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Terrain Mapping using Swarm Robotics (CRITTerLS)

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Abstract— Swarm Robotics is an approach that involves the coordination and cooperation of multiple robots. The robots display a collective behaviour, which is desired, while interacting with each other and the environment. The concept of swarm robotics can be applied in many fields where task distribution and cost reduction is of prime importance. One of the fields where swarm robotics can be applied is Mapping. This paper introduces a technique for building a 2D representation of a terrain using this concept of swarm robotics.

Keywords—*Swarm Intelligence, Swarm robotics, Terrain Mapping, 2D terrain map, Swarm Robots*

I. INTRODUCTION

Swarm robotics is the study of how to design groups of robots that operate without relying on any external infrastructure or on any form of centralized control. In a robot swarm, the collective behaviour of the robots results from local interactions between the robots and between the robots and the environment in which they act. The design of robot swarms is guided by swarm intelligence principles.

Swarm robotics appears to be a promising approach when different activities must be performed concurrently, when high redundancy and the lack of a single point of failure are desired, and when it is technically infeasible to set up the infrastructure required to control the robots in a centralized way. Examples of tasks that could be profitably tackled using swarm robotics are demining, search and rescue, planetary or underwater exploration, and surveillance.

Swarm robots are basically simple, small robots with low cost. They are termed as individual agents with simple and single abilities. These agents have the ability to evolve themselves when dealing with certain problems to make better compatibility. They are autonomously controlled by a plain set of rules and local interactions. These individuals are not necessarily unwise, but are relatively simple compared to the global intelligence achieved through the system. Some intelligent behaviours never observed in a single individual will soon emerge when several individuals begin to cooperate or compete [1].

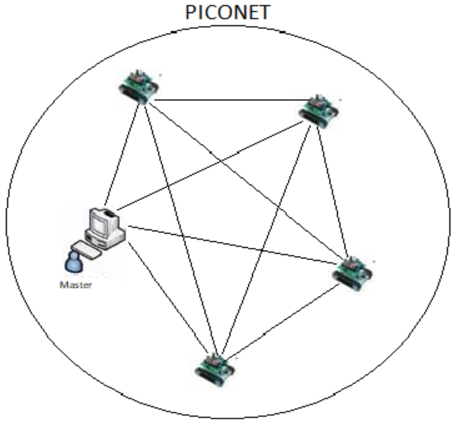

Fig. 1 General Architecture of Swarm Robots communication

Fig 1 depicts the general architecture of a swarm robot system. The robots are communicating with each other in a piconet and at the same time, also communicating with the master to deliver the results.

Different methods have been used to map terrains using a single robot system. However, a single robot system cannot achieve the complete utilization of various resources, the efficiency of performance, the cost reduction factor, the scalability, the robustness and the parallelism with which a swarm robot system functions. In some cases, there are even terrains which cannot be traversed by any human being or robot. At present, there is no system that maps a terrain usingswarm robotics. Thus, our approach for terrain mapping utilizes this concept of swarm robotics which will traverse through any terrain, inaccessible to humans as well as robots, capture the data from the environment and create a 2D map accordingly.

II. RELATED WORK

The swarm robotics is a combination of swarm intelligence and robotics, which shows a great potential in several aspects. As an emerging research area, the swarm intelligence has attracted many researchers' attention since the concept was proposed in 1980s.

Since this is fairly a new topic which has a budding future, the research and development in this field is not advanced much [2]. The research and development done in the area of terrain mapping has been discussed below:

A. Autonomous Terrain mapping and classification using hidden Markov models[3]

A new approach for terrain mapping and classification using Hidden Markov models is presented. Mobile robots equipped with 2D SICK laser range finders and a Microstrain IMU is used to differentiate and map terrains. The algorithm used is based on Hidden Markov Models and the Viterbi algorithm. Using this algorithm, the terrain is classified into navigable and non-navigable areas. The data collected from the sensors is used to map a 3D point cloud map. The classification errors in these maps are fixed using the Markov Random fields segmentation method. Their key contribution is creating a classifier that is efficient enough to differentiate concrete flat terrains from grass, gravel and other types of obstacles.

