

# Machine Vision for Obstacle Avoidance, Tripwire Detection, and Subsurface Radar Image Correction on a Robotic Vehicle for the Detection and Discrimination of Landmines

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**Abstract**— In a joint project, research partners across institutions combined specialties to develop a remotely-operable, multi-sensor, robotic device for the detection of land mines, unexploded ordnance (UXO), and improvised explosive devices (IEDs). The robotic detection device uses a novel subsurface radar with imaging and target classification to differentiate between dangerous landmines and harmless clutter. One important aspect of this project has been to develop a system for imaging the terrain and potential obstacles ahead of the moving vehicle. Three important tasks drive the need for this look-ahead imaging: obstacle avoidance, tripwire detection, holographic subsurface radar (HSR) image correction.

## 1. INTRODUCTION

As of 2017, there are an estimated 100 million abandoned land mines littered across 61 countries. Following the wars in Afghanistan, Libya, Syria, Yemen, and Ukraine, there has been a steep rise in casualties across the past three years. Current annual clearance is approximately 230,000 AP and 30,000 AT mines per year, meaning it would take over 500 years to clear all the landmines across the globe. For each of these years, if new mines are deployed, an additional 10 to 20 years would be added to this estimate. The idea of using a robotic platform with the use of a holographic radar was proposed by the authors, and a prototype system operating at 4 GHz was developed [1]. The high resolution of the microwave holographic images allowed us to study and experiment with a classification algorithm that has had a good success rate [2]. We intend for this robotic platform to change the approach to detecting landmines in portions of post-war zones. While it will surely not be effective in all locations and settings, we predict that it will speed up detection and clearance in low-relief fields, meadows, lawns, and roadways, while reducing human-to-mine or animal-to-mine proximity. The design approach is based on the new paradigm of Industry 4.0 in which cyber-physical systems interact and share data, are reproducible everywhere, and are adaptable/expandable with different sensors and actuators. Robot remote control and data sharing are achieved by a sophisticated web-based software architecture which has great potential to migrate the procedures of explosive device detection toward completely remote and autonomous cooperative systems.

## 2. ROBOTIC SYSTEM

Figure 1 shows the following subsystems that are employed:

1. Ground Penetrating Radar (1 TX, 4 RX)
2. Holographic Subsurface Radar system
3. Picoflexx PMD time-of-flight (TOF) camera
4. FESTO 3-axial mechanical scanner
5. Clearpath “Jackal” robotic platform
6. Remote joystick controller
7. Web application board

Raw data from the Picoflexx camera must be transformed into usable data for subsequent elaboration. The processing chain to build digital elevation model (DEM) data follows three steps. The first step is the use of the Pinhole camera model [3] that allows for 3D reconstruction of the image. This model uses the intrinsic parameters of the camera — i.e., focal distance, principal point

