3-Survivor: A Rough Terrain Negotiable Search and Surveillance Mobile Robot with Real-Time Object Detection

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Overview

- **Abstract**
- **Background**
- **Related Work**
- **Methodology**
- **Result Analysis**
- **Summary**

Abstract

- In this paper, the design and integration of 3-Survivor: a rough terrain negotiable search and surveillance robot is presented.
- In 3-Survivor, a modified double-tracked chained wheel with a caterpillar mechanism is incorporated in the body design. A passive adjustment is established in the body balance that enables the front and rear body to operate in excellent synchronization.
- The robot is remotely controlled using a handheld Radio Frequency (RF) transmitter. The entire operation is telecasted with a Raspberry Pi Sony IMX477R camera and monitored through a web control portal.
- An object detection module (ODM) is combined with live streaming to integrate the surveillance system. A learning-based EfficientDet-D7 network is integrated for target recognition and interaction to obtain precise and versatile detection from the proposed ODM.
- The target recognition includes a computationally-efficient bi-directional feature pyramid network (BiFPN) as the backbone network that allows multi-scale feature fusion in the D7 model.
- A custom dataset containing 5000 images of indoor-outdoor objects is developed to train and validate the ODM for performing SAR tasks.
- A very impressive 56.7 mAP is acquired from this proposed D7 model. The feasibility and efficacy of the proposed system are tested and validated by indoor-outdoor SAR trial operations.

Background

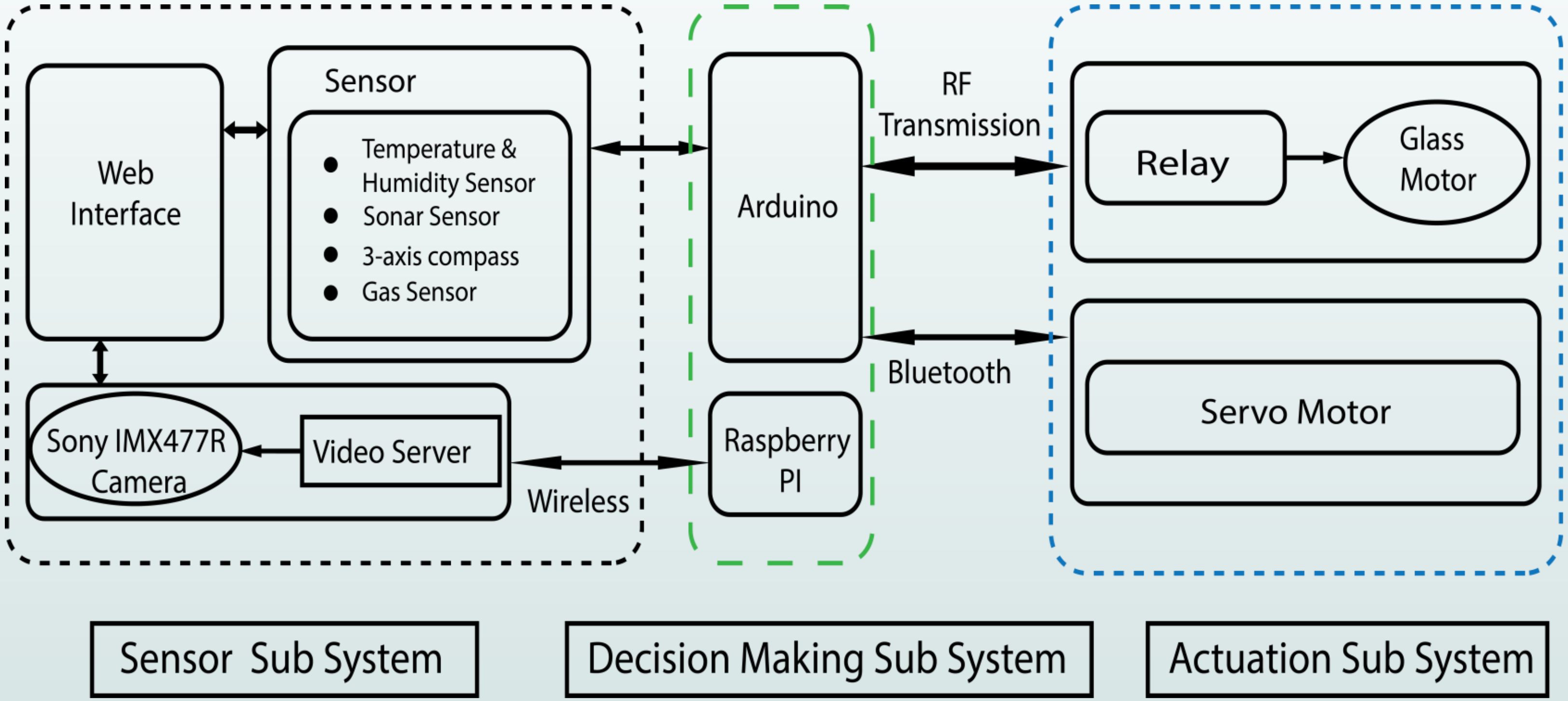
- In modern time, a rescue robot is not only confined as a research or industry problem, but also a helping hand for humans. Such kind of robots is designed with features like **autonomous navigation**, **Picking and removing objects** using manipulator, **rescue humans and animals** from a hazardous environment, **detecting objects and surveillance of the environment**.
- But, a complete service or rescue robot with full functionalities is due to date. One of the most important aspects of such a robot is the **surveillance of the environment and plan activities** accordingly. There are some examples of such systems where the robot is able to acquire and facilitate autonomous movement, but most of them are not integrated with the idea of locating the distance between source and destination which is an important aspect for any service robot.
- Also, previous novel works aren’t capable of adopting the idea of **autonomous navigation** by detecting obstacles from streaming or live video. Due to this limitation, most of the robot adopts either autonomous navigation without detecting objects.