B. High-Resolution Terrain Map from Multiple Sensor Data[4]

3D vision techniques for incrementally building an accurate 3D representation of rugged terrain using multiple sensors. An ERIM laser scanner is used to create a range or depth image. A grid-based representation i.e elevation map is used to represent rugged terrain. The locus method, which exploits sensor geometry, efficiently computes a dense and uniform elevation map of the terrain at a desired resolution using the range image and the consequent elevation map. A digital elevation map (DEM) is used reduce error accumulation in the map. Their key contribution is combining feature matching, iconic matching and inertial navigation data to achieve the required accuracy.

C. Cooperative Hole Avoidance in a Swarm-bot[5]

Coordinated motion in a swarm robotic system, called a swarm-bot, is used for tasks that require all-terrain navigation abilities while avoiding falling into holes. The swarm-bot, consisting of four s-bots, is controlled by a neural network connecting its sensory inputs to the motor outputs. A simple generational evolutionary algorithm is used for the synthesis of neural controllers. The fitness of the genotype is computed by measuring the performance of the corresponding group of four robots. A traction sensor is used for achieving coordination in the swarm-bot. Their key contribution is creating a self-organising system that is consequently robust to environmental changes and to the number of s-bots involved in the experiment.

D. 3D Simultaneous Localisation and Map-Building Using Active Vision for a Robot Moving on Undulating Terrain[6]

A real-time EKF-based SLAM system permitting unconstrained 3D localisation, and in particular developing models for the motion of a wheeled robot in the presence of unknown slope variations. In a fully automatic implementation, the robot observes visual point features using fixating stereo vision and builds a sparse map on-the-fly. Combining this visual measurement with information from odometry and a roll/pitch accelerometer sensor, the robot performs accurate, repeatable localisation while traversing an undulating course.

E. A new terrain mapping method for mobile robots obstacle negotiation[7]

A new terrain mapping method for mobile robots with a 2-D laser rangefinder. In the proposed method, an elevation map and a certainty map are built and used for the filtering of erroneous data. The filter, called Certainty Assisted Spatial (CAS) filter, first employs the physical constraints on motion continuity and spatial continuity to distinguish corrupted pixels and missing data from uncorrupted pixels in an elevation map. It then removes the corrupted pixels and missing data, while missing data is filled in by a Weighted Median filter. Uncorrupted pixels are left intact so as to retain edges of objects. The key contribution of this project is the demonstration that the CAS filter has better performance in erroneous data reduction and map detail preservation than existing filters.

III. PROPOSED METHODOLOGY

Terrain mapping using human beings or a single robot is a tedious task which requires a lot of time, man power, cost and other such resources. So, the proposed system, "Terrain Mapping using Swarm Robotics", known as "CRITTerLS", can alleviate these problems by implementing swarm robots that can map the terrain by acquiring the terrain information and generating a 2D map of the terrain.

The objective of our project is to develop swarm robots using the concept of swarm intelligence to map a terrain where big robots or human beings cannot enter. The use of swarm robots, ensures that the collection of data required for mapping is faster, work done is effective and there are minimal losses in every factor.

The proposed system broadly consists of swarm robots. The robots will interact with the other robots, exchanging data of the obstacles as well as the coordinates of the robots. This data will then be utilized to map the required terrain.

Obstacle detection and avoidance by robots is as crucial as interaction between the robots and the central server. The robots need to detect the obstacles which can be inanimate objects as well as other fellow robots and skilfullymanoeuvre themselves to avoid hitting the obstacles. This is accomplished using the sensors on the robot. Fig 2 depicts the basic structure of how each robot performs its task of mapping of the terrain and collectively making a map.

