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Robot Advanced Intelligent Control developed through Versatile Intelligent Portable Platform

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***Abstract*— The paper presents a versatile, intelligent portable robot platform VIPRo, which involves developing intelligent control interfaces by applying advanced control techniques adapted to the robot environment such Robot Neutrosophic Control (RNC), Robot Extenics Control (eHFPC), Robot Haptic Control (RHC), human adaptive mechatronics, implemented by high speed processing IT&C techniques and real time communication for a high amount processing data. An original virtual projection method is applied to SMOOTH firefighting robots through representation of the intelligent mobile robots in a 3D virtual environment using VIP-F²Ro with robotic strong simulator, an open architecture system and adaptive networks over the classical control system of the robot.**

Keywords: VIPRO platform, robot simulation, graphical user interface, reference generation.

I. Introduction

Mobile robots have caught the attention of the research community and the manufacturing industry as well, leading to a great hardware and software developing. Some applications of great interest for researchers are human behaviour in fires and the simulation of the movement of individuals in such hazardous environment [1-3]. Simultaneously, the real time robot control with remote network control having human operators' ability play an important part in hazardous and challenging environments of human life exposed to great dangers such as support and repair in nuclear contaminated area, fire, earthquake or any other disaster area in case of an accident or a terrorist attack involving CBRN materials. [2-3]. A big amount of researches led to the development of different robots with sensing abilities, transport and manipulation of different applications [4-7].

This calls further developing of the mobile and remote control autonomous robots which can help people to perform searching and saving operations, representing a priority and a complex task.

In general, the total impact costs of large incidents are very high, and are much higher that of counter-measures. For biological threats, the indirect economic impact is assessed to be in the range of several billion to tens of billions of US dollars. The countermeasure cost range is much lower, ranging from hundreds of millions to about 10 billion USD. Taking the bio defence programs alone, a few hundred thousand to tens of millions are spent by European countries for a reference year, while the USA invests about 200 million euros.

Intelligent heterogeneous robot networks, remotely controlled by humans, have an increasingly important role in hazardous and challenging environments, where human lives might be at risk [8-10]. This is in fact the challenge of developing autonomous systems perceptive to human requirements and having the ability of continuous learning, adapting and improving in "real world" complex environments, so as to provide support in natural disasters, fires, or other calamities [14-17].

The paper presents a VIPRo versatile, intelligent robot platform, which involves developing intelligent control interfaces by applying advanced control techniques adapted to the robot environment such Robot Neutrosophic Control (RNC), Robot Extenics Control (eHFPC), Robot Haptic Control (RHC), human adaptive mechatronics, etc. An original virtual projection method is applied to SMOOTH firefighting robots, through the development of VIP-F²Ro Platform, which allows representation of the intelligent mobile robots in a 3D virtual environment using a strong robotic simulator, an open

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architecture system and adaptive networks over the classical control system of the robot.

The VIP-F^{2}Ro Virtual Intelligent Portable platform, is the one designed to acquire the data received from unmanned ground vehicles (UGV), to process and analyse them, to provide feedback. The VIP-F^{2}Ro brings the virtual robots to the real world, wanting to create an innovative robot platform, which will allow to develop mechatronic systems of mobile robots in virtual environments and communicate with real robot systems through a high speed interface.

The obtained results lead to the conclusion that the advanced intelligent robot control methods using ***neutrosophic control***, ***extended control*** (Extenics), ***human adaptive mechatronics***, developed through versatile intelligent portable platform, allow a correct evaluation of robot behaviours in hazardous or challenging environments and improving the robot performances at the interaction with the environment.

II. VERSATILE INTELLIGENT PORTABLE PLATFORM

The VIP-F^{2}Ro Virtual Intelligent Portable Platform for firefighting robots, is the development of an e-learning and remote-control platform enabling community interested in the topic and long-term plans to further develop research and innovation. This, in fact, is the tool of ensuring the ability of continuously learning, adapting and improving in "real world" complex environments, modeling in real time the information gathered by advanced technologies so as to provide support in "big data" management and development of international clusters able to process the information in an unifying vision.

This way, networking activities will be in good balance with scientific and technical activities contributing equally to advance the project and to achieve the specific objectives mentioned above [18, 20].