Proposed Solution

To summarized, the main contribution of this paper is stated below-

- An improved and custom body design is built with a flexible system architecture that allows smoothing the vibration absorption system for better body mass distribution and reduce the pose estimation error. The improved passive double-tracked chained wheel mechanism minimizes the systematic mechanical design faults by allowing more passive adaptivity to stabilize body movement in rough terrain.
- To automate the SAR operation, a one-stage detector model is designed to use both the spatial and temporal features of live streaming video to classify events. The robot has to target objects while moving with various frame rates and the same trained object from different angles and sizes.
- Calibrating and removing the computational deficiencies in both body and ODM mechanism such as improving critical response time, providing more training access into hazardous terrains, increasing controllability and stability.

Methodology



1. A decision-making system transmits and receives data from the sensor system.
2. An actuation system drives all the actuators and motors to maintain communication with the decision-making layer.
3. The Sensor System connects the decision-making layer and alleviates the fundamental decision.

Control System and User Interface

- Two control stations - robot station and Base station is incorporated with 3-Survior.
- The base station is the robot operator’s zone where a 6CH FS-CT6B radio controller controls the robot.

The block diagram of an integrated user interface of the control system is shown in Fig.

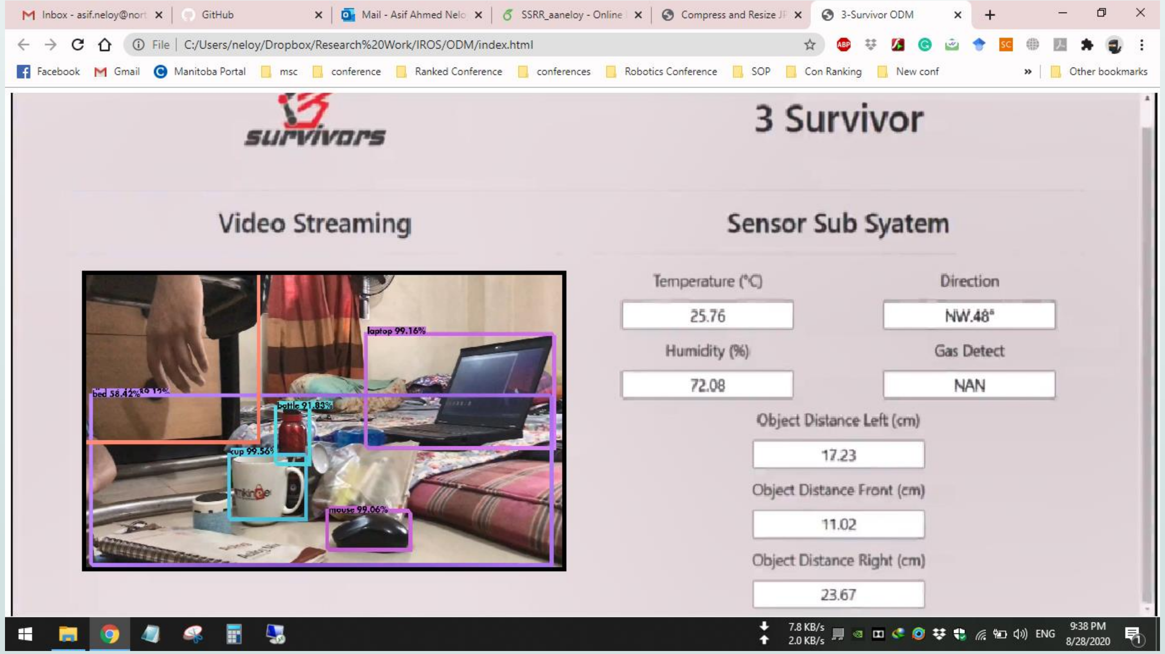
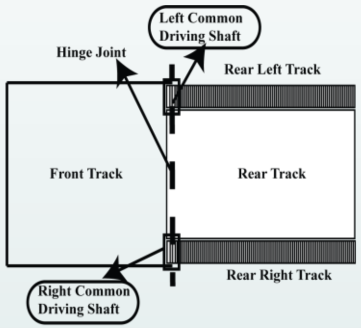
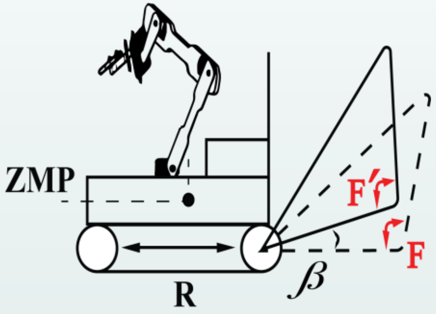
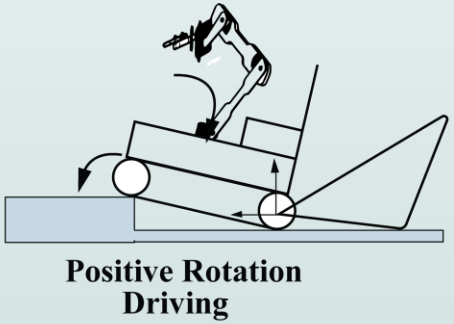