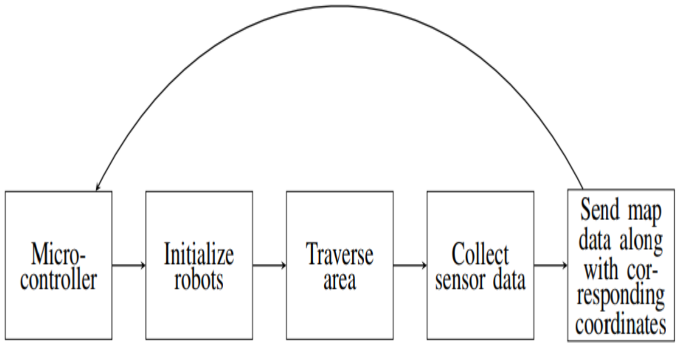

Fig. 2 General Diagram for the Swarm Robot system

A. Components used for the proposed methodology

The main components used in designing the proposed system which are used for map generation are:

1. XBee

XBee modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. They are designed for high-throughput applications requiring low latency and predictable communication timing [8].

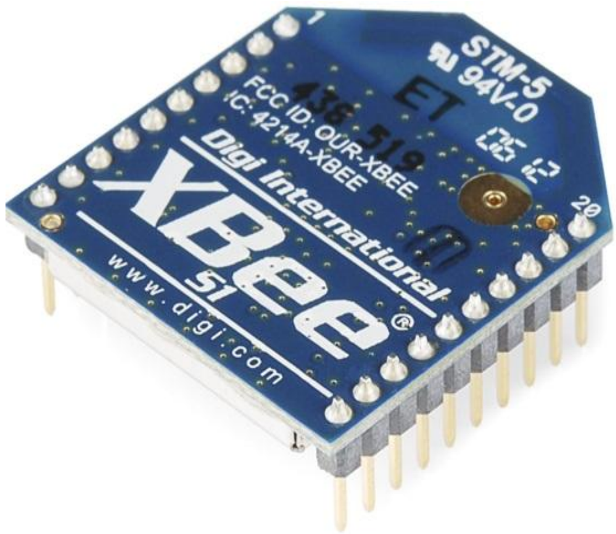

Fig. 3 XBee

2. XCTU

XCTU is a free multi-platform application designed to enable developers to interact with Digi RF modules through a simple-to-use graphical interface. It includes new tools that make it easy to set-up, configure and test XBee® RF modules.XCTU is a free, multi-platform application compatible with Windows, MacOS and Linux [9].

