Demining Facilitation Organization (Temporary Name)

In collaboration with

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Mission

The organization seeks to aid in demining efforts in Ukraine and potentially other regions of the world through deep learning techniques, namely object detection. By procuring a diverse dataset of landmines and carrying out data augmentation to improve the generalization capabilities of the object detection algorithm, the resulting model should be able to be used in conjunction with drones to conduct landmine mapping tasks. In collaboration with other demining organizations, the aim of this future non-profit is to utilize the capabilities of sensors to maximize object detection capabilities such that the model can be employed in various environments, including man made structures, railways and water bodies.

Background and Motivation

The Russo-Ukrainian conflict has led to extensive military operations that saw both sides make use of landmines at a grand scale. Russian forces on the southern front in the Zaporizhzhia Oblast have notably created an elaborate network of minefields that will need to be cleared as Ukrainian forces continue to liberate these positions (Khurshudyan & Hrabchuk, 2023). Unexploded ordnance in these areas, where the Armed Forces of Ukraine is said to be expending up to 8,000 shells per day, will need to be meticulously mapped and eliminated before the local population can safely return ("Clearing Landmines," n.d.-a). The situation is further complicated by the Russian use of landmines such as the PFM-1, whose largely plastic composition proves difficult to detect using standard electromagnetic induction (EMI) demining operations (Baur et al., 2020). Other regions that previously saw heavy combat and great expenditures of explosives, such as the Kherson and Kyiv Oblasts, are also greatly contaminated with the remnants of heavy cluster bomb usage and extensive deployment of landmines. Given the scale of the contamination, novel solutions for demining are required such that liberated urban and rural regions can be sufficiently secured to allow for displaced populations to safely return to their lands. Yet, as of now, it is estimated that approximately 62,000 square miles of Ukrainian territory are likely contaminated with various types of ordnance (“From Farmers”, n.d.-a).

As such, a cost-effective demining solution with an object detection algorithm could potentially supplement Ukrainian demining operations and thereby lessen civilian and military casualties. Drones can prove to be instrumental in this case due to their heavy use during the conflict for tasks such as reconnaissance and providing close air support to infantry. Given their vast usage for these applications, drones can act as a supplement to existing manual clearance methods for demining. The project seeks to focus on providing such supplemental aid to Ukrainian forces by developing a drone system that can safely detect mines without the need for demining teams to comb through dangerous terrain.

Ultimately, the project aims to culminate in the successful development of a cost-effective drone, enhanced with high-precision sensors and the YOLO v8 object detection algorithm, to serve as a safer means for mine clearance teams to locate mines in both former and current combat zones. With a dataset of landmines that covers a wide variety of both anti-personnel and anti-tank ordnance, alongside the usage of state-of-the-art object detection algorithms and a robust platform for labeling data and deployment, the final product will seek to play its part in the multinational effort to safeguard the Ukrainian population and its armed forces from unexploded ordnance.

Areas of Focus and Applications

Recent efforts to apply deep learning techniques for demining are concentrated on the demining of farmlands in former combat zones, with The HALO Trust and other organizations leading the way in demining operations in Eastern Ukraine (“The Fields”, n.d.-a). At the same time, however, landmines have been found in other critical areas that have seldom received attention at the moment in comparison to the dramatic efforts being made to secure farms. For example, landmines in buildings and other manmade structures pose an immense threat to the returning local population, which are a unique challenge for demining operations. The situation is further compounded by the possibility that such explosives can be set up as booby traps in residential buildings, with local infrastructure itself potentially mired with unexploded ordnance that poses a threat to critical systems such as the energy grid and railways. Sensors that rely primarily on surface mapping of terrain are also ineffective in these situations if they are unable to penetrate surfaces.

Another critical area to which the project seeks to devote attention is the presence of ordnance in water bodies. Coastal areas that have seen heavy combat will likely be contaminated to a similar degree as inland areas, with primary examples being the banks of the Dnipro River in the Kherson Oblast. Furthermore, recent environmental disasters in the Kherson region have resulted in significant quantities of unexploded ordnance being scattered by the sudden surge in water, which brings the implication that some of the ordnance may now be covered by small water bodies resulting from the upsurge in water levels. Given that water-based object detection requires a different subset of sensors and mechanical techniques, the project considers this task an imperative goal that is of equal priority as land-based object detection.

