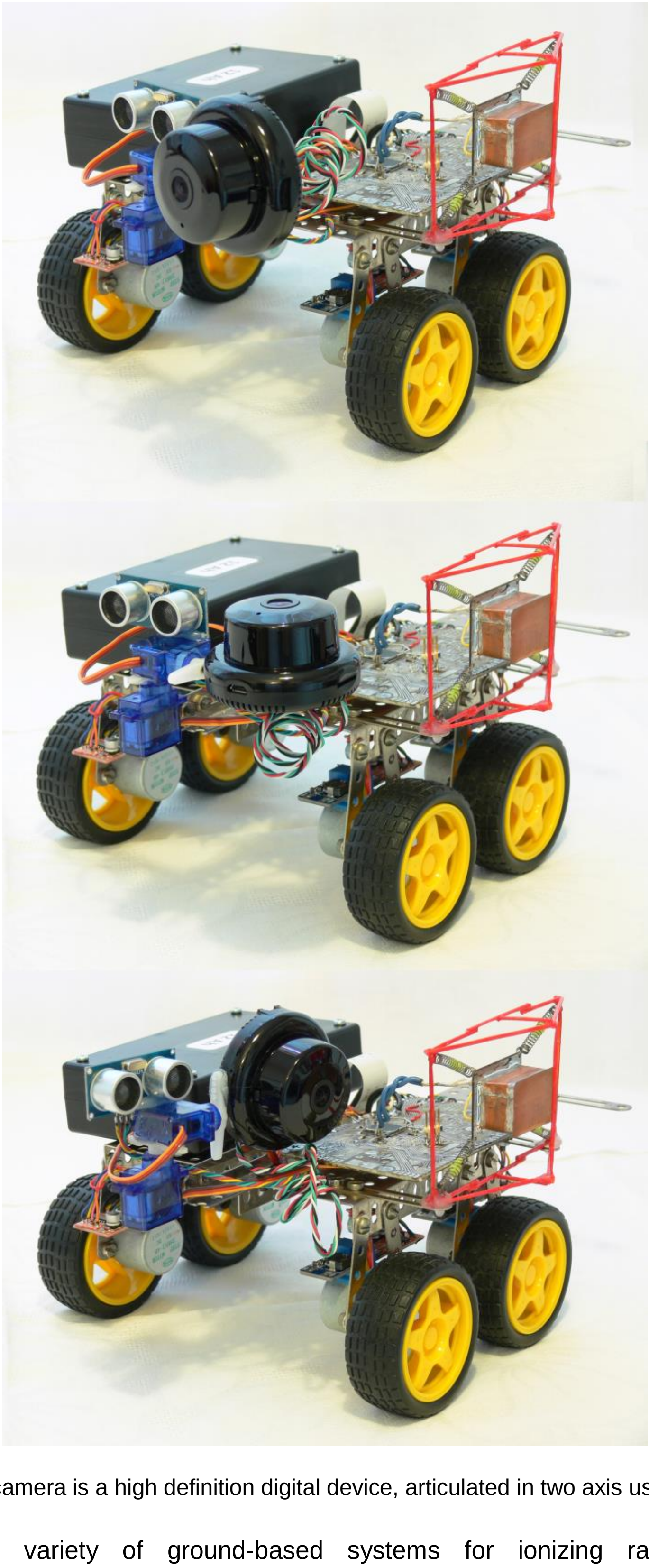

Fig. 3. The employed camera is a high definition digital device, articulated in two axis using servo mechanisms

Although the variety of ground-based systems for ionizing radiation surveying is overwhelming, most if not all of the apparatuses have their electronics unprotected from high radiation doses. The major reason for this vulnerability is the implementation of standard electronics lacking radiation hardening or radiation resistance. These unmanned platforms are nonetheless expensive. The cost is expected to be high for specialized equipment, but combining high cost with high failure rate and significant unit weight makes the utilization of such systems very inefficient and problematic.

Taking into account all these drawbacks of the existing systems we came to the conclusion that we should develop our ionizing radiation platform around low cost and radiation resistant electronics.

The platform design

As already mentioned we defined several goals to be satisfied by our design. These include low cost, low weight, simplicity of design to achieve low failure rate and finally implementation of radiation resistant electronics.

