Distributed Localization in Partially GPS Denied Environments

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***Abstract*—The goal of this project is to develop a technique for distributed absolute localization of robot swarms that interoperate between GPS accessible and GPS denied environments. Such scenarios typically arise in search and rescue operations for disaster management tasks. Especially, in calamities such as earthquakes, where it is impossible for humans to reach victims trapped under collapsed debris and structures, an army of small robots that can crawl through tight spaces between the rubble to locate victims can be a life-saving tool. However, such robots would need to locate themselves reliably in an hostile GPS denied environment (such as a collapsed building). This problem can be approached by combining previous work on Simultaneous Localization And Mapping (SLAM) [3] and Distributed Relative Localization of Swarms [4] with Wireless Sensor Networks.**

I. Introduction and Background

The information available to robotic swarms is not always consistent across all the robots. This can happen through either environmental factors or failure of robotic components. Environmental factors that can contribute to these inconsistencies include constriction points in the terrain, areas with overhangs like caves or buildings, or areas with partial Faraday cage effects due to high concentration of ferrous materials in the walls or other structures in the environment. One such case was Operation Surya led by Indian Army during floods in 2013 at Kedarnath which was caused by monsoon rains, flash floods, and landslides. During this calamity, as many as 207 mobile towers were knocked down by the fury of the floods and approximately 10,000 troops were deployed to rescue and help the needy people. Today, we can use a number of robots and map and scan the area affected and deploy the rescue measures as per requirement. However, such systems heavily depend on GPS based localization for navigation, which limits their usage in situations like going in an underground cave or inside a metallic bunker. Failure of some sensors can cause an error in navigation and render the robot inoperable. Furthermore, when this inconsistency in information is on localization information this can pose challenges to determining the most appropriate behavior for the swarm and especially individual members of the swarm. In the case of damaged but still otherwise operable robots, the ability of the swarm to provide localization information may improve the chances of recovering said robots. In the case of disparities in localization information, the ability of the swarm to provide absolute localization information may aid in many other tasks including: obstacle avoidance, exploration, or search and rescue. Furthermore, for mixed ability robot swarms reducing the number of robots that have GPS may offer significant cost savings or the ability to use other resources on limited systems. Thus, the precise and accurate absolute localization of robotic swarms is an important ability to develop.

A. Prior Work

The challenge of localization has long been approached through the use of various techniques. In [8], problems about the localization of two robots without any prior information of each others location has been discussed. In this paper, two robots are initialized each unaware of others location. As they navigate, the robots wirelessly share and match laserscans attempting to solve for the others pose in the local frame. After observing a common area, the robots compute a transformation between their local coordinates frames. Thus a combined 3D map is initialized and the map and estimated transform are refined online based on new sensor measurements. The combined map contains sections independently explored by each robot. To accomplish this strategy, pose correspondents are built by matching sensor measurements shared by each robot. Robots can localize to one another online, even after being initialized in different buildings. Hence larger areas can be explored using multiple robots.

In [5], the overall goal is to perform a building-clearing mission, where a swarm of robots enter whose layout is unknown. The robots then disperse thorugh the building and attempt to locate an object of interest. Once the object has been located, the swarm remains in the building to protect the item of interest until friendly forces arrive. For this, they developed distributed algorithms. Their solution consisted of collaborative localization algorithm, dynamic task allocation algorithm and collaborative mapping. The authors showed some promising results using both simulated and real robots.

In [3] , they use Triangulation and Probabilistic techniques. Triangulation technique use simple geometric properties along with probability to calculate the location of an object from the locations of other objects.

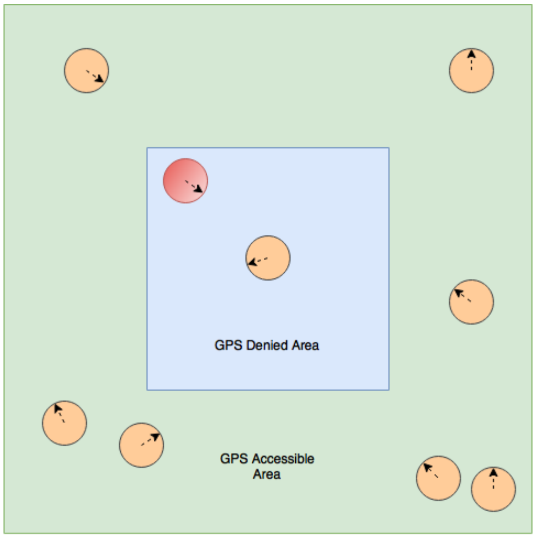

Fig. 1. Arena with GPS Denied and Accessible areas. The term GPS Denied is used to decribe areas where the robots cannot obtain their own GPS location data. The term GPS Accessible is used to describe the areas where the robots can obtain their own GPS location data. The robot in red is the point of interest.

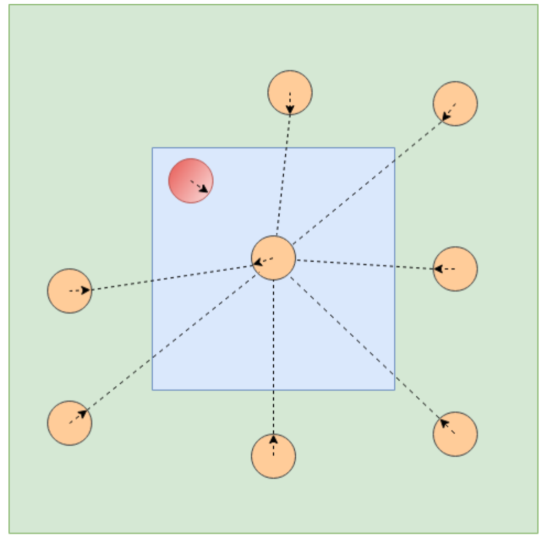

Fig. 2. Arena showing swarm providing localization information to a robot in GPS Denied area.

