FSR Backpack: A Wearable Device to Improve Humanitarian Demining Operations

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Abstract

This paper presents the Field and Service Robotics (FSR) Backpack, a wearable kit that was designed to improve and speed up field demining operations. We describe the hardware and the integration of all sensors comprised in the kit, as well the software developed, which enables real-time monitoring of humanitarian demining tasks. A preliminary field test was conducted to assess the localization system and overall potential of the FSR Backpack and we discuss the usability and advantages of using the device. The results show promising system capabilities and enable us to outline future directions of research work in the context of the EU FP7 TIRAMISU project.

1 Introduction

Humanitarian Demining is a serious problem in post-war countries. Around 55 people are killed or injured every day in landmine related incidents, specially civilians. Clearly, there is a need to improve safety, reliability and speed of demining operations while reducing time, labor and fund wasting due to false positive detection as well as tediousness and stress levels of demining operation teams [1, 2].

The objective of the EU FP7 TIRAMISU project is to provide the mine action community with a toolbox to assist in addressing the many issues related to humanitarian demining, thus promoting peace, national and regional security, conflict prevention, social and economic rehabilitation and post-conflict reconstruction [3]. The team at the Institute of Systems and Robotics of the University of Coimbra (ISR-UC), a project partner, has been developing research related with robotics tools for field demining operations, chemical sensors and sensor fusion for landmine detection [4, 5].

Having this in mind, in this paper we present the FSR Backpack (*cf.* Fig. 1), a wearable kit that was designed to improve and speed up field demining operations. Using this device, a human deminer can test the adequacy of commonly used sensors in field robots, continuously transmit field data to a remote center of operations such as camera feeds or accurate position, record field datasets for further assessment, receive instructions related with trajectory planning and coverage, and much more.

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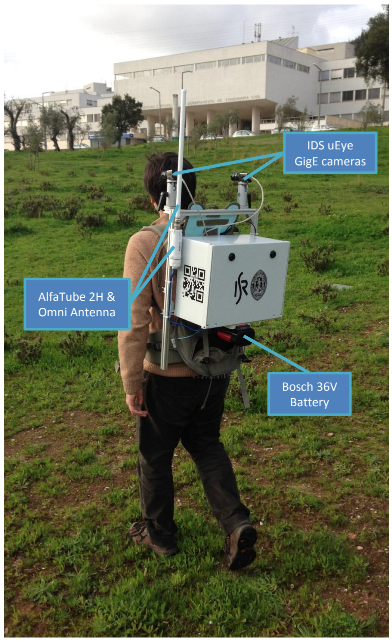


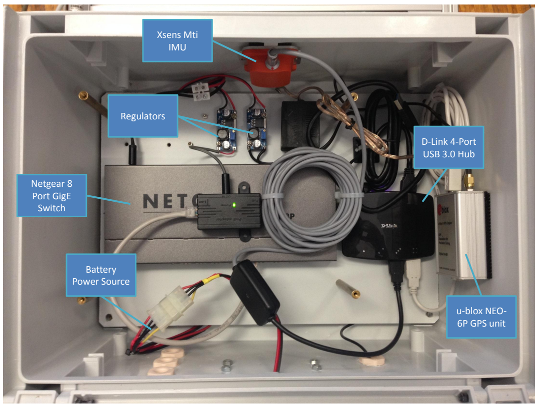
Figure 1: An operator equipped with the FSR Backpack during field experiments.

In the remaining of this paper, we describe the hardware components that are integrated in the FSR Backpack and make a brief overview of the software developed to provide intelligent capabilities to the device. We also conduct a field trial for preliminary validation of the FSR Backpack and discuss the results obtained in the field. Finally, the article ends with concluding considerations and future research directions.

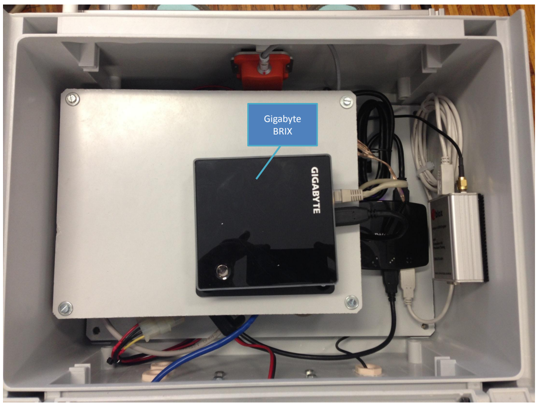
2 The FSR Backpack

The FSR Backpack is comprised of several sensors and hardware. Most of them are placed inside the main compartment, where two shelves enable an adequate organization of the components. The disposition of these components is displayed in Fig. 2. Below, we describe the modules that integrate the kit.