To develop new features for the unmanned ground robotic mobile vehicle, like motion on uneven ground, or motion by overcoming or bypassing obstacles, high level intelligent algorithms are required to be developed. This is due to the fact that the motion mechanism is a complex process, and because it is a repetitive process of tilting and unstable movements that sometimes occur on a bumpy road, it will lead the robot to tip over.

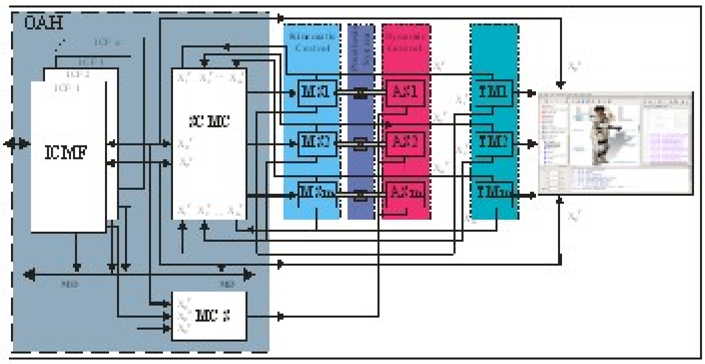

Fig. 1 Virtual projection method by Vladareanu-Munteanu applied to VIP-CBRN Platform

The virtual projection method [19] (Figure 1) tests the performance of dynamic position-force control by integrating dynamic control loops using a Bayesian interface for the sensor network and neutrosophic interface for decision making [9-11]. The CMC classical mechatronic control directly controls servomotors MS1, MSm, where m is the number of the robot's degrees of freedom. These signals are sent to a virtual control interface (VCI), which processes them and generates the necessary signals for graphical representation in 3D on a graphical terminal CGD. Development of an open architecture control system by intergrating ***n*** control functions in addition to those supplied by the CMC mechatronic control system. With the help of these, new control methods can be implemented, such as: contour tracking functions, motion control schemes, control of the centre of gravity , the orientation control through image processing, Bayesian interface for sensor networks, decision making by neutrosophic logic control [11,12]. Priority control, real time control and information exchange management between the n interfaces is ensured by the multifunctional control interface MCI, interconnected through a high speed data bus.

The optimization of intelligent control methods allows the Unmanned Ground robotic mobile Vehicle (UGV) to adapt to environmental scene of in case of the fire investigation, hazardous chemicals detection, fire and rescue threat the firefighter's safety and life, through real time control, without losing its stability during the mission.

For modelling through the adaptive mechatronics methods of the robot implemented by the versatile, intelligent and portable robot VIPRO platform are presented three intelligent control interfaces (ICs). Human adaptive mechatronics are intelligent electrical-mechanical systems that are able to adapt themselves to the human's skill in various environments and providing assistance in improving the skill, and overall operation of the combined human machine system to achieve the improved performance. The VIPO platform architecture, in correlation with the virtual projection method (Figure 1) is developed in Figure 2.

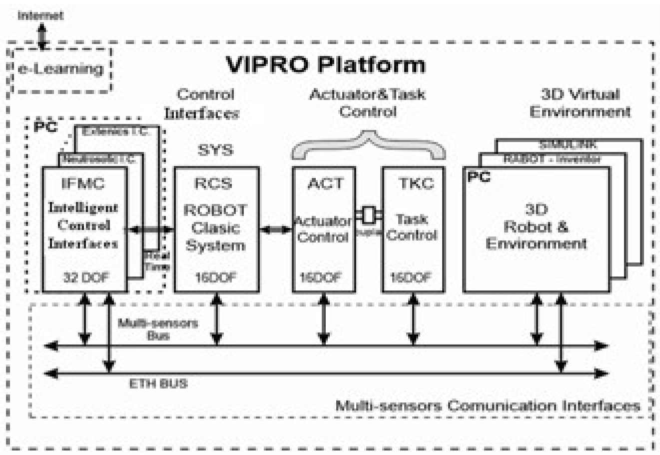

Fig.2 Integration of the VIP-F^{2}Ro Platform in the VIPRO Platform architecture

The results of simulation investigation and identifying the features and parameters of the virtual intelligent platform VIP-F^{2}Ro are obtaining by simulation studies. These will be used to establish the UGV optimal parameters for intelligent interfaces development. VIP Platform allows intensive simulation studies for damping motion, motion compensation, UGV swing amplitude, UGV rotation/advance, motion timing, motion orientation, UGV tilt over, landing position.

