ROBOTIC LOCALIZATION OF RADIOLOGICAL SOURCES

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Abstract: The paper presents current means in the field of the autonomous robotic localization of gamma radiation sources. It introduces a method for speeding up the localization which is based on a partially direction-sensitive two-detector system and its limitations. In comparison with a referential radiation mapping, the method offers three times faster localization preserving the similar accuracy. Finally, an integration of the results into the multi-robotic system ATEROS via the augmented reality is outlined.

Keywords: radiological sources, mobile robot, GNSS, autonomous search, augmented reality

1 INTRODUCTION

At present, radiological sources can be found in many industrial, medical, and scientific facilities. Under some circumstances, these sources may become a target of a criminal act and consequently get lost or even dispersed in an urban zone during a ‘dirty bomb’ attack. In order to minimize the negative impact of such an incident, the first responders should be equipped appropriately. Our team at the Faculty of Electrical Engineering and Communication is developing the multi-robotic system ATEROS (autonomous telepresence robotic system), in which a robot capable of autonomous localization of radiological sources is included.

The goal of this paper is to introduce methods for speeding up the process of source localization using an unmanned ground vehicle (UGV). Different methods for the localization can be found in the scientific literature. The traditional way is represented by helicopter-borne detection systems [1]. A modern approach consists in utilizing unmanned aerial vehicles (UAVs) [2]. Although these methods are usually fast, they have relatively limited accuracy due to the large distance from the sources. Conversely, UGVs do not share this disadvantage and can be employed when the accuracy embodies a crucial parameter. Solutions based on mobile robots are outlined in, e.g., [3].

The paper is organized as follows: Sec. 2 describes the technical equipment. Algorithms for the source localization using the two-detector system are presented in Sec. 3. In Sec. 4, the directional detection system is introduced. Sec. 5 offers an overview of the achieved results. Sec. 6 deals with the visual presentation of the results. The overall outcomes are summarized and discussed in Sec. 7.

2 SYSTEM DESCRIPTION

Our team developed advanced reconnaissance robot Orpheus-X4 and it is available for our research without restraint, therefore all algorithms are demonstrated using it. Orpheus-X4 is a mid-size four-wheeled robot with a differential drive; the whole system (including the equipment) is shown in Figure 1 (left).

Beside the robotic platform, the system consists of a precise Global Navigation Satellite System (GNSS) receiver Trimble BD982 with the dual antenna input that enables measurement of the azimuth. The device works in the Real Time Kinematic (RTK) mode, thus is able to measure the robot's position with the error under one centimeter. The navigation module for the robot is described in [4].

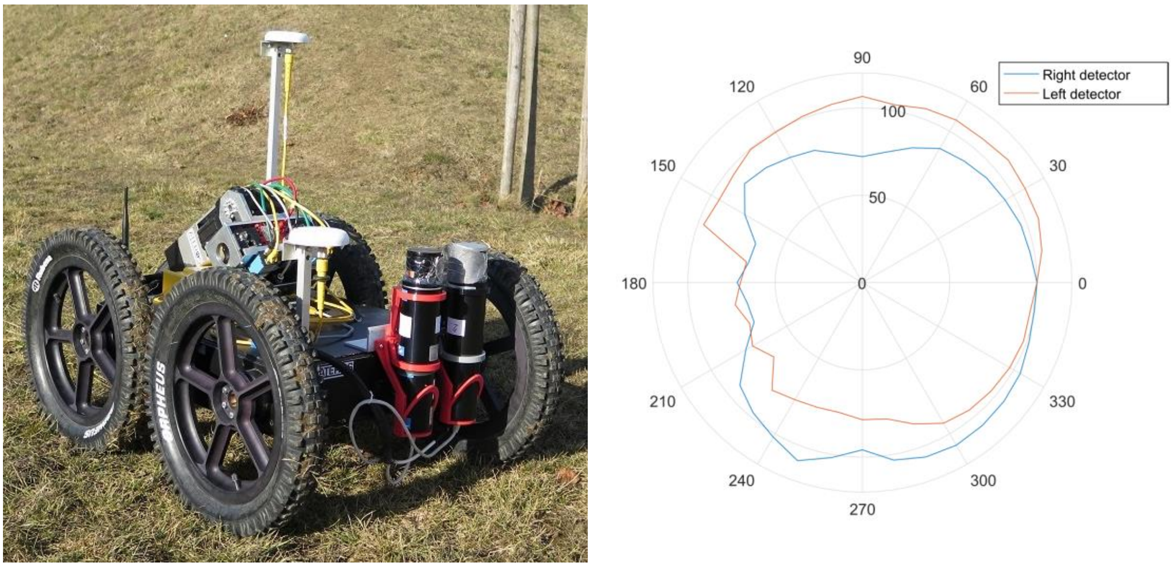

Figure 1: The Orpheus-X4 (left), the directional sensitivity of the two-detector system (right)