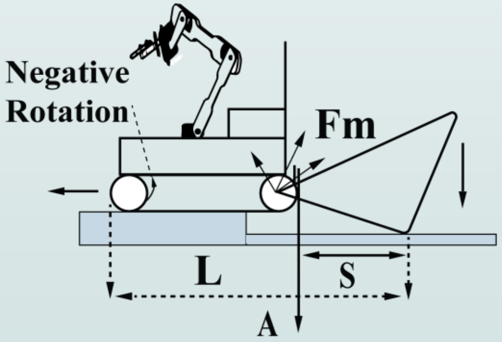
Figure: Control System Interface

Double-Tracked Chained Wheel Body Mechanism

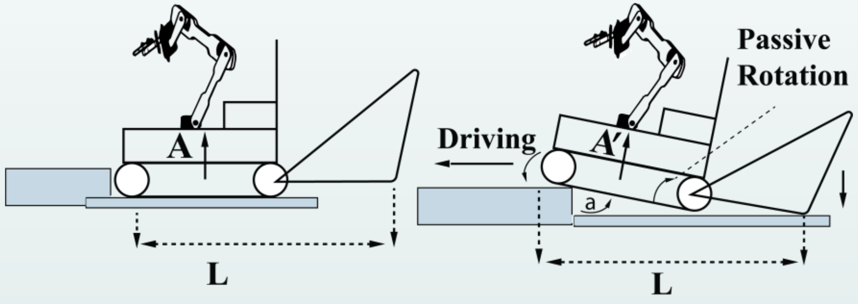


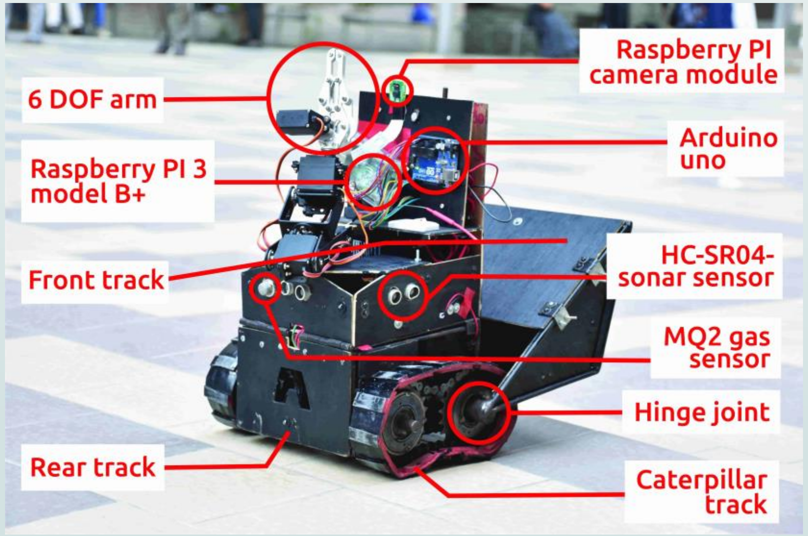






1. An adjustable shaft connects the front and rear parts of the body. This shaft is also working as a common axis for the joint of front motors with the same hinge axis.
2. The passive adaptivity of the front and rear body establishes balance by moving the center of mass and Zero Moment Position.
3. In the rugged grounds, the center of mass moves towards δ and changes the initial position to α.





Object Detection Module (ODM)

The proposed approach of target identification in SAR operation utilizes the idea of semi-supervised operation protocol. Framework for developing such a model to automate the SAR application consists of several steps:

- dataset collection and pre-processing,
- model development, training, testing, and hyper-parameter tuning and on-board configuration.

Dataset Preparation:

- Along with COCO-MS, RGB-D dataset, an additional 5000 images divided by four parts, containing indoor and outdoor objects were added.
- To perform the accuracy testing of live streaming from the camera module, one additional dataset is collected in the form of a video.