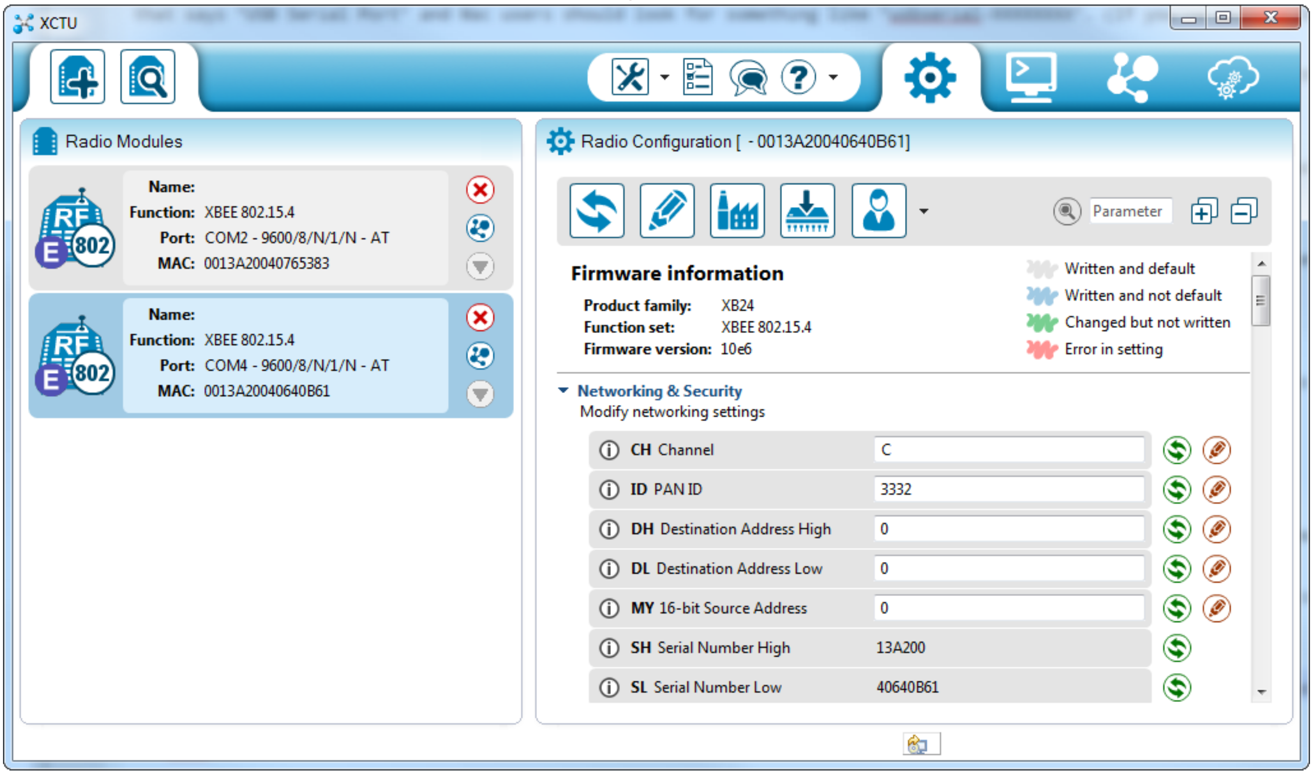

Fig. 4 XCTU

3. Sharp IR Sensor

The Sharp distance sensors are used for accurate distance measurements. IR sensor is more economical than sonar rangefinders and provides much better performance than other alternatives. Interfacing to most micro-controllers is also simple. The detection range of the Sharp IR sensor is approximately 10 cm to 80 cm [11].

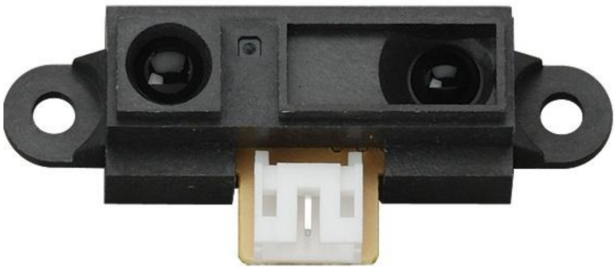

Fig. 5 Sharp IR Sensor

4. DC Motor

Geared DC motors can be defined as an extension of DC motor. A geared DC Motor has a gear assembly attached to the motor. The speed of motor is counted in terms of rotations of the shaft per minute and is termed as RPM .The gear assembly helps in increasing the torque and reducing the speed. Using the correct combination of gears in a gear motor, its speed can be reduced to any desirable figure [10].

Fig. 6 DC Motor

5. Encoder

A rotary encoder, also called a shaft encoder, is coupled with the motor shafts to get the rotation ticks from the encoders. Encoder is an electro-mechanical device that converts the angular position or motion of a shaft or axle to an analog or digital signal [13].