A diagram of all the modules, which illustrates how they communicate and how they are powered is presented in Fig. 3. The power of the kit is handled by a Bosch 36 V battery which is placed under the main compartment, as shown in Fig. 1. Fours regulators provide the needed outputs of 5 V, 12 V, 19 V and 24 V to power all the components of the backpack. As seen further on, the latter regulator was not necessary since we did not make use of the optional laser range finder.



(a) Lower Shelf.



(b) Upper Shelf.

Figure 2: Hardware and sensors inside the main compartment of the FSR Backpack.

Regarding sensors, two IDS uEye GigE cameras are placed over shoulders height to provide real-time imaging in the field with a resolution of 1280×1024 at 50 FPS and equipped with 8 mm lenses. These cameras are mounted on ball joints on top of rails that allow adjusting the baseline and camera orientation. A wide variety of computer vision algorithms [6] can be used to perform different tasks in the field such as stereo reconstruction, visual odometry localization, tracking of a hand-held mine detecting systems, and more.

Additionally, an Xsens MTi-300 Inertial Measurement Unit (IMU) provides 3D orientation, acceleration and rate of turn to the FSR Backpack. This component features vibration-rejecting gyroscopes and a novel sensor fusion algorithm that overcomes limitations in Kalman filtering, named Xsens Estimation Engine (XEE). It also has a 1.0 degree accuracy in roll, pitch and yaw measurements. This equipment enables us to track the backpack pose in 3D, and can optionally be used to control and stabilize the cameras.

A very useful sensor for outdoor navigation is a Global Positioning System (GPS) unit. The FSR Backpack is equipped with the u-blox NEO-6P GPS, which combines the high performance of the u-blox 6 position engine with Precise Point Positioning (PPP) technology. It yields extremely high levels of position accuracy in static and slow moving applications. The raw data output is used by the Real-Time Kinematic (RTK) software to improve the estimation of latitude and longitude, providing global positioning with centimeter-level accuracy.

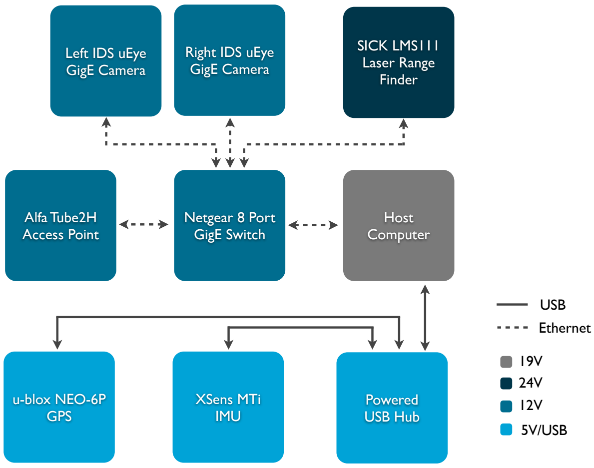


Figure 3: The FSR Backpack hardware.

Finally, an optional sensor is included in the FSR Backpack: the SICK LMS111 Laser Range Finder (LRF). This is a commonly used sensor in Robotics for 2D distance sensing, obstacle detection, navigation and mapping. It scans the environment using laser beams to determine the distance to objects and build 2D representations of the environment, eventually allowing RGB-D perception if used together with the stereo pair. The maximum range of the SICK LMS111 is 20 meters at 25 to 50 Hz, with a field of view (FOV) of 270 degrees and a resolution between 0.25 and 0.5 degrees. In the preliminary outdoor tests reported herein, we did not make use of this sensor.

In addition to the above sensors, the FSR Backpack includes some more hardware components. The AlfaTube 2H is an outdoor WiFi access point, which is equipped with a 2.4 GHz and 9 dBi outdoor Omni Antenna, being placed on the side of the backpack (*cf.* Fig 1). This equipment enables the Backpack to be persistently connected to a base station, receiving feedback and retrieving field data for online and offline analysis. Furthermore, to enable the interaction between all modules, an 8 port switch and a USB 3.0 hub are placed inside the kit. The switch used is a Netgear GS108T-200 GigE with a 16 Gbps full duplex bandwidth, which provides Ethernet interface between the stereo pair cameras, the LRF and the access point to the host computer. On the other hand, for USB interface a D-Link 4-Port USB 3.0 Hub at 4.8 Gbps connects the XSens IMU and the GPS unit to the host computer.