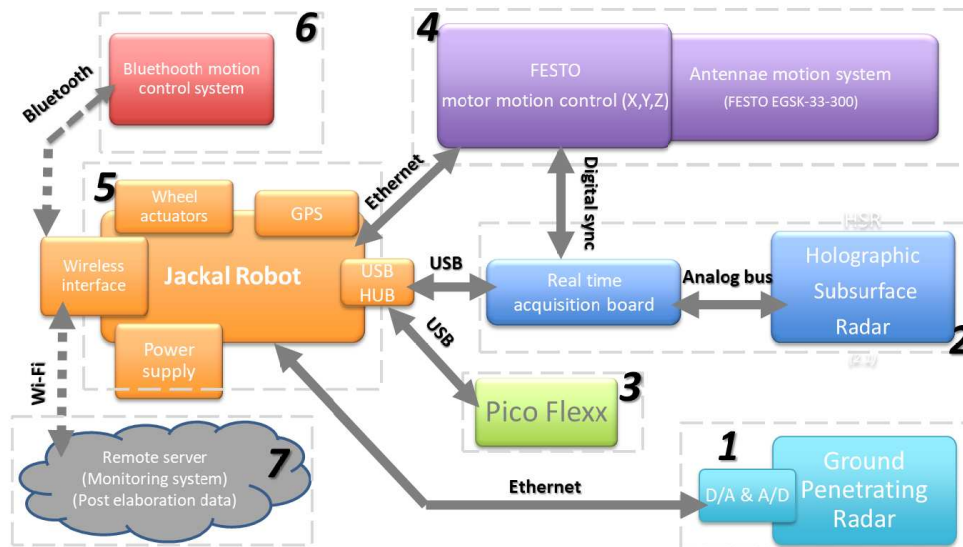


Figure 1. Logical architecture of robotic system.

offset, skew. To correct for the radial and tangential distortion introduced by the lenses, Brown's model was used [4]. The undistorted 3D image, represented in the camera frame, is rotated and translated to match the frame of FESTO scanning system. This allows the superposition of 3D camera images with holographic radar images. Figure 2 shows the physical layout of the system sensors.

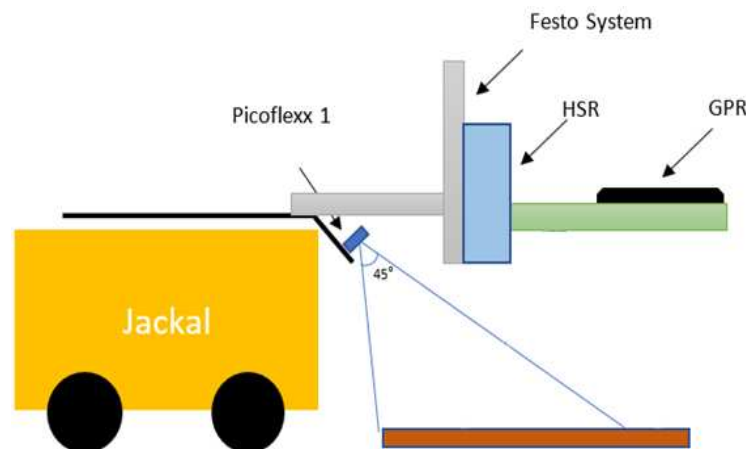


Figure 2. Layout of system sensors.

### 3. OBSTACLE AVOIDANCE

Analysis of the conventionally-recorded relief profiles from the test site near the conflict zone in Ukraine indicates that the robot faces minimal threat in these areas of nose-in and hang-up failure due to topographic relief alone [5]. Figure 3 summarizes these results. Of course, things like trees, stray rocks, roadway berms, etc. will surely present obstacles, but the DEMs created from the Picoflexx TOF camera will provide warning of these on approach. The robot can subsequently be steered around such obstacles with human intervention. Ultimately this will be done with automation.

### 4. TRIPWIRE DETECTION

The development of automated tripwire detection with the system is underway but not complete. Testing so far indicates that the best detection is provided by a FIR or thermal imaging camera.