The technical solution for the VIP-F^{2}Ro platform contains the intelligence control interface module, which uses advanced control strategies adapted to the robot environment such as extended control – Extenics, neutrosophic control human adaptive mechatronics, etc., implemented through various IT&C techniques, with fast processing and real time communication. This module contains mainly the interface for intelligent neutrosophic control by integrating the RNC (Robot Neutrosophic Control) method [12], known as Vladareanu-Smarandache method, Extended Control Interface through Extenics (ICEx) [10, 13] and Haptic Robot Control Interface (CRH) [9-11].

The control system comprises the proposed intelligent control interfaces: neutrosophic control interface (ICN) which integrates neutrosophic robot control (RNC), extended control interface (ICEx) which integrates extended hybrid force-position control (eHFPC) and the multifunctional control interface (ICM). In addition, the haptic robot control interface (CRH) is designed for movement and navigating on uneven terrain and uncertain environments.

III. ADVANCED INTELLIGENT CONTROL OF THE SMOOTH ROBOT, THROURGH VIP PLATFORM

The new virtual intelligent portable platform of firefighting robots, VIP- F^{2}Ro, is the one designed to acquire the data received from unmanned robotic vehicles, to process and analyse them, to provide feedback. The , VIP- F^{2}Ro brings the virtual robots to the real world, wanting to create an innovative robot platform, which will allow to develop mechatronic systems of mobile robots in virtual environments and communicate with real robot systems through a high speed interface