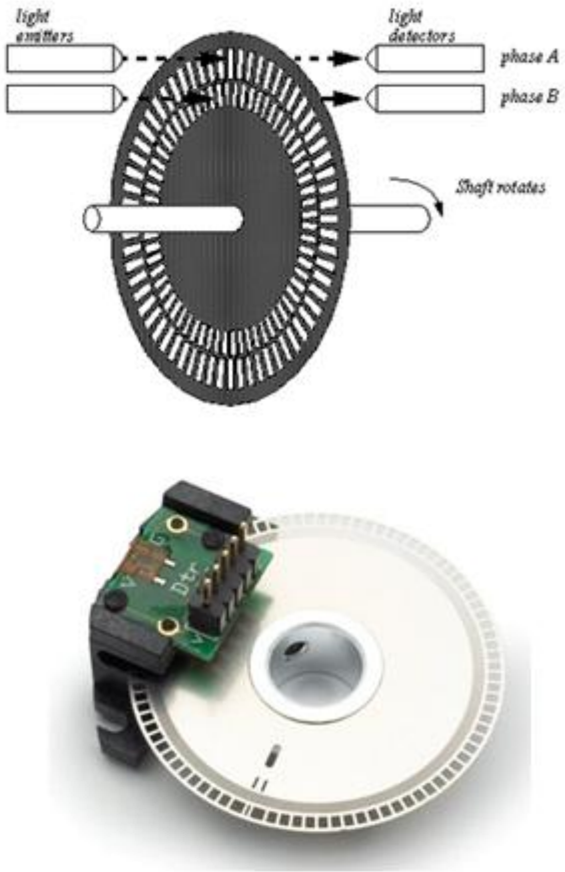

Fig. 7: Encoder

6. Matplotlib library in Python

B. Design of the Proposed Methodology

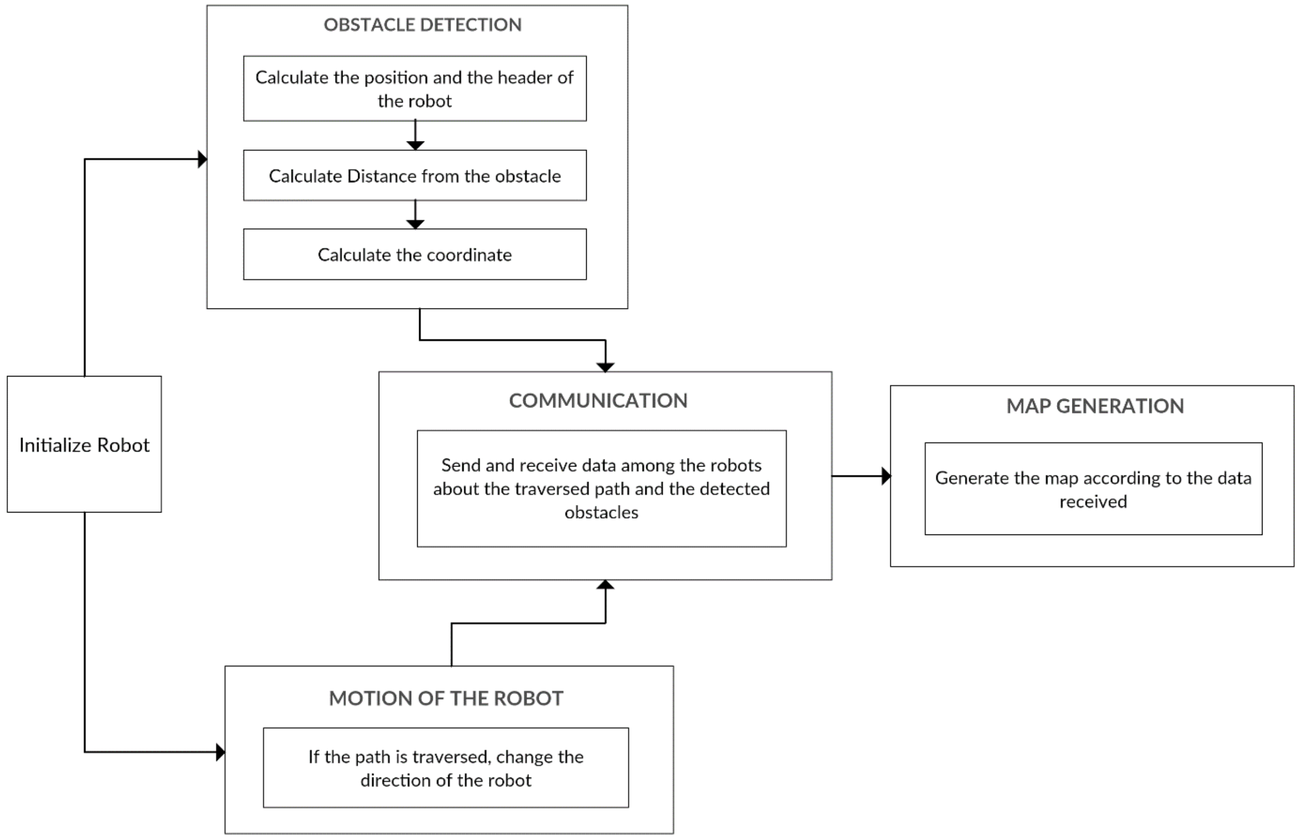

Fig. 8Block Diagram

The design of the proposed methodology has been explained from the above block diagram. The robots are first initialized and then the map generation is performed. There are four modules in the design of the proposed methodology:

1) Communication

The communication module of the CRITTerLS involves communication between the server and the robots. The component used for this communication is XBee. The four robots communicate through a simple-to-use graphical interface called XCTU. The XCTU provides the output in the form of a log file (Hex).

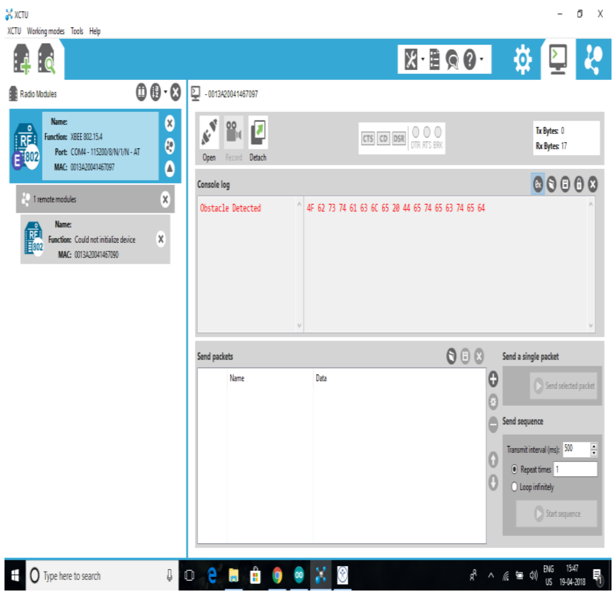

Fig. 9 XCTU Log file (Hex)

A python script is used to separate the readings of the received log file. The robots calculates the encoder left and encoder right readings respectively and the results are stored in a text file respectively. The encoder readings are then plotted using a python script. The result of the encoder readings are plotted into a map.

2) Obstacle Detection

The obstacles are detected using the Sharp Infrared Sensors. As soon as the IR sensors mounted on the front of the bot detect an obstacle, the bot checks for the readings of the left and right sensors mounted on the robot. If the left sensor has a greater distance value than the right, the robot turns left and vice versa. If both the left and the right sensors have equal value then the robot turns right by default. The obstacle detection can be explained by the following diagram:

