2020 4th International Conference on Automation, Control and Robots

Handheld Localization Device for Indoor Environments

Jan Bayer, Jan Faigl
Faculty of Electrical Engineering
Czech Technical University in Prague
Technicka 2, 166 27, Prague, Czech Republic
e-mail: {bayerja1|faiglj}@fel.cvut.cz

Abstract—**In this paper, we address the problem of human safety during the search of underground or unknown indoor environments in scenarios where it is required to share the information about the position of the personnel such as first responders or speleologists. We report on the developed localization device to estimate and transmit the user position and state through a custom communication system. The information provided by the device serves to monitor the user state, enable communication between the user and the base station located outside the environment being searched. The personnel's position in the environment is thus provided to the mission supervisor in the case of an emergency. The device is based on low-cost off-the-shelf cameras for vision-based localization and low-bandwidth communication modules suitable for long-range communication in underground environments. Furthermore, the communication range is extendable by affordable transceivers that allow the dynamical building of independent communication networks in the operational environment. The performance of the communication system has been examined in an experimental scenario where five transceivers sufficiently cover 280 m of cave tunnels. The system can localize a human independently on any infrastructure supported by a report on the experimental deployment in an urban scenario with both indoor and outdoor areas.**

Keywords-localization; underground communication; GNSS denied; handheld device; indoor localization; visual localization; intel RealSense T265

I. INTRODUCTION

The localization is essential for an overview of the situation when an agent search underground cave systems or unknown indoor environments. When the agent is not at the line of sight from the base station, it is desirable to communicate the agent's position to the mission supervisor. In mobile robotics, there already exist several approaches addressing the robot localization and communication in various environments [1], [2]. These approaches are based on the sensor and communication equipment developed to be carried by mobile robots. In this paper, we report on the development of a suitable device to address the localization and communication that can be handheld by human personnel, which requires a small, lightweight, and easy to use solution. The proposed solution consists of a handheld localization unit that broadcasts its position to the base station placed at the entrance of the mission area. Furthermore, the communication range can be extended by droppable retranslation communication nodes. The prototype of the developed handheld localization device is shown in Fig. 1.

Figure 1. The prototype of the proposed handheld localization broadcaster device (light version).

The rest of the paper is organized as follows. An overview of the related approaches to search in unknown environments focusing on localization and communication is briefly mentioned in Section II. The proposed equipment prototypes are described in Section III. Results from the experimental deployment of the localization device and communication network building are reported in Section IV. The summary of the performed experimental deployments and concluding remarks are presented in Section V.

II. RELATED WORK

Solutions capable of localization independent on any infrastructure and that report the estimated position through an independent communication network can be found in the domain of mobile robotics motivated by extraterrestrial deployments [3] or search-and-rescue missions [1], [2] recently deployed in the DARPA Subterranean Challenge [4]. Although these solutions are capable, they are designed for mobile robots that can carry relatively heavy sensory equipment, powerful computers, and bulky communication

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modules [1]. However, we decided to develop a localization unit using lightweight sensors, a small embedded computational unit, and pocket-size communication devices to address the usability of the device by human users.

The crucial part of the desired system is localization. Unlike Global Navigation Satellite System (GNSS) [5], and pattern tracking systems [6], the localization systems suitable for unknown indoor-like environments cannot rely on any external infrastructure or line of sight. The needed localization methods have to use only sensors carried by the localized entity. Light Detection, Ranging sensors (LiDARs) [7], and different types of cameras for vision-based localization [8], [9], [10], [11] are currently dominating the utilized sensory equipment [12], [13]. The main disadvantage of these approaches is their computational requirements. For example, the state-of-the-art ORB-SLAM2 [14], according to the experiments reported in [15], requires a computer at least with the Intel i5 CPU class to run at 7 Hz. Such a CPU itself has reported power consumption about 15 W, which increases the battery drain, especially for small and light battery packs suitable for a handheld sized device. On the other hand, there is recently introduced tracking camera, the Intel RealSense T265 [16], capable of running a visual localization algorithm on the dedicated computational unit to increase the power efficiency and lower computational requirements on the external processing unit. The T265 requires only units of watts, which thus represents a suitable and affordable localization solution [17].