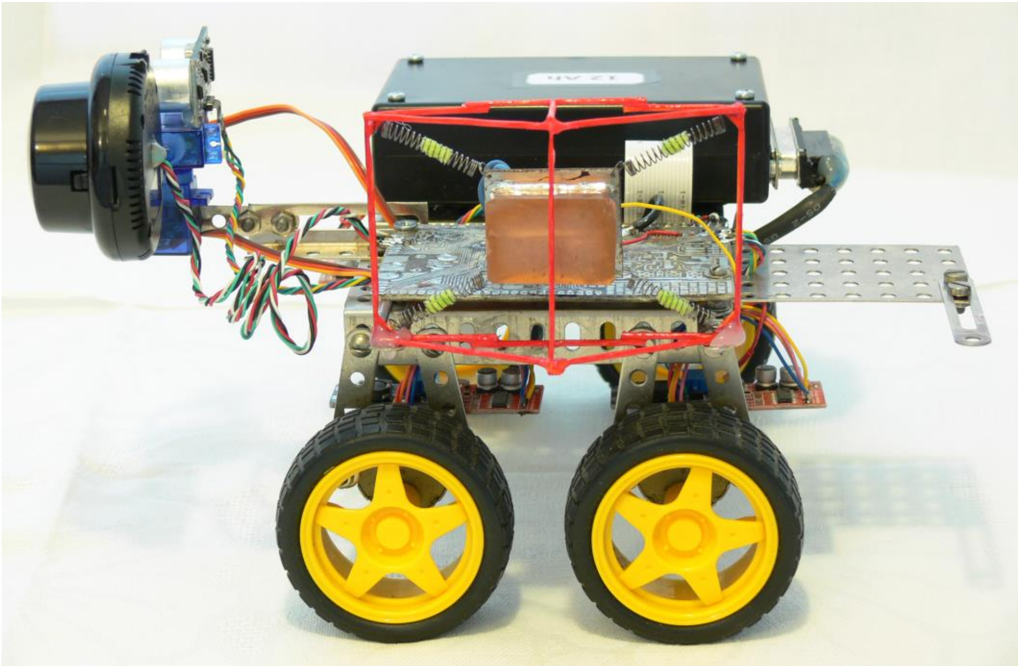

Fig. 4. The novel platform has dimensions of 300×250×170 mm and weighs only 1.11 kg

The low cost and weight make the system deployable in large numbers easily. We target cost of at least ten times lower than the average price of the existing platforms. Our total vehicle weight along with the payload is also tens of times less in comparison with the existing platforms and was established at 1.11 kg. Most employed parts, including the motors, camera and servo actuators, are off-the-shelf components. Two modules were designed and developed by us – the main control board and ionizing radiation sensor. These units are also built around standard components.

The dimensions of the vehicle are 300×250×170 mm (Fig. 4). A single person is able to carry and deploy several devices simultaneously.

Starting with the chassis, there are two boards connected through a pivoted suspension. There is no differential mechanism for the pivot – hence the vehicle is simpler and more robust in design. Each board, left and right, mount two wheels, thus each wheel is always in contact with the ground (see Fig. 2). Each wheel is driven by an electric stepper motor. The motors rely on a reduction gear mechanism realizing a portal axle. This approach increases the ground clearance of the vehicle which is 50 mm.

Our platform uses skid-steering (differential steering). It offers simplicity and reliability. In order to maintain low tension on the gear boxes and less power consumption during steering we designed the distance between the front and rear wheels to be much less than the distance between the left and right wheels. Further, the vehicle suspension is unsprung.

A block diagram of the platform electronics is shown in Fig. 5. They are built around a control board of our own design. This board is a modification of an experimental autopilot board we have developed previously for use in multirotor drones. The heart of the board is a digital signal processor (DSP) microcontroller unit (MCU) of the Kinetis family – the DSP MCU MK22FN1M0VLL12. This MCU is ARM-core based and offers a 32 bit architecture. It has an auxiliary computational unit – a single precision floating point unit. Its core is the Kinetis ARM Cortex-M4. The chip is packaged into a 100 pins low-profile quad flat package (LQFP). We have at our disposal two analogue to digital converters (ADCs) with 16 bit accuracy. The MCU has 128 kiB random access memory (RAM) and 1 MiB of flash memory. The latter may be used as a substitute to electrically erasable programmable read-only memory (EEPROM). The processor of the MCU runs at 120 MHz clock and offers plenty of performance adequate for the expected computational tasks and real-time control function. The process of the chip is 90 nm and the MCU is powered with 3.3 V supply.