The robot also carries a radiation detection system embodied by two detectors and counting electronics. Two-inch crystals of sodium iodide doped with thallium (NaI(Tl)) serve as the detectors. The measured signal is processed in analyzers Nuvia NuNA MCB3 which are also responsible for a communication with the control module. The reason for using two detectors consists in a partial directionality of the resulting system; it is in addition improved by a 4 mm thick lead layer placed between the detectors. Achieved directional sensitivity is charted in Figure 1 (right).

The robotic system includes miniature network camera AXIS P1214-E which is designed for outdoor surveillance. It comprises a main unit which is hidden inside the robot and a separate sensor unit mounted on the robot's sensor head.

3 LOCALIZATION ALGORITHMS

The essential algorithm for the localization of lost radiation sources in a pre-defined region of interest is denoted as a *radiation mapping*. It is based on the conventional approach of surveying the ROI along parallel lines. The advantage of this algorithm consists in an independence of the result on initial conditions; it is capable of dealing with all kinds of scenario, e.g. a presence of area or anisotropic sources. However, the utilization of the radiation mapping constitutes great time requirements and is not suitable for a quick survey of large areas.

The idea is that adding another type of information could lead to speeding up the process of the localization; for example a direction from which the radiation is coming. Since the directionality of the used detectors is rather indistinctive it is beneficial to explore the area along closed loops such as a circle; the measurements taken on one should form a cyclic signal containing peaks in points that correspond to directions of sources in a detectable distance from the circle.

Due to the statistics of the radiation decay, the measurements usually do not form a smooth signal; it tends to be full of insignificant peaks that need to be ignored (a peak is defined as a point having greater value than its two neighboring points). Only those peaks whose value multiplied by a constant denoted as *prominence* is greater than the corresponding reference level are accepted. It is possible that the highest value does not correspond to the direction in which the source is. Moreover, the measurement results in rather rough quantization of the directions. Considering these circumstances, better estimation of the direction should be achieved by utilizing the interpolation. Then, by applying the two-detector system it is possible to decide on the direction of the source unambiguously (whether it is located inside or outside the circle).

The direction itself does not constitute a sufficient piece of information for determining the location of the source. It is not possible to decide whether the radiation is emitted by a near weak source or a far strong source. There are several approaches to acquire additional data to localize the source. First, it is possible to send the robot in the estimated direction and measure data along this line. In accordance with the intensity increase rate it is possible to calculate the distance from the inverse square law [5]. However, the estimation of the direction is usually not accurate, therefore, the source is approached under some non-zero angle which is not known, thus cannot be compensated.

Second, the robot follows the directional line until a local maxima of the radiation intensity is passed. Again, due to the inaccurate estimation of the direction coordinates of the maxima generally do not correspond to coordinates of the source. First possible fix is to measure additional data along a line segment perpendicular to the directional line intersecting it in the local maximum. Another fix consists in a continuous update of the robot's direction to minimize the difference between intensity measured by both detectors: if the controller is set well, the maximum should correspond to the source's location. Finally, the source can be detected from multiple points and its location estimated as the intersection of directional lines. Given this idea, the process of the sources localization could be speeded up by covering the region of interest by circular trajectories where each circle provides partial information.

The radiation measurements are generally inaccurate for the described scenario due to the statistical character of the radiation decay, a randomness induced by the radiation background and a short integration period insufficient to suppress these effects. One way to improve the estimation of the source's location comprises a model of the radiation field and its iterative update of parameters using gradient methods. The modelling of the radiation is outlined in [3]. The Gauss-Newton algorithm [6] was chosen as a candidate for the improvement of the model's parameters.