The additional essential part of the desirable handheld localization system for underground environments is communication that allows users to share information with the base station. In large cave systems, and other challenging environments like underground mines, the communication infrastructure is simply non-existent, it is very limited [18], or it can be damaged, especially during search-and-rescue missions. Wired communication is not always possible to utilize, such as in dangerous environments where the wire may get damaged by, e. g., fire, or roof fall [19]. Moreover, the wireless communication network is usually easily shareable by multiple users. Thus, it saves material carried by the users who can instead carry extra retranslation nodes to extend the range of wireless communication. There are multiple strategies for retranslating signals for mobile robots [20]. In underground scenarios, the wireless signal propagation depends strongly on environment properties [21], which induces requirements on the placement of the individual retranslation modules [22]. In the worst-case scenario, when no information about the environment is available, we can use the Received Signal Strength Indication (RSSI) to support a decision when the retranslation module should be dropped.

III. PROPOSED EQUIPMENT FOR LOCALIZATION BROADCASTING

The idea of the handheld localization device to share the entity position via the wireless communication network is to accompany the Intel RealSense T265 tracking camera with the necessary computational unit and communication node. We can also employ an RGB-D camera to provide the user with an online 3D or elevation map [23] of the searched environment. Besides, we can further imagine additional modules. Therefore, we propose to build the central block of the device using 20 mm Rail Interface System (RIS) to ensure the modularity of the developed device. The handle is attached to the bottom rail, where is also space for the embedded computer. The configuration of the prototype is visualized in Fig. 2.

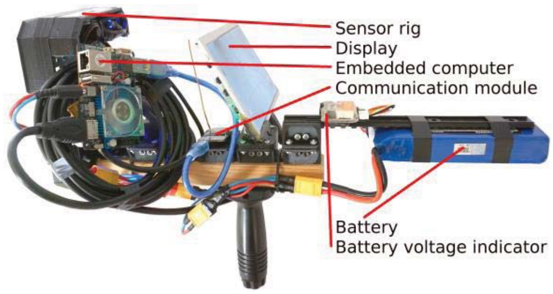

Figure 2. Device prototype with the display, due to the display cable management during the experiment, the embedded computer was moved from the bottom part of the device.

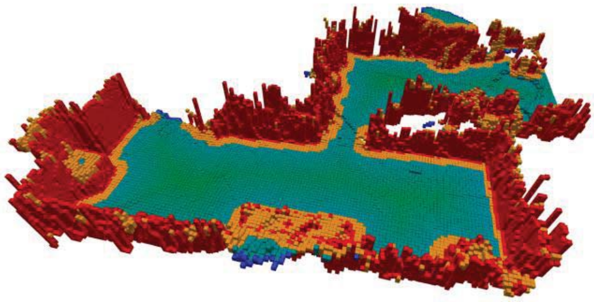

Figure 3. An elevation map of an indoor office environment captured by the sensor rig.

The device has a mounted sensor rig consisting of the tracking camera Intel RealSense T265 and the depth camera Intel RealSense D435 [24]. There is a set of controllable LEDs to illuminate dark environments, which is necessary to support the tracking camera for visual localization. Besides, the LEDs also serve as a personal flashlight. The depth camera allows building the local map of the environment, but it is not mandatory for providing localization. An example of the build map is shown in Fig. 3. The embedded computational platform is based on the Odroid XU4, and the battery used is 5.2 A h. The total weight of the device with both cameras, battery, and embedded computer is about 1.3 kg that the device lasts for at least 2.2 h.

The utilized RIS enables the attached modules to be replaced or removed. The configuration without the display and with sensor rig for non-dark environments is shown in Fig. 4 has weight approximately 1 kg, and with the 5.2 A h battery lasts for 5.3 h. The modularity of the device allows various modifications, such as usage of the battery with high capacity to increase the runtime. Moreover, the localization and communication modules are attachable to other equipment with RIS carried by the user.