Finally, the host computer chosen to process all data and run the developed software is the ultra compact Gigabyte BRIX with an Intel Core i7-3537U at 3.1 GHz, with 8 GB DDR3 RAM and a 60 GB solid-state disk (SSD). The BRIX computer is currently the only com-

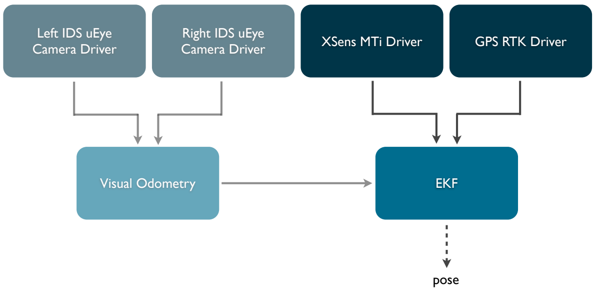


Figure 4: Pose estimation algorithm, which fuses data from the the IMU and the GPS unit, and optionally from the visual odometry estimation using the stereo pair cameras.

ponent placed on the top shelf, which has additional space for further extensions. Depending on the application, other sensors and hardware can be added.

In terms of software, the FSR Backpack is fully integrated in the Robot Operating System (ROS) framework [7]. All the components are launched using appropriate ROS drivers, which are responsible for publishing sensor data in dedicated ROS topics. The integration in ROS is beneficial as it promotes hardware abstraction and code reuse, therefore several algorithms available by the community can be utilized in field experiments, such as Particle Filter (PF) or Extended Kalman Filter (EKF) localization by fusing multimodel sensor data, Visual Simultaneous Localization and Mapping (Visual SLAM), object recognition and perception, etc.

3 Field Trial

A fundamental capability of the FSR Backpack is localization. Endowing the kit with accurate pose estimation, enables the system to identify the areas traversed by the human operator in the field, as well as those that should still be visited, *e.g.* for mine clearance in demining operations. In this section, we focus on the description of a preliminary field trial conducted to test the localization system of the FSR Backpack. Having this in mind, in Fig. 4 we present a diagram of the pose estimation algorithm.

Sequential images provided by the stereo pair of cameras may enable the system to extract odometry-equivalent information to estimate the distance traveled by the operator. Such approach relies on image processing to remove lens distortion effects, matching features across the two images obtained by the cameras at the same instant, and constructing optical flow fields to estimate camera motion. Despite its usefulness, visual odometry [6] is expected to accumulate error over time, thus by itself it does not represent an accurate pose estimation algorithm. Therefore, a classical pose estimation method - the EKF - can be primarily used to fuse the output data of the visual odometry algorithm, together with the global position estimate given by the GPS unit and the Euler angles provided by the IMU. This way, we expect to have high localization precision coming from the EKF in outdoor field experiments.

In this section, we present our first validation test of the EKF using only information from the IMU and GPS unit, and we leave the fusion of the visual odometry estimates for future work. In order to test the aforementioned localization approach, we carried out tests with the FSR Backpack in an open outdoor area with irregular terrain relief in the University of Coimbra - Pólo II Campus[1]. The operator was instructed to follow a cyclic path with quadrilateral shape, visiting four known landmark positions in the terrain.

During the experiment, the FSR Backpack was connected to a base station running the Ubuntu 12.04 Linux OS with the ROS Hydro distribution, which was responsible to monitor the whole experiment. In particular, the base station had real-time access to the data of all the sensors of the backpack and was able to track the position of the operator during the experiment. Additionally, it served as a single reference station with known and fixed position, enabling the RTK software to provide real-time corrections of the GPS estimates of the backpack position.

Figure 5 illustrates the path followed by the operator by the end of the experiment in the ROS visualization software *rviz*[2]. As can be seen, the resulting estimated path from the EKF is consistent with the four defined landmarks, which shows that the method is extremely accurate, yielding a centimeter-level accuracy.

In addition to validating the system's pose estimation algorithm, the field trial has proven the suitability of the hardware and sensors chosen to incorporate the kit. Also, important sensor data has been collected, which will be subject to further analysis in the near future.