By focusing on areas of demining that have received comparatively less attention in the past two years, the project seeks to contribute in a unique manner to landmine mapping to aid demining operations in areas outside of the primary focus of most organizations at the moment. Contributing to these distinct demining operations will also be of benefit to future organizations and other entities that may seek to collaborate with and build upon our work.

Procedures for Model Development

Model Training Platform

The training of an object detection algorithm on a dataset of such scale and complexity requires a streamlined process for model training, testing and deployment. In addition, pretrained models can help to greatly facilitate the learning process for the algorithm and shorten training times, which allows for a dynamic training procedure that provides opportunities for rapid testing and therefore frequent feedback.

Based on the above criteria, we have chosen to use Roboflow as the primary framework for building and training the object detection algorithm. Roboflow offers a wide variety of options for streamlining the process of organizing our dataset, including image labeling services, class manipulation and the ability to filter these images by class for cleaning purposes. Furthermore, the platform provides options for pre-trained YOLO algorithms, with the training process providing performance metrics at every epoch of training as a means of verifying model performance. Finally, the platform also appeals to us due to the wide variety of options for deployment, ranging from deployment to a local machine on a hosted API to deployment in a cloud-based environment.

Data Collection and Augmentation

With regards to data collection for constructing a training and testing set, the project will follow the procedures outlined by Baur et al. by collecting image data in various terrain types that fit the diverse Ukrainian landscape consisting of steppe and extensive forests with climate conditions that will need to be considered when constructing the training dataset (Baur et al., 2020). It is certainly impossible to currently simulate a perfect landscape due to the inability to collect data within the country, but Baur et al. has demonstrated that even images that have some environmental error can still be used to train the model effectively. For the first stage of project development, the DJI Tello EDU drone will be used for various testing procedures, including determining the feasibility of mine detection and supplementing its capabilities with sensors.

The above procedures outlined the necessary steps for data collection in the first stages of the project. Once the project begins considering landmines embedded in manmade structures and mines in water bodies, however, additional steps will need to be carried out to ensure a balanced dataset. With these two areas of focus, sensor data, such as LiDAR and SONAR, will play an indispensable role as images for the training set will be procured from the data gathered by these sensors. The resulting dataset should thereby not only cover standard scenarios of landmine detection without the aid or format of any sensors, but also provide detection capabilities for situations where sensor systems in other areas (residential areas and water bodies) will be needed for effective detection.

The data collection procedure must also consider the acute shortage of landmine images that can be procured from existing datasets. In addition, as of now, landmines such as the PFM-1 and MON-50 are overrepresented in most landmine datasets, thereby leading to a significant class imbalance that can make the detection of other anti-personnel and anti-tank mines a daunting task. Under such circumstances, several techniques for collecting data must be carried out to optimize generalization capabilities. The effectiveness of the deep learning algorithm in detecting these landmines will ultimately depend on the diversity, quality and reliability of the data that is provided.

Firstly, data augmentation schemes offered by Roboflow can be effective at simulating different conditions in which landmines may be found while ensuring that the model's generalization is improved through the increased availability of high-quality data. For example, augmentation techniques involving spatial transformations such as horizontal and vertical flipping, noise and shear have been considered to be effective ways of applying transformations to object detection such that the dataset is diversified (Kunichik & Tereshchenko, 2023). These techniques were already successful in increasing our model's performance when compared to initial training procedures without augmentations, with the mean average precision (mAP) increasing from 87.5% to 90.8%, precision from 94.6% to 95.6% and recall from 82.2% to 86.7%.

Other data augmentation techniques that are currently being used in the project include the use of 3D printing to create realistic samples of landmines. Given the general unavailability of ordnance for sale and the significant costs and ethical implications involved in their usage, these 3D-printed samples provide us with a cost-effective way of acquiring additional data while simulating different scenarios for diversification purposes. Potential data augmentation schemes for the future include the use of generative adversarial networks (GANs) to generate realistic portrayals of mines based on the dataset on which they trained, which can also aid the model in generalization.

Sensors

To facilitate the process of mine detection, the computer vision architecture needs to have image data that can be easily processed and have identifiable features that allow for the model to be trained on mine detection from a model acquired via transfer learning. Based on this idea, various sensors need to be integrated such that various data formats that clearly highlight mines in varying conditions and landscapes can be inputted into the model. For example, a thermal infrared sensor can be integrated, which collects thermal infrared spectral data that can be valuable for mine detection after being transformed into a compatible format for further processing. An RGB camera and monochrome sensors that capture green, red, red edge and near infrared bands is also under consideration, which could further enhance detection capabilities.