The next version of the vehicle is planned to employ a new control board built around a radiation resistant MCU. We have again selected representatives of the Kinetis family of MCUs. These MCUs are built using the 130 nm process and have a number of noise immunity techniques engaged. They are powered with 5 V supply. An example of such a microcontroller is the MKE02Z64VQH4. This microcontroller withstands 30 krad(Si) when exposed to 20 keV X-rays. Its core is ARM Cortex-M0+and has no floating point unit, but is also based on 32 bit ARM architecture. The delivered processing power is adequate.

The control board also has an inertial measurement unit (IMU) inside. The latter is designed around microelectromechanical devices, namely a three axis gyroscope, three axis accelerometer and three axis magnetometer. Barometer device is also employed. The magnetometer and gyroscope units come at hand with a ground vehicle when navigation using magnetic field is required. The accelerometer reports the inclination of the vehicle and any vibrations that might be transferred to the chassis from the ground.

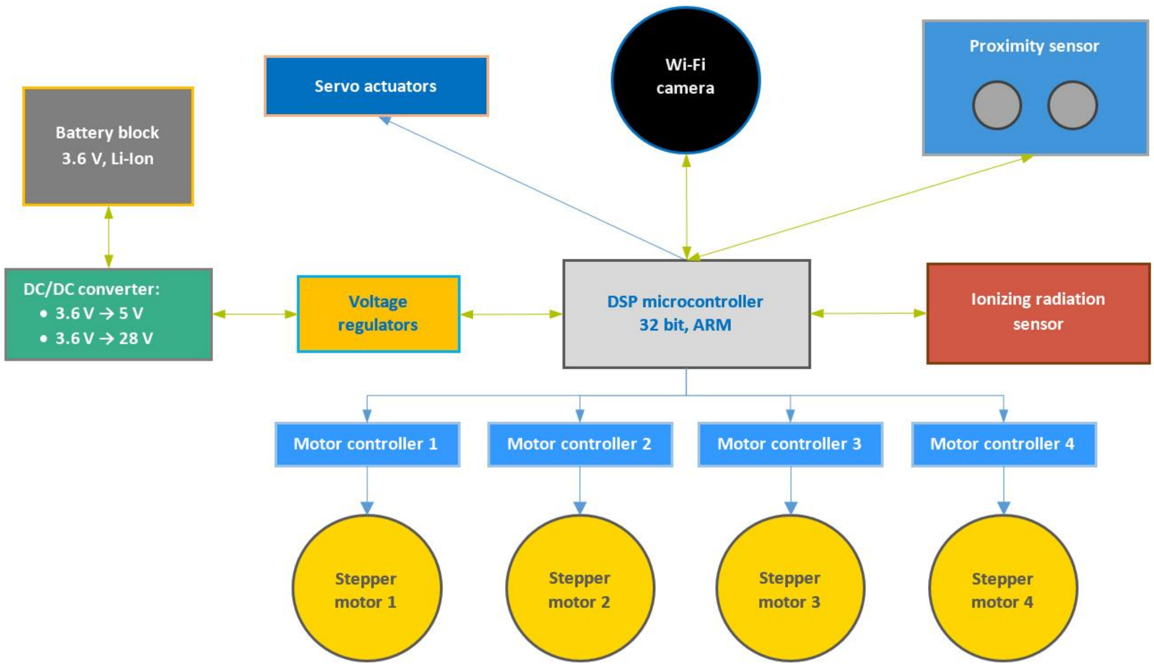

Fig. 5. A block diagram of the platform electronics

Each motor is controlled through four wires by a motor controller. All four controllers are directly connected to the main control board. The stepper motors ensure electrical noise free operation and precise command of movement.