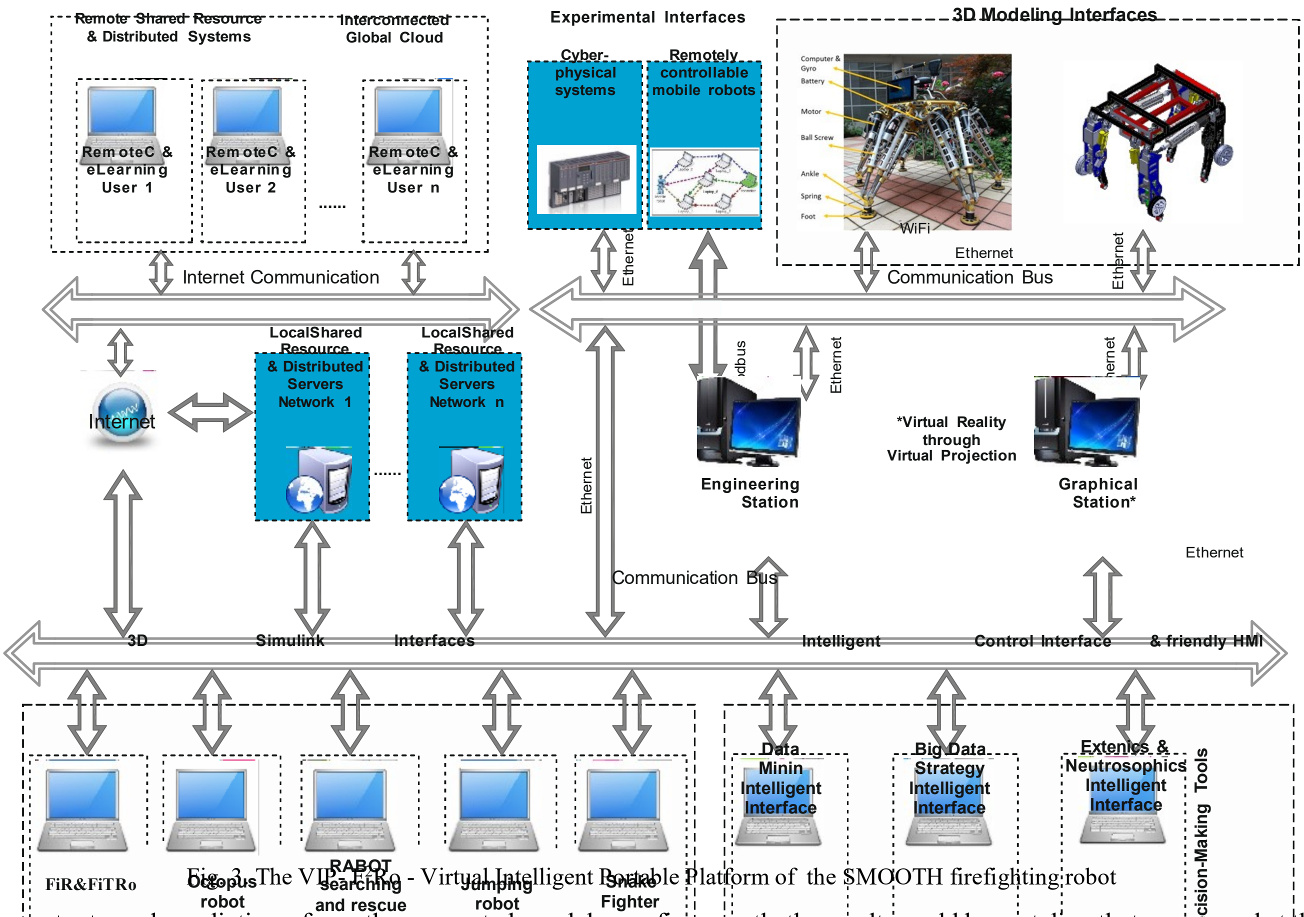

Fig. 3. The VIP-F^{2}Ro - Virtual Intelligent Portable Platform of the SMOOTH firefighting robot

The outputs and predictions from the generated models could be used in multiple ways. In some circumstances, such as fire growth, the results could be sent directly to personnel at the fire ground or to other community services. If the model were to predict that the fire might spread into a portion of a building where toxic compounds are known to be stored, the model could be integrated with a smoke-generation model and a weather model to predict the likely impact on the surrounding community.

That information then would be sent directly to disaster management departments, law enforcement agencies as well as local hospitals to enable planning for a potential evacuation and treatment of victims. In most cases, model outputs and predictions would drive real-time 3D visualization of the fire ground, equipment, and personnel. The ICs would use the display to monitor the evolution of the fire incident and to analyse the potential impact of decisions and actions before issuing any commands to personnel. The visualization then would be recorded for future analysis, lessons learned, and training.

The computational platform VIP-F^2Ro designed in this project will be based on the virtual projection method. VIP-F^2Ro is extendable for integration, testing and experimenting of firefighting environments through building an open architecture system and adaptive networks, combining the expertise of a team of specialists in fire engineering, electronics, mathematics, computer sciences with the expertise of a diverse group of researchers in different fire specialties.

The innovative platform VIP- F^2Ro (Figure 3), developed as open architecture system and adaptive networks integrates Future Internet Systems vision enabling: cyber-physical systems by adaptive networks, intelligent network control systems, human in the loop principles, data mining, big data, intelligent control interfaces, network quality of service, shared resources and distributed server network - remote control and e-learning users by interconnected global clouds. Based on all the above, the challenges and, therefore, expected progress of VIP- F^2Ro are its ability to be interactive, integrated and competitive with advanced scientific research concepts.

The idea is that the robotics mobile unit will go to the safe proximity of the firefighting emergency area, in particular fire and rescue operations such as aircraftIairport rescue, wilderness fire suppression, and search and rescue, including emergency medical services. It can do that as it is equipped with innovative devices that determine the direction and the identification of dangerous clouds and the toxic environment created by combustible materials, their moving direction, nature of agents that contaminate, oxygen deficiency, elevated temperatures, and poisonous atmospheres, provided in safe condition for personnel protection. After the safe stop of robotics mobile unit, there are the correlated actions of unmanned ground and aerial vehicles (VIP- F^2Ro and UAV), all of these coordinated by the virtual intelligent platform, as follows next.

The need to manage all behaviors and interactions is solved by developing a new interface for intelligent control based on advanced control strategies, such as extended control (Extenics), neutrosophic control, human adaptive mechatronics, implemented by high speed processing IT&C techniques in real time communication for a high amount of data processing, including a remote control & e-learning component and an adaptive networked control. This will allow the development of new methodologies, evaluation metrics, test platforms, reproducibility of experiments, novel approaches to academia-industry co-operation, of the products and process innovation and last but not least, an fire engineering network for research and modeling complex of the data for firefighting quick actions, and management of fire and emergency services.

Robotic control is essential in developing control and perception algorithms for robotics applications. A 3D simulator for mobile robots must correctly control the dynamics of the robots and of the objects in the environment. Moreover, real-time control is important in order to correctly model interactions among the robots and between the robots and the environment, so it is often necessarily an approximation to obtain real-time performance.