Dataset Features

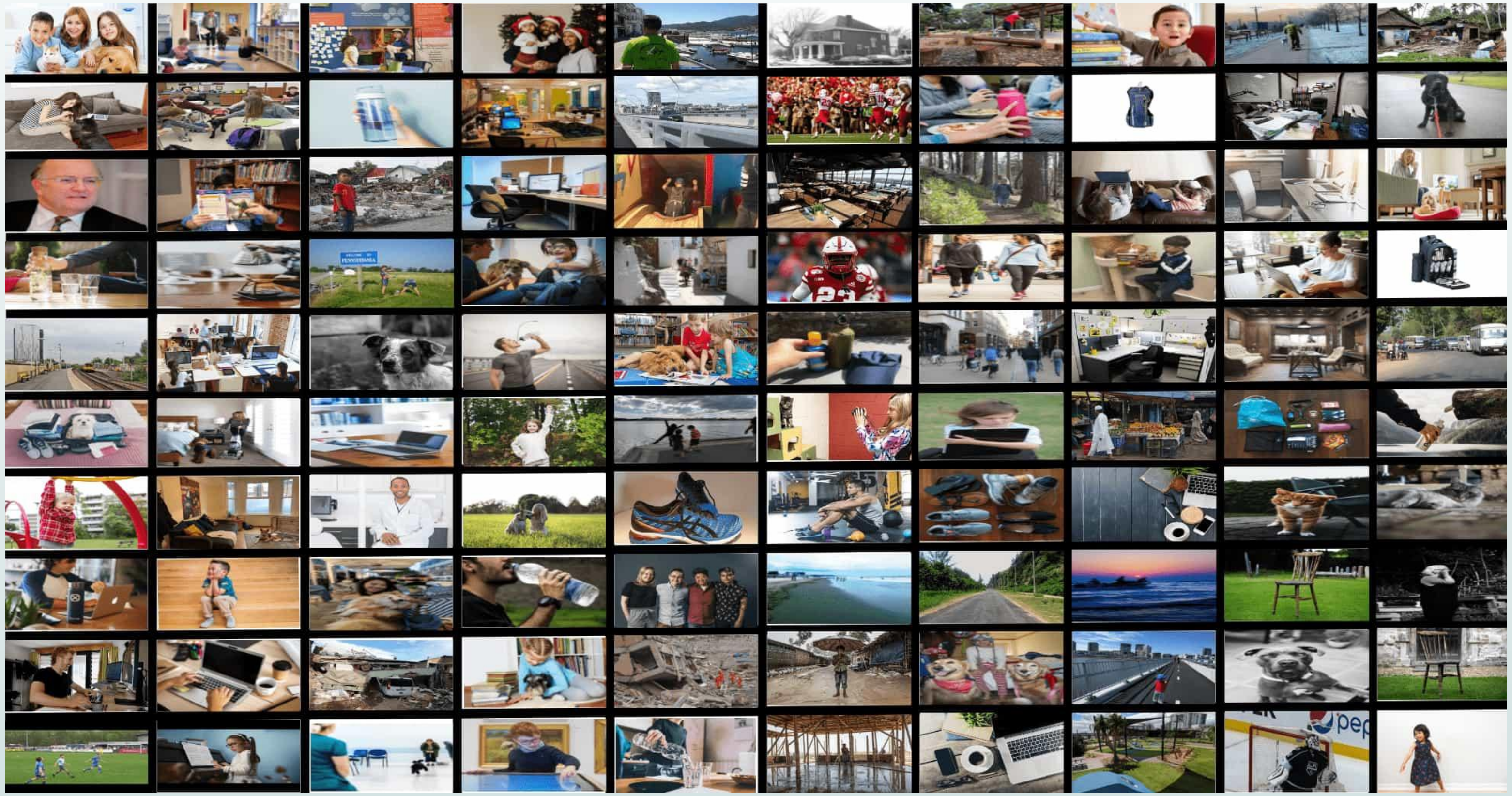


Figure: Custom Dataset Sample

Table: Custom Dataset Features

Dataset	Nature	Testing Feature	No of Sample
D1	Fast-moving blurred objects	Fast movement detection	1250
D2	Fast and Slow rotation of an object	Expend the frame rate for the model	1200
D3	Same object with small and large size	Correct the error rate for mismatch detection	1000
D4	Lower pixel image	Improve the partial translation rate	1550

ODM Model Configuration

Model Development

- The best performance of the EfficientDet is achievable with very few training epochs and computational resources.
- This scalable ability makes the D7 more reliable for a lower computational device like Raspberry pi.
- This proposed solution only focused on incorporating this model with the lowest possible processing module. Therefore, no significant computational layer like BiFPN, Compound Scaling, and Backbone Network was changed. Instead, this system emphasized on the computational complexity and finding optimum parameters to make this framework the most efficient one for 3-Survivor.