Given the localization accuracy obtained by fusing the IMU and the GPS data, instead of using the stereo cameras for visual odometry, alternatively these can be used to track a hand-held mine detection tool carried by the operator in the field, to register the covered area by the detection system and improve the security of the demining operation. Ensuring at the same time a 100% clearance ratio in a demining task.

4 Conclusions

In this paper we have described the FSR Backpack, a wearable sensor suite developed to speedup and improve the safety of humanitarian demining operations in the field, providing means to collect important field data, receiving and sending communication to/from the remote center of operations, and test new algorithms and methods for humanitarian demining, such as sensor fusion of different detection sources for mine identification, field coverage algorithms, localization and several more.

Being equipped with modern sensors and hardware for pose estimation, global positioning, vision, range de-

[1] `https://www.google.com/maps/@40.184853,-8.4146164,206m/data=!3m1!1e3`

[2] `http://wiki.ros.org/rviz`

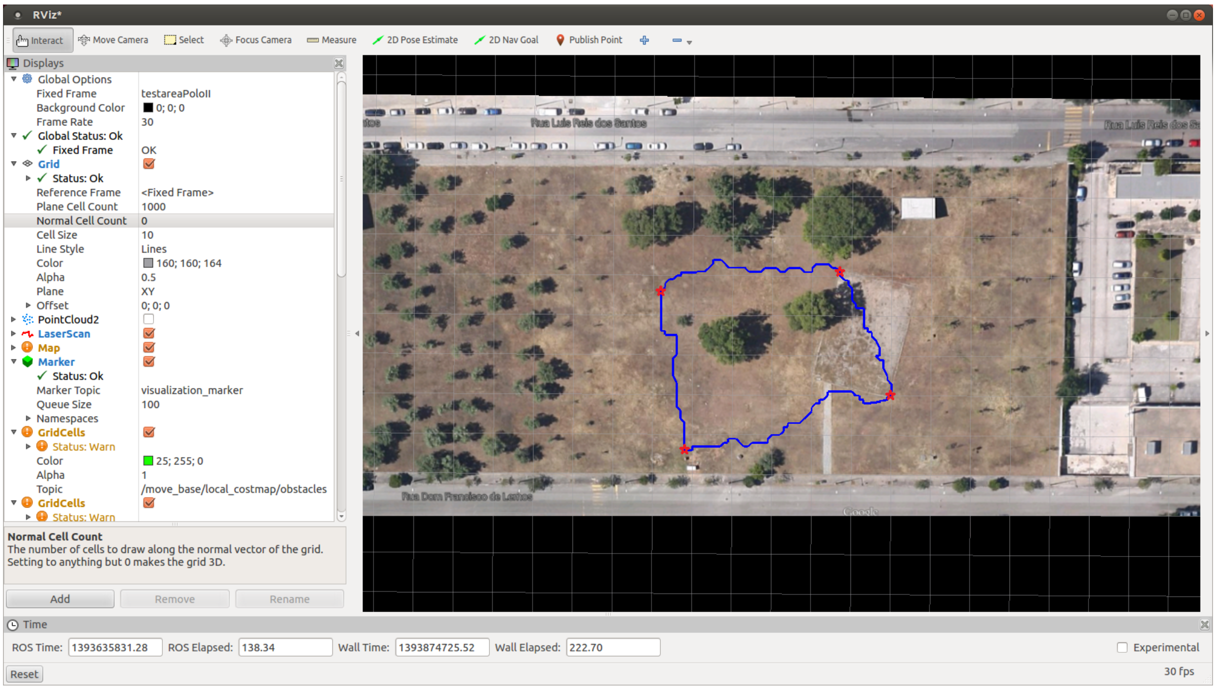


Figure 5: Final trajectory obtained from the pose estimation algorithm. Red stars depict the known landmarks defined *a priori* for the operator's trajectory.

tection, longe-range wireless communication, processing power and a robust power supply, the FSR Backpack has demonstrated its usefulness in a preliminary field experiment where its localization system was assessed.

In the future, we intend to test the stereo cameras together with the laser range finder for terrain examination and traversability analysis, as well as using the FSR Backpack together with a lightweight mine detecting system carried by a human operator to perform coverage tests and analyze the success of sensor fusion algorithms for mine detection, as illustrated in Fig. 6.

Figure 6: Backpack and Advanced Lightweight detecting system performing coverage of the area to be cleared.

Acknowledgment

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