The innovative firefighting robotic mobile ground vehicle, is sent for support to people, physical evaluation, examination and collection of material I evidence. Some "plus (+)" aspects of this innovative firefighting robot are: high stability and ease of remote control (manoeuvrability) in severe ground topography and I or narrow spaces like pipes; modular structure with, relatively, low costs specific components; ability to work in natural disasters and emergency incidents threatening life and property.

The networked real- time control will be distributed and decentralized using multi-processor devices for fusion control, data reception from transducers mounted on the robot, peripheral devices connected through a wireless LAN for off-line communications and CAN, MODBUS, PROFIBUS or ETHERNET fast communication network for real time control. The VIP- F^2Ro system was designed in a distributed and decentralized structure to enable development of new applications easily and to add new modules for new hardware or software control functions. Moreover, the short time execution will ensure a faster feedback, allowing other programs to be performed in real time as well, like the apprehension force control, objects recognition, making it possible that the control system have a human flexible and friendly interface.

The VIP-F^2Ro Platform develop the intelligent interfaces using Robot Neutrosophic Control (RNC), Robot Extenics Control Interface (eHFPC) and Robot Haptic Control (RHC) Interface for Unmanned Ground robotic mobile Vehicle (UGV) which acts in correlation and interaction with Unmanned Aerial Vehicle (UAV) through implementation of the network mobile robot system over Mobile Ad-hoc Network. The target robot is equipped with a robotic arm to execute various tasks. The relay I observer robot can route network packets between the controller and the target robot. It also produces visual feedback of the target robot to the user at the controlling end.

IV. HAPTIC INTELLIGENT CONTROL INTERFACES

In the recent years haptic interfaces became a reliable solution in order to solve problems which arise when humans interact with the environment. If in the research area of the haptic interaction between human and environment there are important researches, a innovative approach for the interaction between the robot and the environment using haptic interfaces and virtual projection method is presented in this paper. In order to control this interaction we used the Virtual Projection Method where haptic control interfaces of impedance and admittance will be embedded.

For moving of the firefighting robots in uncertain environments, allowing actuation in crisis situations or natural disaster, in which human life is in danger, SMOOTH will develop haptic interfaces that provides the robot spatial orientation and navigation based on that the robot feels the land on which it moves by changing the stiffness of the robot paw joints and of the segments robot joints, using the stiffness associated of the paw joints position X_C on the robot environment map if uneven ground is detected [9-11].

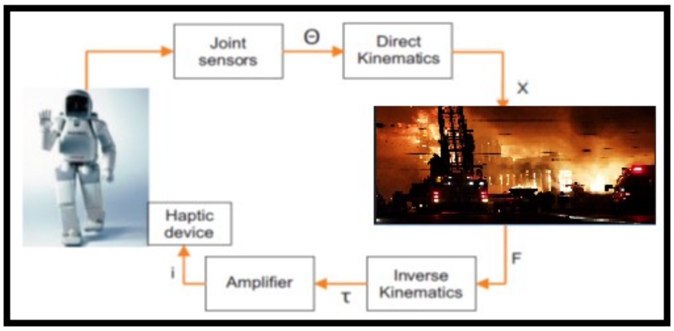

Figure 4. Haptic interfaces for firefighting robots using VIP-F^{2}Ro Platform

This leads to successively change the robot movement scheme and change the position control loop to the force control. Thus, the human operator can remotely control the robot's movement through two parameters, first visual and the second haptic (Figure 4). Respectively, the human operator sees the robot environment map and simultaneously feels damping of the robot leg movement at actuation of the haptic device lever, with the possibility of generating the haptic Cartesian positions X_{CH} for adapting the robot movement, on uneven and unstructured terrain.

Haptic interfaces intend to reproduce or to include the sense of touch through manipulation or, perception of real environments using mechatronic devices and computer control. They consist of a haptic device and a computer for control, which incorporates software that associates input data from the human operator with haptic information rendering. Figure 4 illustrates how haptic interfaces work and the way it will be implemented for controlling firefighting robots using VIP-F^{2}Ro Platform.

