SEVERE NPP ACCIDENT MANAGEMENT BY INTEGRATED DRONE-BASED MONITORING SYSTEM

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ABSTRACT

Post-accident monitoring system (PAMS) assure measurement of criticality important parameters, transmission of data and support of decision making to minimize consequences of NPP accidents. PAMSs must be tolerant to equipment and communication failures and destructions caused by accidents. Existed wired network-based NPP PAMSs are vulnerable to multiple failures caused by severe reactor accidents and nature disasters. A conception and principles of development and implementation of reliable and resilient post-accident monitoring system based on application of wireless communications and multi-functional drone fleet (PASDM) are suggested. The principles are following: diversity of data sources/sensors and types, communications, decision options; mobility (by drones and robotics); dynamical reconfiguration and redundancy of sensors and communications; self-organization of embedded, ground and mobile devices. These principles assure receiving date about accident in conditions of multiple failures and uncertainty of environment parameters. Tasks of PASDM creation and implementation and structure of system are described.

1. Introduction

The implementation of reliable and resilient post-accident monitoring systems (PAMS) is requirement of regulatory bodies after Fukushima NPP emergency [1]. PAMSs are necessary for other critical systems and infrastructures (chemical enterprises, oil-gas transport systems, etc) to assure measurement of criticality important parameters, transmission of data and support of decision making to minimize consequences of accidents by crisis center. Severe reactor accident monitoring and post-accident safety management systems must be tolerant to any failures and destructions caused by accident/disaster.

Existed NPP PAMSs are based on wired networks (WRN) connecting sensor area with the crisis center. Reliability and survivability of such systems can be assured by redundancy of equipment, cable communications and other components. However, WRN-based PAMS can completely or partially fail in case of severe reactor accident or/and natural disasters. To improve characteristics of PAM and similar monitoring systems Wi-Fi communication and drones can be applied [2-5].

Goal of the paper is to suggest a conception and principles of development and implementation of reliable and resilient post-accident monitoring system based on application of multi-functional drone fleet (PADMS).

2. Tasks

Tasks of creating and implementing PADSM are the following:

2.1. Creation of a PADSM to provide monitoring and real-time data communication for pre- and post severe accident conditions at the NPP by:
- requirement analysis for NPP monitoring and management systems;
- analysis and development of scenarios models for typical severe accidents at NPP;
- development of methods and tools to provide the trustworthiness of sensors data transferred to wired or wireless communication channels;
- creation the special wireless communication network, which provide the required bandwidth till required level during severe accident based on repeaters on the boards of many drones, which are interacting with each other [2];
- development of reliability, availability, survivability and safety assessment and assurance models for analysis of system characteristics influence on NPP safety [5-7];
- development of a core basic version of the decision support system which will be used at severe accidents NPP mitigation to ensure communication security of channels between:
a) the measurement and control modules and transponders drones;
b) drone-repeaters and crisis centers;
c) PADSM and IoT;
d) IoT and experts;
e) experts and crisis center.

2.2. Development of methods and tools to improve the trustworthiness of sensors data and to provide ability for construction of reliable and precision models. The main technology is a testing of all parts of the measurement channel. The main requirement is to provide the necessary error level (or error, which can be evaluated in the real-time) in condition of pre-emergency situations and during the accident.

2.3. Creation of supplementary mobile ad-hoc wireless communication network for sensors data collection based on repeaters located on drones, which will:
- provide the required bandwidth till required level during severe accident in conditions in which other channels of receiving sensors data and commands transmitting are appear particular or full damaged during severe accident;
- provide fast deployment;
- low bandwidth and low cost but high device density;
- provide adequate reliability of data collection and transmitting from sensors to external emergency control rooms;
- low probability of damage during the accident, reparability in any time, high flexibility of use.

2.4. Development of hardware/software capabilities for drone navigation that provides:
- monitoring of drones states during both pre-deployment and flight operation;
- space-localization of drones using global and/or local navigation subsystem;
- detection of static and moving obstacles, and implementation of collision-avoidance methods between drones and uncharted obstacles;
- maneuvering of the drones through indoor passageways, maintaining its current or new position, as well as, take-off and landing at a defined coordinate position with a given tolerance;
- autonomous cooperation between drones during NPP monitoring and accident surveillance, and the formation of a connected spanning network for sensor data collection and transmission.

2.5. Involving investigation results needed for PADSM safety ensuring in pre- and post severe accident conditions at the NPP by:
- reliability, availability, survivability and safety assessment and assurance;
- analysis of PADSM characteristics influence on NPP safety;
- development and research of reliability models taking into account monitoring of the location and sensor configuration and variants of drone fleet and robots application;
- development and research of survivability models considering NPP monitoring system as system with a multi-level degradation and recovery;
- development and research of availability models for various maintenance strategies and processing modes.

2.6. Development of the decision support system which will be used at severe accidents NPP mitigation. For that the following methods and means are developed:
- methods and tools on adapting the basic core version to the terms of a specific NPP;
- methods and tools on implementing the information that comes from the drones-repeaters and drones-observers about currently state of NPP equipment and environment;
- presentation design concepts for a decision support system using cognitive work analysis methods;
- decision support information technology according to technical and regulatory requirements, accident scenarios and terms of a specific NPP;
- tools to generate recommendations by external experts using Internet of Things.