The power source is 3.6 V Li-Ion battery pack which is changeable and is connected by means of a plug. Different packs offer different capacities. We carried out our tests using a 12 Ah battery which offers about 4 hours of operation time under vehicle motion and all systems working. There are a number of voltage converters on board with the purpose of delivering all required voltages by different electronics modules including the payload. Some of the voltages, as required, are regulated with the help of low noise low drop-out (LDO) voltage regulators.

The platform relies on a digital high definition Wi-Fi camera. It offers Wi-Fi connection with the control station and the radio link is used for video transfer, information exchange and control commands. Control of the vehicle over the Internet is possible converting the system to an Internet of Things (IoT) device. The camera has night vision capabilities using internal switchable filter and active infrared (IR) illumination. The articulation of the camera is realized through two servo devices (see Fig. 3). This approach ensures two-axis tilting by 180°.

An ultrasonic distance metering sensor is mounted on the first servo device manipulating the camera covering 180° horizontally (see Fig. 3).

Ionizing radiation sensor

Our platform is designed with the idea to carry any type of ionizing radiation sensor as payload that meets the maximum allowed payload weight. For the current version of the vehicle this limit is 400 g. For the purpose of our parallel project – a micro drone carrying an ionizing radiation sensor as payload – we have developed our own sensor that is extremely lightweight and weighs only 10 g. For all our tests we used this sensor and it can be seen on Fig. 1, 3 and 4 enclosed in a copper shielding and suspended on a frame using springs (see Fig. 4 and 5). The sprung suspension solves a notorious problem with PIN photodiode based ionizing radiation sensors – parasitic registering of vibrations. When we started the development of our sensor we had as starting point the Liulin family of ionizing radiation sensors. Liulin radiological instruments have been designed and developed at the Space Research and Technology Institute – Bulgarian Academy of Sciences and have a long history of successful devices. We aimed at an instrument that has no internet MCU and relied on the MCU of the control board it was connected to. Thus we intended to save board real estate, component count, weight and power consumption which we achieved successfully. Another benefit is the theoretically reduced failure rate – the simpler a device is, the less prone to failure it proves to be.

Our radiation sensor follows the tested path of employing a solid state radiation sensitive component – a PIN photodiode. The very thin shielding of only 50 μm stops light, moisture, dust particles and electromagnetic interference, and at the same time lets through gamma rays having energies well below 60 keV and low energy beta particles. Further, we achieved spectral identification of the radioactive sources using spectral analysis. We should mention that a PIN photodiode based sensor can detect fast neutrons with energies above 1 MeV, accelerated protons and heavy ions apart from beta and gamma rays.

The employed PIN photodiode is Hamamatsu S5107 with 100 mm^2 active area and sensitive silicon volume thickness of 0.3 mm.

The sensor also hosts an analogue transimpedance amplifier and signal shaper. The output signal is delivered directly to the ADC of the MCU of the host board by means of a shielded cable. The high resolution in both voltage and time of the ADC allows direct sampling of the signal. Any hardware such as sample-and-hold circuits and threshold detectors have been discarded. By these means we have further reduced the weight and power consumption of the platform while increasing its reliability. Further, the complete digital signal processing reveals exciting ability of extracting as much information as it is possible from the single. The computed and experimentally measured output RMS noise voltages coincide to an ample degree and are at 15 mV. Our Americium-241 sample (see Fig. 6 – left) emitting 60 keV gamma rays generates 120 mV positive amplitude signal. By adjusting channel 1 to correspond to 60 keV gamma ray energy we record 512 channels of ionization event energies. We tested the system with a number of radioactive samples among which Potassium-40, Uranium-238 (see Fig. 6 – right), Radium-226, Thorium-232, background radiation.

Fig. 6. Some radioactive samples used in the experiments with the sensor and the mobile platform. Americium-241 on the left and Uranium-238 on the right. Radiation levels are harmless.

Conclusions

We have achieved a competitive ground-based unmanned platform for carrying ionizing radiation sensors on board. The platform is Internet of Things capable and has low cost for manufacturing and maintenance. Along with the developed radiological sensor it becomes a good starting point for further progress in the field.

For our next version of the system we want to improve the radio communications capabilities, the navigation of the system in confined spaces, the self-governing capacity. We also aim at lowering further the costs and elevating the radiation resistance of the electronics.

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