Model Training and Optimization

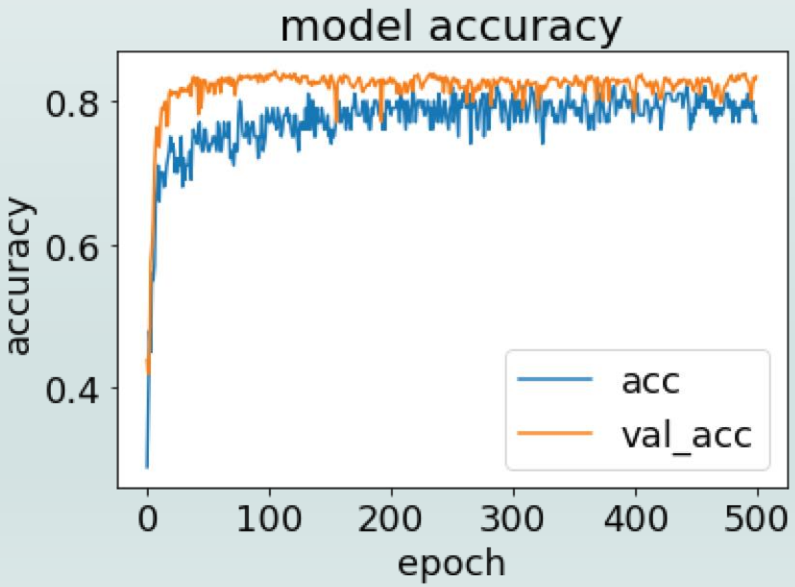
- A manual iteration process of the "Test and Fix" approach is used for the training and parameter optimization.
- Technically, the training of the model facilitated in the Google Colab TPU containing three cores.
- SGD with momentum 0.9 is utilized for the optimization performance. Initially, the weight decay was set to 4e-5, and the learning rate was linearly increased from 0 to 0.09.
- Batch size of 128, an epoch of 500 with batch norm decay of 0.997, and epsilon of 1e-4 gradually tuned for best accuracy—the optimum result obtained with the learning rate of 0.03 after 56 iterations.
- Furthermore, the model was also trained in the custom dataset with video clips after completing the initial training. The frame patches changed; starting with the ten frames, the experiment continued with 15, 20, 25, and 30 frames.

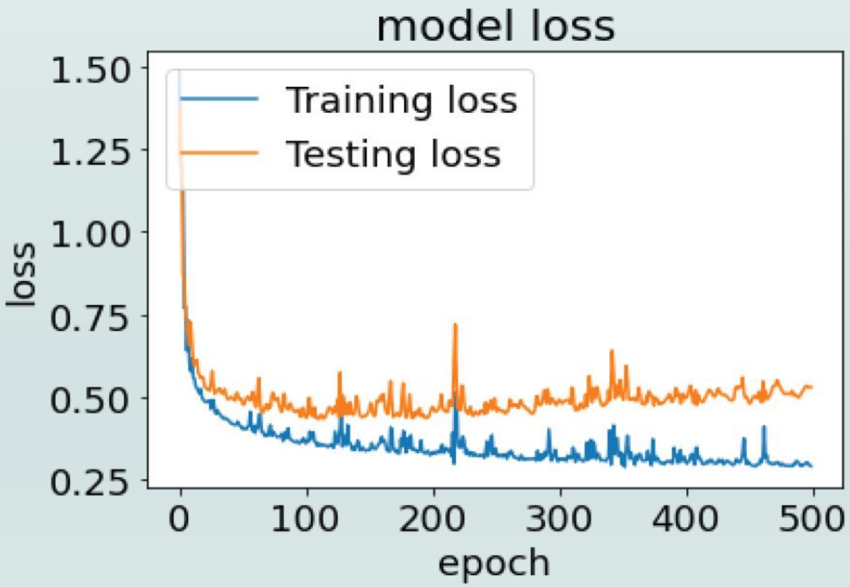
Result Analysis

- A staircase with a height of 8 inches, each with a slope of 45° was used in the experiment. Although 3-Survivor is developed for roaming on the rough terrain, it can be evident that it also fulfilled the stair climbing condition.
- Moreover, using the hinge joint control mechanism adopted from Sigma-3 the maximum allowable inclination angle was obtained with a load of 3.9 lbs. It is expected that 3-Survivor can carry up to a weight of 11 lbs. and successfully maintain climbing conditions by using motion control Inverse Kinematics espoused from Sigma-3.