4 RESULTS

The suggested algorithms were verified using real radiological sources. The region of interest was defined as an irregular polygon with the area of 438 m^2. In the first experiment the radiation mapping algorithm was tested. Spacing of parallel lines was equal to 1 meter, consequently the mapping took 15 minutes. The result after the interpolation of the radiation map using a Delaunay triangulation can be found in Figure 3 (left), the black crosses mark estimated position of sources. In order to evaluate results, the accurate position of the sources had been measured prior to the experiment. Achieved accuracy was equal to 6.3 cm RMS.

In the second experiment the circular algorithm was employed to perform the localization. Three radionuclides with similar intensities were used for the verification, the ROI was covered by six circles. With this setup, the data acquisition took approximately 5 minutes. Then the Gauss-Newton algorithm was applied resulting in the accuracy of the localization was equal to 17.8 cm RMS. The measured data as well as the sources' reference position and estimations are shown in Figure 3 (right).

5 PRESENTATION OF A THREAT TO A HUMAN OPERATOR

Once the points of interest are localized, they can be presented to a human operating robots via the telepresence using a technique called the *augmented reality*. The idea is to calculate the position of the points within the image frame acquired by the onboard camera and then visualize them for the operator and optionally add detailed information on the point. The task can be divided to two major steps: first, the coordinates of a point are transformed from the world coordinate system to a local coordinate system of the camera, second, the point is projected to the camera's image plane.

Approximately zero tilt of the robot is considered in this paper for simplification due to limitations of the GNSS receiver. In order to measure all components of the orientation, it would be necessary to extend the system with an inertial measurement unit (IMU). Considering this constraint, the transformation of the point's coordinates to the system originating in the center of the robot O_R consists only in a translation and a rotation along the *z*-axis.

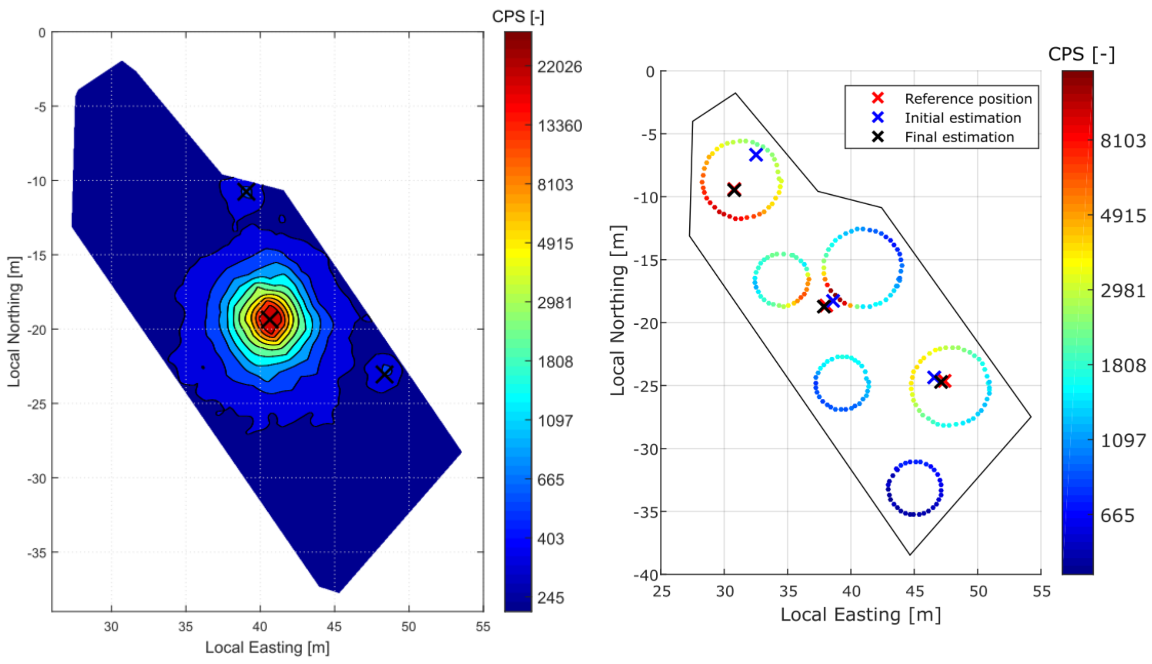

Figure 2: The result of the radiation mapping algorithm (left), the result of the circular algorithm followed by the Gauss-Nexton method (right)

A kinematic scheme of the robot which is used for the transformation of coordinates from the system O_R to the system originating in the optical center of the camera O_C is presented in Figure 4 (left). The calculation of coordinates of the point in the image plane of the camera is described in [8]. To do so, intrinsic parameters of the camera need to be identified during a process called the *camera calibration*. It is based on taking several pictures of a chessboard-like pattern with a different position and orientation. The calibration itself was performed utilizing the GML C++ Camera Calibration Toolbox [9] which was supplied with 8 images containing two different calibration patterns.