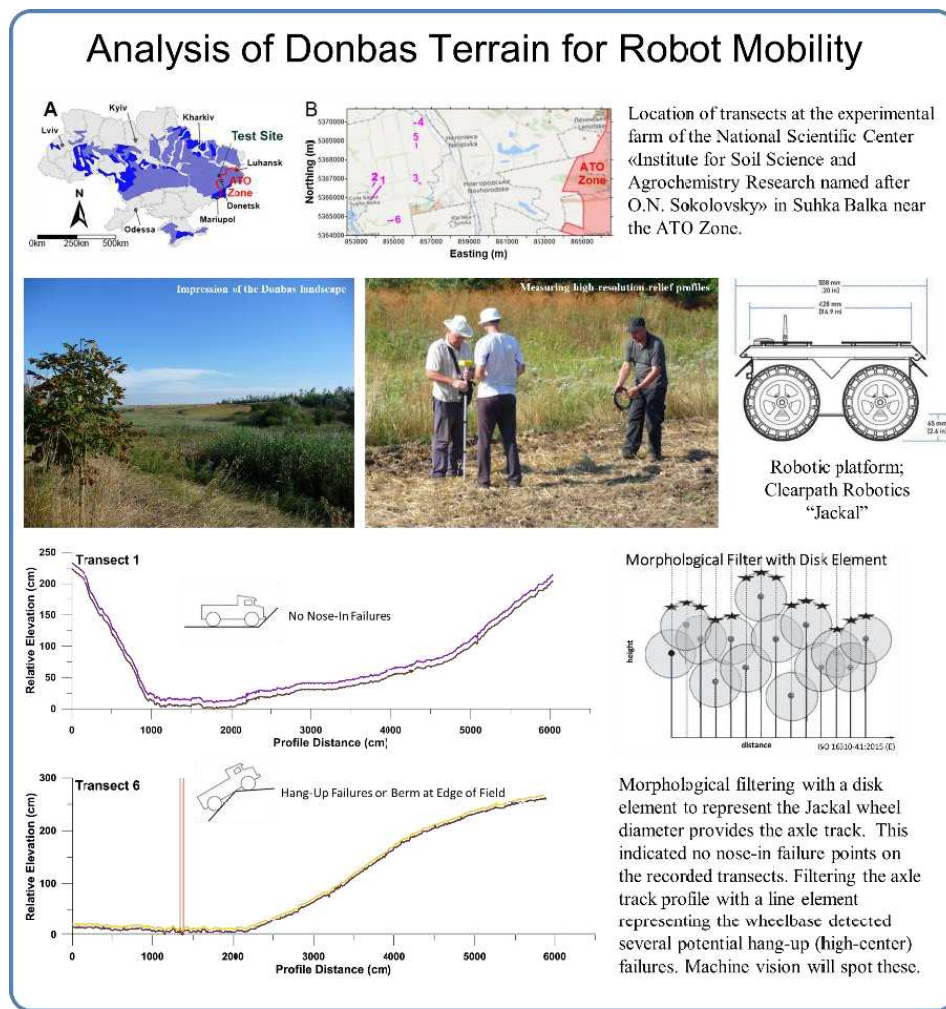


Figure 3. Analysis of Donbas terrain for robot mobility.

This may be due partly to the lack of influence from ambient light conditions that strongly affect the visible and NIR images. In addition, the difference in emissivity between tripwire materials (monofilament nylon, organic or synthetic twisted-fiber string, metal wire, etc.) and obstructing vegetation may help tripwires stand out in thermal images.

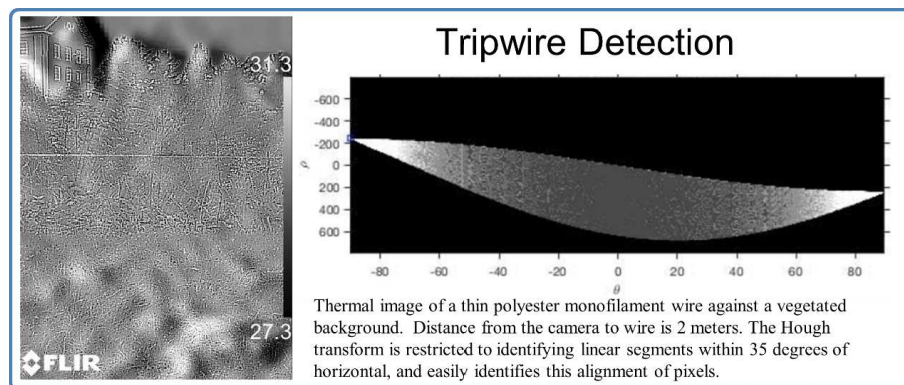


Figure 4. Hough transform for line detection.