The primary sensors currently planned for implementation for land-based operations are LiDAR and ground-penetrating radar (GPR) systems. Systems implementing LiDAR usually consist of a laser scanner or sensor that is mounted on a platform. With this sensor, laser pulses are emitted that bounce back and are received by the sensor. A rotating mirror can then be used to scan surroundings. This sensor is ideal for landmines in fields as it is capable of providing detailed captures of terrain for surface-based mapping. LiDAR can provide an accurate point cloud representation of the surrounding terrain, vegetation and objects, which means that it can also detect surface irregularities (e.g., disturbed earth or other peculiar details). Furthermore, since LiDAR is based on point cloud data, it can measure distance quite accurately. At the same time, however, this sensor will not be effective for other aforementioned areas of focus, with man-made structures such as buildings being a primary weakness as LiDAR cannot penetrate surfaces. Furthermore, this sensor is sensitive to ambient conditions; that is, poorly lit environments are more difficult to scan. Nevertheless, it can be mounted on a drone and is a popular sensor for drones due to its relatively light weight. Its effectiveness will depend on the sensitivity of the receiver and the reflectivity of objects and terrain.

To address the above concerns regarding landmines that are potentially embedded below surfaces or within structures, a GPR has been considered at the moment. For the GPR systems, the ideal implementation consists of an antenna, control unit and power source. In these systems, the antenna emits electromagnetic pulses and receives the reflected signals. The control unit is subsequently responsible for controlling data collection and the EM pulses, as well as providing an interface for such controls. The power source usually consists of an external power supply or a portable battery. Since a GPR can penetrate the ground and walls, it can be used to locate objects that are hidden below or behind these structures. As such, it is possible to see anomalies or irregularities within structures. The depth depends on the frequency of the antenna. Low frequencies provide poor resolution but penetrate deeper; conversely, high frequencies provide excellent resolution but poor penetration. For the purposes of the project, there will be discussion regarding the balance between surface penetration and resolution, with the latter receiving higher priority. A handheld GNSS system will also be indispensable for obtaining accurate coordinates for the mines and ground control points, which can then be used for georeferencing and further post-processing. SONAR data is to be the primary form of data collection and object detection for mines that are found in water bodies. Rather than an airborne UAV, an unmanned underwater vehicle (UUV) must be considered for this sensor to be effective.

Drone Functionalities

While the DJI Tello EDU drone will play a significant role in data collection, considerations must be made regarding the total weight of all sensors that will be mounted and the quality of the camera that is to be used by the drone.

Rather than relying on object detection with a live camera feed, the drone will ideally cover a certain predefined area. Using a mounted APV camera and sensors, images of the terrain will be captured by a drone at specific intervals. These resulting images, which will be in various formats depending on the sensor that captured them, will be in various formats that are to be subsequently preprocessed in an appropriate format for input into the YOLO v8 model. The algorithm will consider different distances at which the drone will capture images. Object detection for man-made structures will need to be carefully planned, given that a drone equipped with some form of a GPR or other sensor that can penetrate surfaces will need to also be capable of maneuvering around potentially tight spaces. SONAR-based data collection will be carried out with the aid of an unmanned underwater vehicle (UUA) due to the nature of water bodies. SONAR systems will need to be adjusted based on the depth of the water, with some systems providing better performance in shallower water. Furthermore, high resolution will be important to maintain the quality of the input data, but will need to be considered against poorer penetration in underwater conditions.