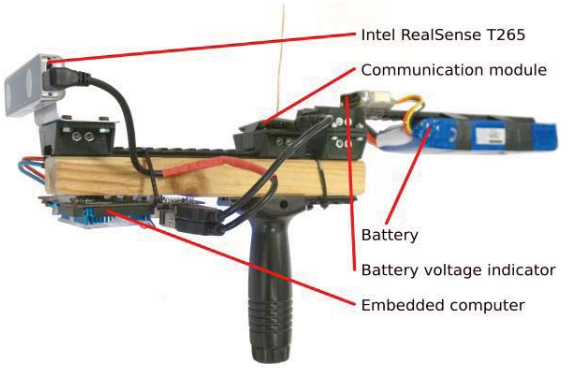

Figure 4. The light version of the device prototype without display and with a sensor rig suitable for non-dark environments.

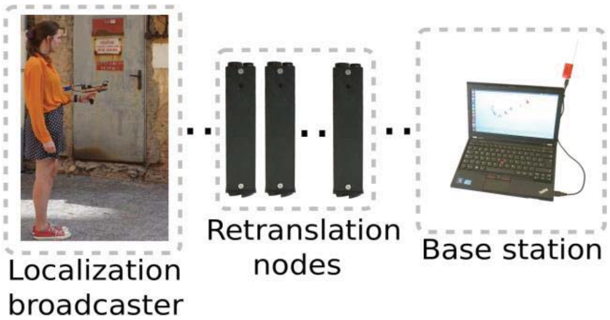

Figure 5. Application schema.

The proposed localization device communicates with the base station directly or through retranslation nodes, as indicated in Fig. 5. Each node rebroadcasts the incoming packet that allows multiple users to utilize the retranslation nodes deployed in the environment. Besides, it also supports sharing positions of the users in the environment. However, efficient sharing of the positions in the same coordinate frame requires correct initialization of the initial pose of all devices before the deployment, which is considered to be out of the scope of this paper.

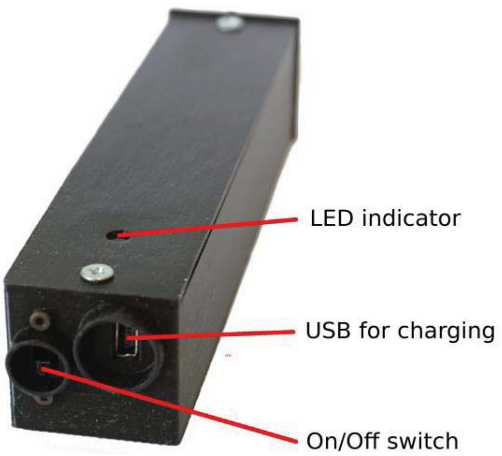

Figure 6. Droppable retranslation node; the weight of the node is 120 g, and its dimensions are 14.7 × 3 × 3 cm.

The (retranslation) communication node is shown in Fig. 6. It has an independent internal 18650 Li-Ion battery with under-voltage protection circuit and charging circuit. A single Li-Ion battery with the capacity 3 A h is able to power retranslation modules for 18 h.

The same communication module is utilized for retranslation nodes and the handheld localization device. Thus, when the RSSI measured from the packets sent by the localization device to the closest node is below the threshold r_σ , the retranslation node should be switched on and dropped to build the communication network. The node automatically starts to rebroadcast incoming packets, and the observed RSSI increases.

IV. Experimental Results

Two experimental deployments have been designed to test the proposed device and show its usage in real-world conditions. The first deployment is focused on the examination of the communication system capabilities in the real cave system. The second experiment is a deployment of the whole system in an urban scenario, where both the precision of the localization, and the communication system have been examined.

A. *Testing Communication Network in a Cave Scenario*

The communication network has been put under the test in a cave tunnel shown in Fig. 7. We tested the range of the retranslation nodes and the reliability of sending messages through the network. Five retranslation nodes covered a 280 m long part of the tunnel. The network created during the experiment was capable of sharing information between all possible pairs of nodes, and less than 50% of messages were lost. The positions of the nodes measured by a total station with sub-centimeter precision are visualized in the created 3D map of the cave tunnel depicted in Fig. 8.