3. Principles
UAVs (unmanned aerial vehicles) such as drones to monitor NPPs at the pre-accident stage should be used considering possibilities and restrictions of their application at the post-accident stage are discussed.

The following principles are suggested:
- diversity principle using:
a) diversity of data sources/sensors which is provided by application of wire sensors, Wi-Fi sensors, Li-Fi sensors;
b) diversity of data transmission which is provided by application of wire network, wireless drone based network, Li-Fi drone based network and Internet of Things based network;
c) diversity of data types which is provided by application of sensors and video data;
d) diversity of pre-decision options (diversity of knowledge for decision making) which is provided by application of pre-decisions by internal group located at the crisis center and pre-decisions by group consisting of external experts);
- mobility (by drones and robotics);
- dynamical reconfiguration and redundancy of sensors and communications;
- self-organization of embedded, ground and mobile devices to assure receiving date about accident in conditions of multiple failures and uncertainty of environment parameters.

Application of a few monitoring channels improves integrity (as most important attribute of security) in extreme conditions. Risks of IoT application, as additional channel of data collection in cloud, caused by attacks on its components and communication are minimized by implementation of well-known techniques. Including of external experts to support decision making by crisis center (internal experts) is very important considering experience of Fukushima accident.

4. Structure
To assure stable work of WLN-based PADSM subsystem after accident in conditions of powerful jamming a special means are required to support reliable transmission of data considering probable failures of WRN. For that and to improve survivability of PADSM introduction of drone fleet subsystem (DS) has been suggested in [2,5]. The drone fleet is located permanently at a considerable distance from the NPP.

The communication network (WLN +DS) is deployed after the accident and drones fly to the accident zone. Drones fleet is divided by the role and equipment into: repeaters (Slave), that work together on a principle of "one leader" and if the "leading drone-repeater" (Master) is damaged then other drone-repeater takes Master functions; observers (equipped with a TV camera), that enable to run the continuous visual monitoring of the accident location; additional sensors, that can be located in drones or be dropped down in certain places).

Drones should be able to change their role by upgrading equipment at the location base. Measurement and control modules are equipped with backup batteries, blocks of wireless communication, as well as, self-testing and self-diagnostic systems. To meet the system requirements the self-adaptability, self-testing and self-healing procedures are used.

5. Conclusions

We propose to use the post-accident monitoring system based on application of multi-functional drone fleet and multi-communication technologies in case of the NPP severe accident. Such PADSM includes one wired network subsystem (as a traditional PAMS) and three wireless network subsystems which are more resilient to multiple physical failures.

Overall the suggested PADSM will provide opportunities for better real-time decisions making and monitoring capabilities to assess the progress of a predicted emergency situation by addressing the following concerns:

- provide real-time comprehensive NPP system status data in terms of various reactor-operating states,
- provide visual and sensor data for plant components (steam pipes and steam-generator tubes), the frequency of events, and evidence of human factors failures,
- provide critical real-time data sets used in a branch-and-bound PSA analyzer, and
- provide situation-awareness data sets for first responders and emergency control room personnel.

References

1. Accident and post-accident monitoring system. Retrieved November 25, 2016, from http://imp.lg.ua/index.php/en/pams-2.
2. Hiromoto, R., Sachenko, A., Kochan, V., Koval, V., Turchenko, V., Roshchupkin, O., Kovalok, K. (2014). Mobile Ad Hoc Wireless Network for Pre- and Post-Emergency Situations in Nuclear Power Plant. In Proceeding of The 2nd IEEE International Symposium on Wireless Systems within the Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS 2014). Offenburg, Germany.
3. Sanada, Y., & Torii, T. Radiation measurement by unmanned aircraft after Fukushima Daiichi nuclear power plant accident (2015). Retrieved November 25, 2016, from http://www.icao.int/Meetings/RPAS/RPASSymposiumPresentation/Day%201%20Session%202%20Massaki%20Nakadate.pdf
4. Towler, J., Krawiec, B., & Kochersberger, K. (2012). Radiation Mapping in Post-Disaster Environments Using an Autonomous Helicopter. Remote Sensing, 4(7), 1995-2015.
5. Sachenko, A., Kochan, V., Kharchenko, V., Roth, H., Yatskiv, V., Chernyshov, M., Fesenko, H. (2016). Mobile post-emergency monitoring system for nuclear power plants. In Proceedings of the 12th International Conference on ICT in Education, Research, and Industrial Applications (ICTERI 2016). Retrieved November 25, 2016, from http://ceur-ws.org/Vol-1614/.
6. Kharchenko, V., Sachenko, A., Kochan, V., & Fesenko, H. (2016). Reliability and survivability models of integrated drone-based systems for post emergency monitoring of NPPs. In Proceeding of The International Conference on Information and Digital Technologies 2016 (IDT 2016). Rzeszov, Poland: University of Rzeszow press.

7. Kharchenko, V. (2016). Diversity for Safety and Security of Embedded and Cyber Physical Systems: Fundamentals Review and Industrial Cases. In Proceeding of 15Tth Biennial Baltic Electronics Conference (BEC 2016). Tallinn, Estonia: Tallinn University of Technology press.