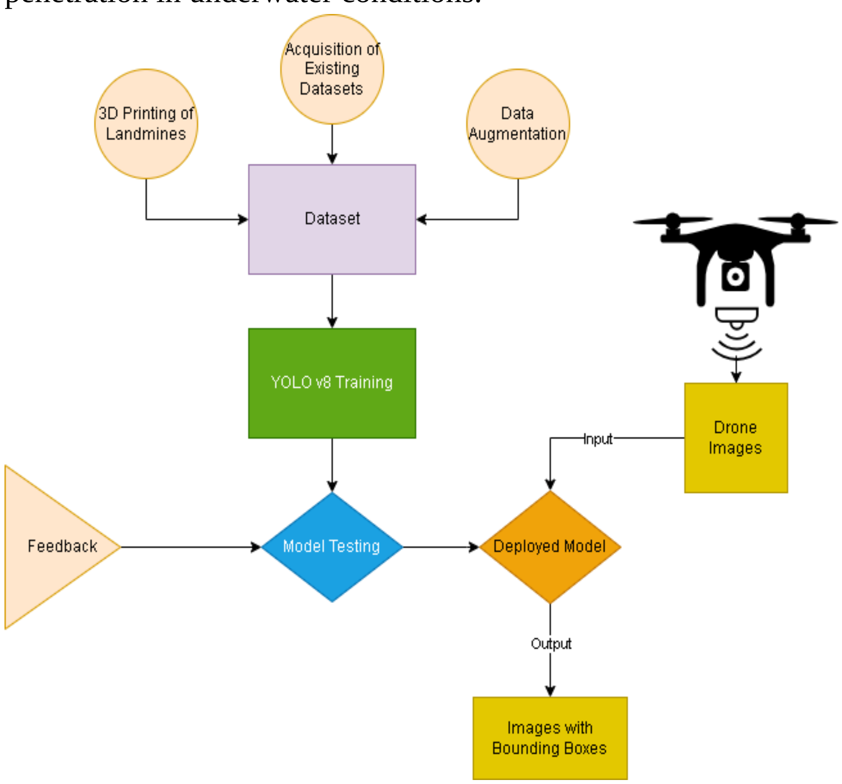

Figure 1. Overview of the model pipeline, including the dataset.

Timeline

The timeline below outlines the project plan, starting from the inception of the dataset and initial testing to the deployment of the algorithm in conjunction with drone mapping capabilities in Ukraine. This plan is established under the presumption that constant feedback from partner organizations and demining organizations will be provided, hence ensuring that the project adheres to an agile methodology for development.

Stage 1: Initial Data Collection and YOLO v8 Training

This stage began in October of 2023 and is set to be successfully completed by the beginning of January 2024. Up until now, the initial dataset of landmines has been constructed, with the FPM-1, TM-62 and MON-50 landmines being represented in the dataset at the moment. The algorithm of choice has been trained through Roboflow and is showing encouraging results with the detection of these landmines. On the other hand, the current dataset is currently being cleaned and supplemented by additional images that will need to be labeled and whose quality will need to be verified.

Stage 2: Sensor Implementation

Equally as crucial as the first stage is the implementation of sensors, which will begin in January of 2024 and end with a drone prototype that has all of the aforementioned sensors. Feedback will be provided at every step of the process by collaborating partners, with the sensors ideally ready for use by the beginning of the summer of 2024.

Stage 3: Data Diversification

With the sensors implemented and in active usage, this stage is set to begin in the summer of 2024 and will extend into the rest of the year. Up until this stage, the dataset will only have covered a select number of different landmines. With the sensors ready for use, additional data will need to be collected that takes into account the format and output of these sensors. Further data augmentation is to be performed to diversify the dataset, with new landmine types also being included.

Stage 4: Field Testing

By the end of 2024, the algorithm and accompanying drones should be ready for testing with real ordnance. Several locations that offer such testing opportunities are being taken into account, with the test field services of the Demining Research Community at the OSU Center for Fire and

Explosives, Forensic Investigation, Training and Research range in Pawnee, Oklahoma being the most appealing.

Stage 5: Deployment

With a tentative completion date of 2025 after field testing has successfully concluded and all components thoroughly tested, the algorithm and accompanying drone with sensors should be ready for deployment to Ukraine for initial mapping operations. The logistical components of such a deployment will be discussed ahead of time between members of the non-profit organization and relevant stakeholders.

Additional Organizational Plans and Operations

To ensure a cohesive and productive project development cycle, the project first seeks to continue its current collaboration with the University of Florida Department of Materials Science & Engineering and The HALO Trust. With these two partners acting as advisors to the project, all components of the timeline may be adjusted as necessary to ensure that the developing product adheres to expectations. Additional partnerships and collaborations with organizations with similar projects are to be sought to expand the

Out of this project shall emerge a non-profit organization, whose structure is to be discussed with relevant stakeholders. Among the points of contention that need to be addressed as the non-profit begins to develop its foundations are potential sources of funding that will need to cover the costs of the sensor implementations and drones alongside ensuring that all testing that is performed with ordnance is done so in accordance with the law. By the beginning of January 2024, a concrete structure for the organization should be established, including the necessary procedures to establish a non-profit, 501(c)3 and the recruitment of members for the Board of Directors. With the establishment of a formal organization, the goals and progress of this project will be unified into a cohesive group that will involve multiple individuals coordinating logistical and practical aspects of the product's development.

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