The augmented reality was integrated to the robot control system and tested using data previously measured during the radiation mapping. Resulting screenshot taken from the operator's station can be found in Figure 4 (right). The source of radiation is represented by the ionizing radiation hazard trefoil accompanied by a distance from the source.

6 CONCLUSION

The paper presented techniques for the localization of gamma radiation sources using a mobile robot. The solution exploits the advanced robotic platform Orpheus-X4 equipped with radiation detectors and precise self-localization module based on the RTK GNSS technology. The algorithm which takes advantage of the partial directional sensitivity of the two-detector system was suggested and tested in comparison with the radiation mapping; it proved that the algorithm is able to cover the same area faster. However, it is necessary to consider disadvantages of the algorithm, namely, a limitation to point sources only, impossibility to correctly localize sources that are not well separated by a space. In any case, the algorithm represents a beneficial fundament for the further development.

The task of the localization of sources is one of possible missions for the multi-robotic system ATEROS. The idea is to extend the system with other functions such as an autonomous map-difference identification which seems to be applicable in the Industry 4.0. The robot equipped with a wide range of sensors, e.g. a three-dimensional optical scanner, a thermographic camera, a chemical detector, may be used for building a multispectral map of the environment. A difference in the map could indicate a trespassing of an unauthorized person, a technological accident or a leak of dangerous substance. It is assumed that some algorithms used for the autonomous gamma radiation sources localization can be applied in the area guarding as well. Although the dangers are planned to be detected autonomously, in specific scenarios it may be required to explore the object by the experienced personnel. In this case, the detected threats may be presented to the personnel using the augmented reality which was described in this paper as well.

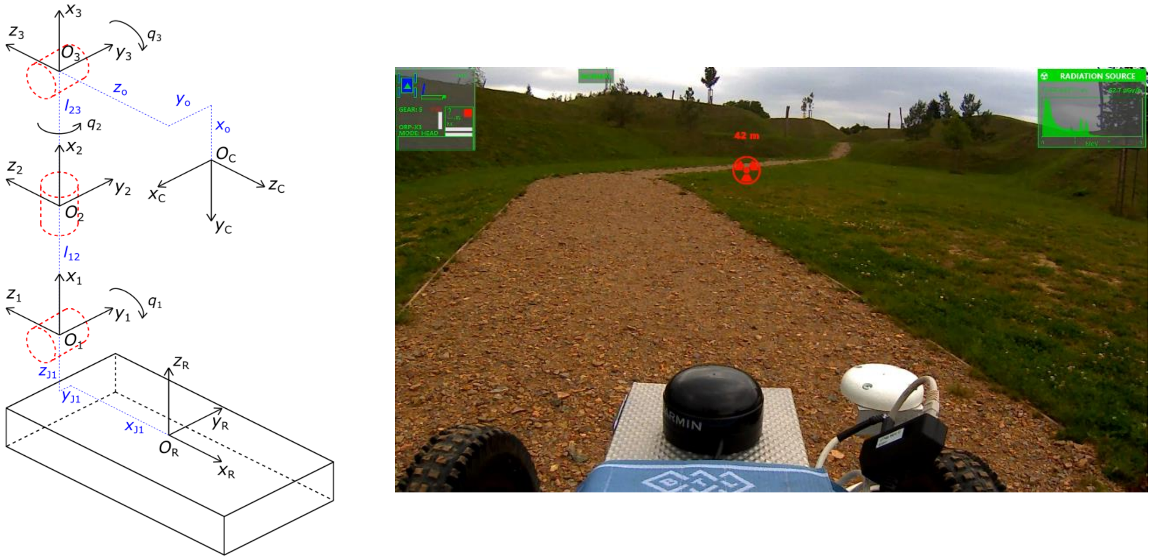

Figure 3: The kinematic scheme of the Orpheus-X4 (left), the screenshot from the operator's station illustrating the augmented reality (right)

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