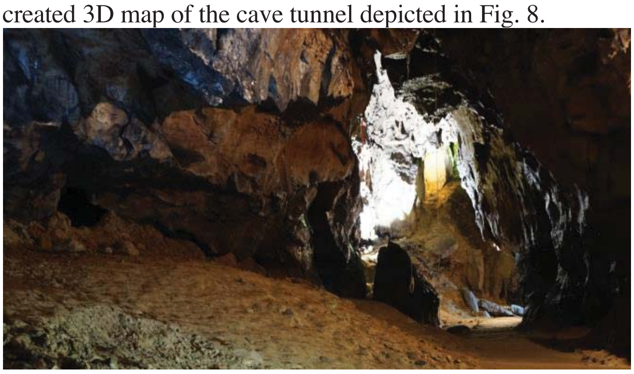

Figure 7 The cave tunnel used for testing the communication network.

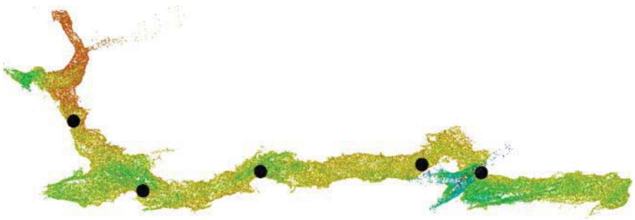

Figure 8. 3D scan of the cave tunnel with marked positions of the retranslation nodes.

B. Experimental Deployment in an Urban Scenario

The second experiment has been located at both indoor and outdoor parts of the university campus, see Fig. 9. In this setup, the user's localization has been shared with the base station through retranslation nodes. The trajectory of the user has been reported to the base station using the proposed equipment. The ground truth trajectory has been obtained utilizing the total station with sub-centimeter and prism attached directly to the handheld device carried by the user. The achieved precision of the trajectory reported by the developed handheld device has been measured by the well-established metric of the Absolute trajectory error (ATE) [25].

Figure 9. Experimental setup in an urban scenario.

The measured and ground truth trajectories are visualized in Fig. 10. The ground truth trajectory was approximately 246 m long and provided at 10 Hz by the total station, while the trajectory of the user was received at the base station at 0.25 Hz. Four retranslation modules have been dropped during the experiment based on the measured RSSI with the threshold $r_\sigma = -65$ dB m. The average translational ATE measured during the experiment is 81 cm, and the root mean squared error of the translational ATE is 119 cm. Although there is a localization drift, noticeable at the end of the trajectory, the shape of the trajectory well captures the topology of the user's motion.

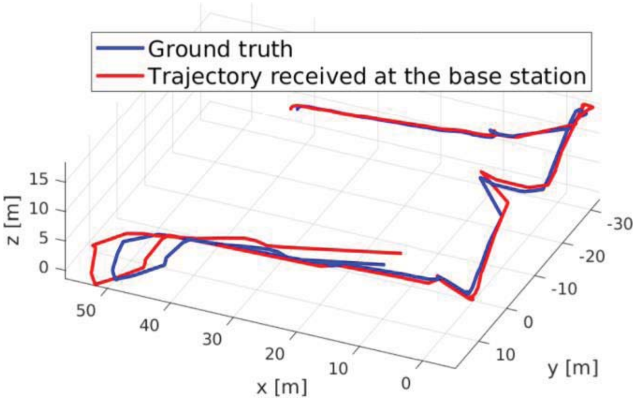

Figure 10. Trajectory of the user reported to the base station and the ground truth trajectory used for the evaluation.

V. Conclusion

In this paper, we report on experimental results obtained from the real-world deployment of the developed handheld localization device based on tracking camera and custom communication nodes. The results achieved in the cave scenario indicates that the proposed communication system is capable of covering a relatively large cave system using units of retranslation nodes. In the urban scenario, the achieved absolute trajectory error is about 81 cm, and the frequency of the user's position is 0.25 Hz that can be considered sufficient for supporting situational awareness of the supervisor in a cave and urban-like missions.

Acknowledgment

The presented work has been supported by the Czech Science Foundation (GAČR) under research Project 18-18858S and GA20-29531S. The support under the OPVVV funded project CZ.02.1.01/0.0/0.0/16 019/0000765 "Research Center for Informatics". The support under grant No. SGS19/176/OHK3/3T/13 to Jan Bayer is also gratefully acknowledged.

The authors would like to thank Petr Čížek for his support with the wireless communication modules.

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