In addition, there may be true differences in temperature between tripwires and obscuring natural features because of their differing heat capacities and consequent warming/cooling lag with ambient air temperature. The Hough transform has been shown to effectively detect straight-line

segments of tripwires in laboratory and simple field trials (Figure 4). Testing with the potentially faster Radon transform under experimental conditions with natural vegetation is underway.

## 5. HOLOGRAPHIC SUBSURFACE RADAR IMAGE CORRECTION

This work has just begun. Algorithms for the calculation of accurate DEMs have been completed, and the procedure for the rotation and translation of these DEMs into HSR image pixel coordinates has been implemented. However, these algorithms must be made to operate faster for use in real- or near-real-time situations.

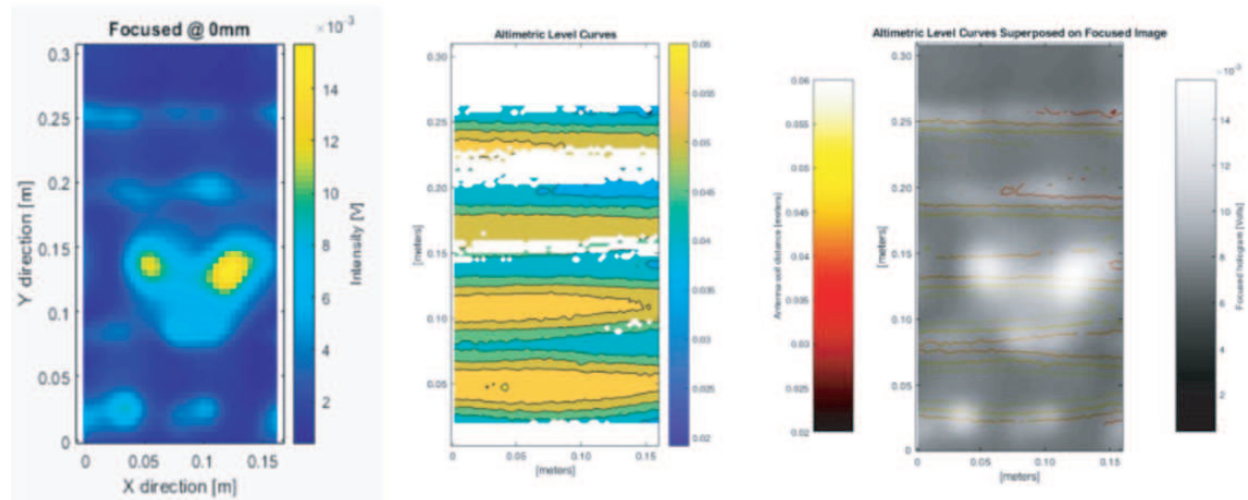


Figure 5. HSR/Picoflexx data superposition.

Figure 5 shows an HSR image of buried mine simulants beneath an undulating testbed surface (left), a topographic map of the terrain (center), and an overlay of the DEM and HSR data (right).

## 6. CONCLUSIONS

The results of the imaging and terrain analysis are promising, but the system is not yet ready for deployment in the field. In its current state of development, the robot could be used in minefield surveying, but it would suffer from slow progress due to the need for significant human intervention and would be susceptible to damage or destruction from encountering tripwire-triggered devices. We intend to continue development of the imaging systems and their incorporation into the robotic platform as automatically cooperating subsystems in keeping with the Industry 4.0 paradigm.

Immediate focus areas for our work include integrating the real-time construction of DEMs and their morphological analysis into the system. Initially, the robot will provide an alarm to the remote operator when encountering obstacles, but eventually we will develop automated obstacle avoidance. The FIR imaging and linear-segmented-feature detection will be developed and integrated so that the robot will stop and transmit an alarm when potential tripwires are detected in its path. Once a rapid and highly accurate transform of a DEM into HSR image coordinates is achieved, we expect an improvement in PD and reduction of FAR, providing high-confidence and high-speed minefield surveying and clearance.

## ACKNOWLEDGMENT

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