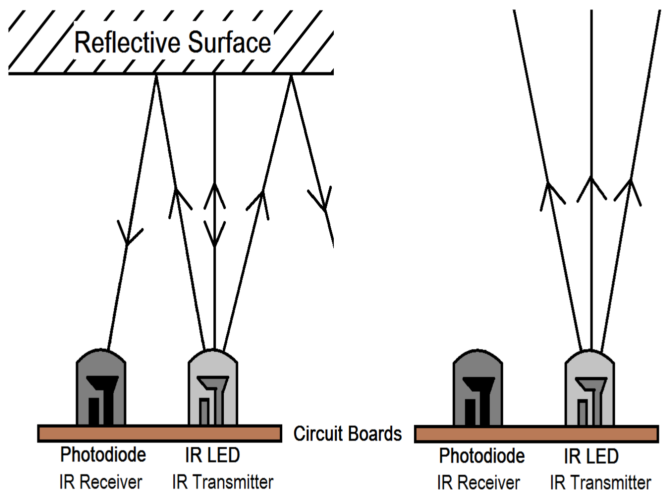

Fig. 10 Obstacle Detection using IR sensors

An IR sensor consists of an IR LED and an IR Photodiode. When the IR transmitter emits radiation, it reaches the object and some of the radiation reflects back to the IR receiver. Based on the intensity of the reception by the IR receiver, the output of the sensor is defined [12]. The output of the obstacle detection is shown below:

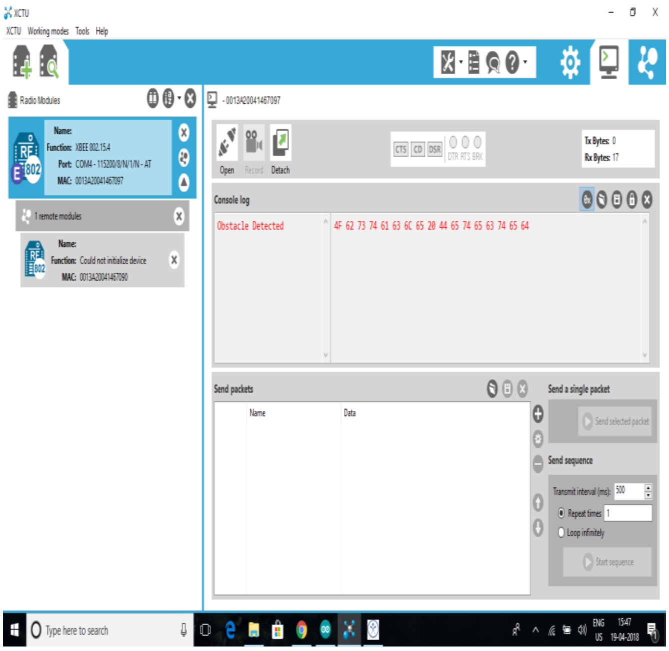

Fig. 11 XCTU obstacle detection

3) *Tracking the motion of the Robot*

For the motion of a robot, two DC geared motors are used. The encoder left and right readings as well as the angle of each turn performed by the robot are calculated and stored in a text file.

4) *Map Generation*

a) *Algorithm*

```
# Find out if there is a turn at all.

ifmotor_ticks[0] == motor_ticks[1]:
    # No turn. Just drive straight.
dist = motor_ticks[0] * ticks_to_mm
theta = old_pose[2]
    x = old_pose[0] + dist * cos(theta)
    y = old_pose[1] + dist * sin(theta)
return (x, y, theta)

else:

    # Turn. Compute alpha, R, etc.

old_theta = old_pose[2]
old_x = old_pose[0]
old_y = old_pose[1]
      l = motor_ticks[0] * ticks_to_mm
      r = motor_ticks[1] * ticks_to_mm
alpha = (r - l) / robot_width
R = l / alpha
new_theta = (old_theta + alpha) % (2*pi)
new_x = old_x+(R + robot_width/2.0)*(sin(new_theta)-
sin(old_theta))
new_y = old_y+(R + robot_width/2.0)*(-
cos(new_theta)+cos(old_theta))
return (new_x, new_y, new_theta)
```

The above algorithm is used to calculate the distance travelled and the heading of the robot. From that we get new point after each tick of the encoders which is plotted using 'matplotlib' library of Python. The map created is shown below:

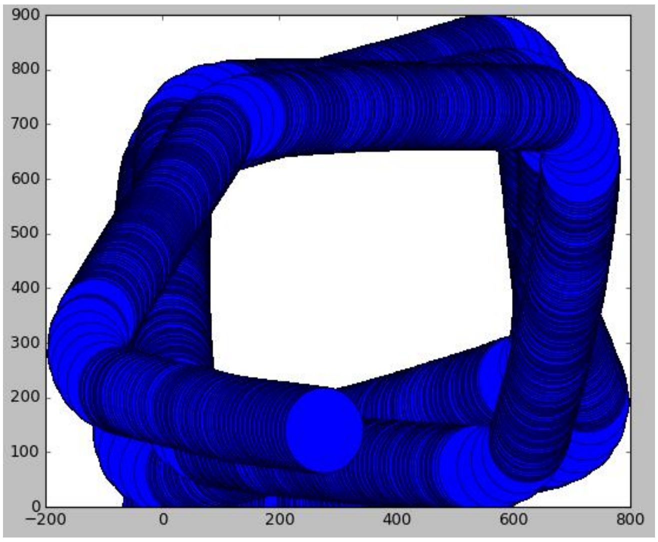

Fig. 12Generated Map

Here the blue fill show the navigable path and the white fill show the non-navigable path.

5) *Problems faced*

One of the most prominent problems faced was the error in the encoder readings. Which usually caused generation of distorted maps. Example of a distorted map:

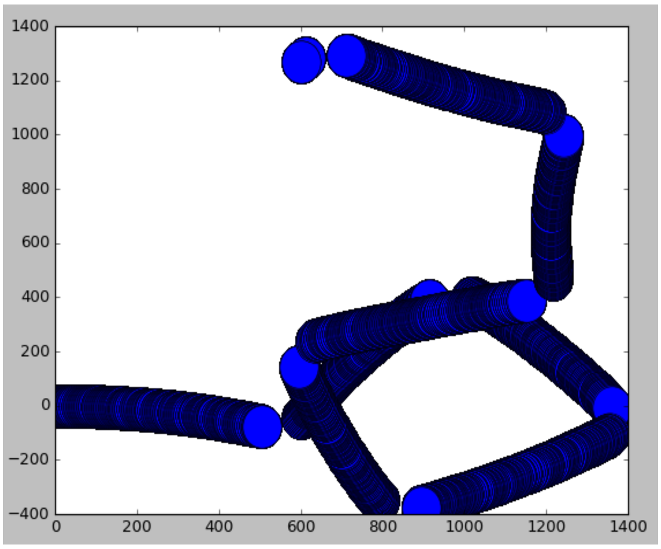

Fig. 13Problem output faced

The map is distorted because the error in the encoders caused error in calculation of new points and the calculation of the robot headings.

CONCLUSION

Terrain Mapping using Swarm Robotics - CRITTerLS is a learning system that implements the concept of swarm intelligence. This system explores any unknown terrain which is difficult to traverse. The sensors mounted on the data continuously keep collecting information about the terrain. Obstacles are detected before encountering them and it is avoided using the best possible path, which can either be turning towards the left or right, or backtracking a few steps till another path is found. The robots periodically send the information collected as well as the coordinates to the central server. The central server then utilizes all the collected information and coordinates and creates a 2D map which represents the terrain. Thus terrain mapping using swarm robotics is performed. CRITTerLS provides faster and efficient execution of work, less time and minimal losses in other aspects such as human life and budget.

As future work, we propose more complex models to represent the terrain, as well as 3D representation techniques of the mapped terrain. Instead of a map for a concrete terrain, there can be different models for different types of terrains, including grass, gravel, water, etc. Combining different sensors such as temperature sensor information and images can also be done in the future. This will be beneficial to better represent the environment.

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