Result Analysis

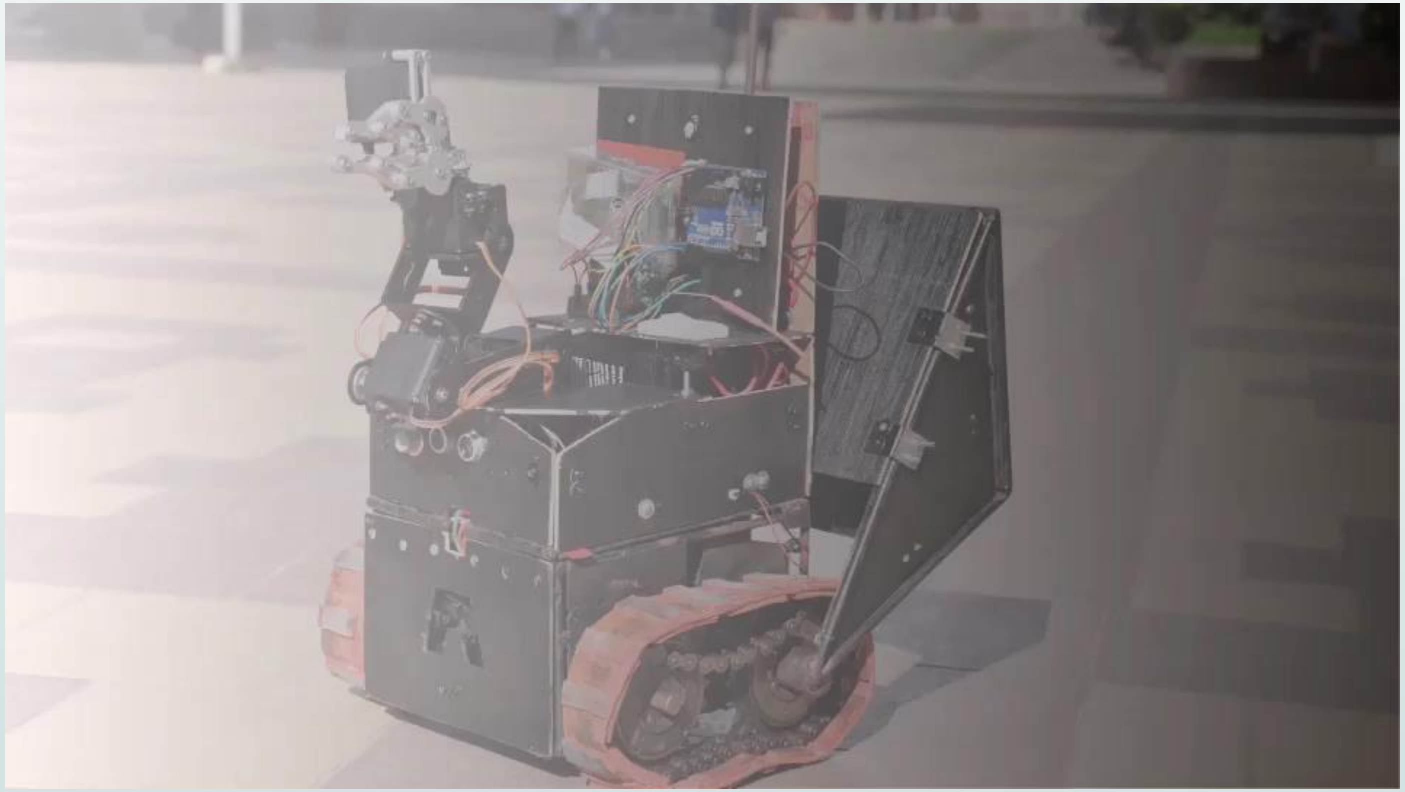
- Finally, some compelling observations came out for the feasibility of ODM. The accuracy and prediction rate largely depended on the motion balance and FPS rate. Simultaneously, while testing the egomotion movement, 48 avg FPS rates were obtained from 3-Survivor, which is significant considering any SAR robot.
- In the case of prediction and accuracy, after 233 trails, with optimized parameters, the mAP of ODM was acquired 56.7 with a maximum object distance of 4 meters and accuracy merging of 92.3





Short Demonstration

Working process of *3-Survivor*



Summary

- In this work, the design, analysis, and development of 3-Survivor are presented. A passive double-tracked mechanism is constructed for rescue missions in a SAR environment.

- The body configuration with versatile parameters has experimented with dynamic analysis of simulation and operational mechanisms.

- A series of experiments displayed the overall accuracy and performance of field operations. It is evident that the operational functionalities of 3-Survivor show significant improvement from its previous version of Sigma-3.

- The ODM and body design are the most researched concern for this robot, and the results from the experiments are reliable. In the future, a military and human assistant version of 3-Survivor will be introduced with autonomous pathfinding and object manipulation to guarantee the reliability of the developed rescue robots.

Thank You.

For Any queries, contact -

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