The innovative solution developed and patented for haptic robot control allows the robot to "feel" the terrain on which the mobile autonomous robot moves by the **modification in rigidity** of the joints and of the joints segment when detecting unevenness depending on the rigidity K_{Xc} associated to the joint position of the robot X_C on the robot environment map. Modifications in rigidity are realized from the time the joint touches the terrain until complete contact of the joint segment. **The human operator** has the possibility to remotely control the robot movement, through two parameters, one visual and the second haptic, respectively seeing the robot environment map and simultaneously to feel remotely the dampening of the robot joint movement when using the haptic device stick. Depending on the type of manipulation of the haptic device, the human operator generates the haptic Cartesian positions X_{CH} to ensure the robot motion is adapted to the uneven and unstructured terrain in crisis situations or natural disasters where human lives may be at risk.

In order to generate the robot environment map, images are processed from a CCD camera, stabilized for the various robot motion directions. This is done by processing the signals received from a 3D gravitational transducer (TGR3D) and a magnetic compass (TBM), resulting in an interface of the 3D robot environment map with a stable image to the robot movement. Each point in the robot environment map is associated with the rigidity of the robot joint position X_C, named associated rigidity K_{Xc}. **The movement damping** at contact between the uneven terrain and the robot joint is obtained by switching from the position control to the force control from the moment when the tip or the posterior of the joint touches the terrain, depending on the robot motion scheme, until complete contact of the joint segment is made.

Haptic control of the robot movement by the human operator is achieved through a haptic device which allows the human operator to feel the damping of the robot joint movement and generates the Cartesian reference positions of the robot movement, called haptic Cartesian positions X^H_{CH}, for adapting robot movement to uneven and unstructured terrain. **The telemetry module (TL)** allows the measurement of the distance to the joint segment by using an optic scanning device.

The novelty VIP-F^{2}Ro Virtual Intelligent Portable platform for firefighting robots, is competitive with other similar virtual simulation platforms with applications in robotics, called virtual instrumentation, CDA, CAM, CAE, Solid Works, etc., very powerful in modeling but only in a virtual environment, or the MatLab, Simulink, COMSOL, Lab View platforms, which allow extensions for real time data acquisition and signal processing. In addition to these, VIP-F^{2}Ro allow the experimental validation of intelligent control methods by integrating the classical robot real time control system in modelling, design, simulation and testing of the robot motion and stability.

V. CONCLUSION

Development of 3D dynamic perception and visualization, and human-robot interaction software systems are formidably challenging and accordingly the activities to support software developments and project management processes are of vital importance to this piece of research. Attribute selected techniques can be categorised on the basis of a number of criteria. Dynamic data come from environmental and wearable sensors, mobile robots and radio communications. SMOOTH will therefore develop software systems for real-time data analytics to assess situational awareness, asses risk and improve decision-making by firefighters and ICs. New computational software tools and virtual reality engines are being developed to support both risk and the decisions. The VIP-F^{2}Ro Platform also develop adequate metrics and testing tools to determine the effectiveness and validity.

This is part of a larger effort to completely define a virtual environment for the simulation and testing of mechatronic systems on a remote virtual platform, encompassing all the usual and innovative aspects in the field of Robotics research, from low-level actuator control and mechanism design to intelligent operational strategies and environment configuration modelling. It has the advantage of allowing virtually all manner of testing to be made remotely, with little or no extra configuration cost, while reducing the risk of equipment damage and maintaining the realism and end-result application value that can only come with actual hardware testing. This approach combines the best features of both scientific lines of enquiry, software simulation and direct hardware implementation.

Major outcome of this work is development of an Integrated Safe Smart Robotics Mobile Unit & Virtual Intelligent Platform for Remotely - Controlled Technologies in the fire investigation, hazardous chemicals detection, fire and rescue threat the firefighter's safety and life in emergency situations. Its innovation potential comes from the fact that it integrates, through VIP-F^{2}Ro Platform, both UGV (with innovative robotic arm module) and UAV (with innovative sensors and miniature sensors). This is how it enables intervention in various ground condition (uneven terrain, narrow spaces) where examination by humans may not be possible, or could be severely restricted. It allows searching and rescuing in smart firefighting control, safe operating in highly contaminated radioactive and chemical environments, and to facilitate the decision making with higher efficiency and collecting evidence / data which are further automated processed and generated reports are transmitted to decision centre. Also, prediction and local prognoses on highly contaminated areas are available.

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