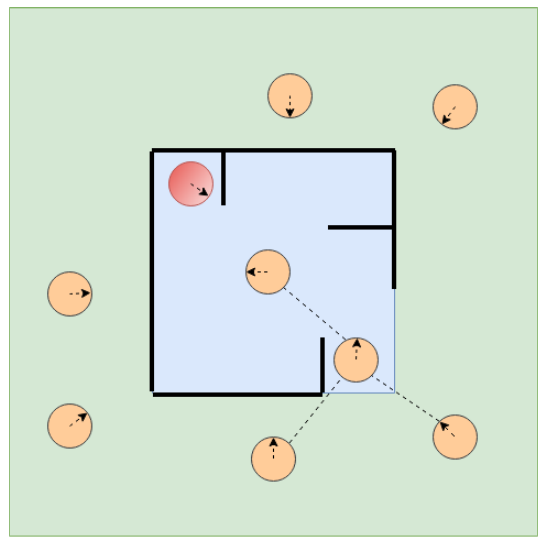

Fig. 3. Arena with Physical Obstructions.

Other pertinent localization approaches include GPS [7] [6] and the approaches suggested by Blusu, Heidemann and Estrin. [1]. The basics of GPS involve the use of a constellation of satellites to enable the global use of a modified triangulation localization technique. By having more than three satellites visible to receivers across the globe the accuracy of the triangulation is improved. In practice, this is frequently supplemented with other localization data to further increase the accuracy of the localization. The approach suggested by Blusu, Heidemann and Estrin utilizes periodic short-range radio frequency beacons from a fixed number of reference points, in a similar system to GPS. However, they use an idealized radio model that assumes perfect spherical radio propagation and identical transmission range for their signal.

II. Proposed Work

This project team proposes to simulate the effects of part of a swarm entering an absolute localization information sparse area, like a cave, and develop accurate and effective methods for the absolute localization of the swarm members in the information sparse area.

1) Representation of the Environment: The arenas will be divided into regions with different levels of absolute localization information available directly to the individual robots in the swarm, as shown in Figure 1. For further experiments, obstacles will be placed to represent different physical obstructions that may or may not cause this information variation. The primary arena with obstacles will have a constriction leaving a narrow passage from one side of the arena to the other representing a doorway or cave entrance, as shown in Figure 3 The area on one side of this constriction would have near complete absolute localization information availability and the other side none. At least one more complicated arena will be developed. This would be a modifications of the primary arena. The modifications would include boxing off the no-GPS region (aka GPS Denied) in a larger arena and allowing for more than one entrance point. The effect of how sharply the information availability drops off at the constriction is another area to investigate.

2) Selection of Robots: For the purposes of this project the robots needed communication, localization, and locomotion abilities. The Khepera IV robot in as simulated in ARGoS provides all three of these properties. It has leds which can be used to convey information to other robots. It has a positioning sensor described as ”a sort of GPS” which can give absolute localization information. It also has wheels and an actuator for the wheels which can be used for locomotion. [2] It also has a bottom mounted infrared sensor that can be used by

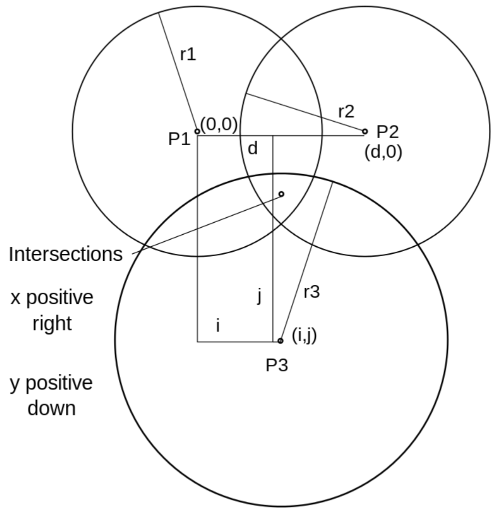

Fig. 4. Geometry of the trilateration algorithm. The GPS accessible robots are located at points P1, P2 and P3 with distances r1, r2 and r3 from the GPS denied robot, located at the intersection of the three circles.

The following algorithm computes the intersection of three spheres. (Trilateration):

1. Given a robot K in GPS denied environment. This robot is surrounded by the neighbour robots who HAVE access to GPS information. The neighbours broadcast their own location and distance to the robot K periodically.
2. From all the neighbours, sample broadcasted information from 3 robots located at points (P1, P2 and P3) with distance (r1, r2 and r3) respectively from robot K. [P1, P2 and P3 are 3x1 vectors and r1, r2 and r3 are scalars]
3. Get the unit vector in direction from P1 to P2
   - $\widehat{e}_x = P2 - P1 / \|P2 - P1\|$
4. Get the signed magnitude of x component of vector P1 to P3
   - $i = \widehat{e}_x \cdot (P3 - P1)$
5. Similarly, get the unit vector in y direction
   - $\widehat{e}_y = P3 - P1 - i\widehat{e}_x / \|P3 - P1 - i\widehat{e}_x\|$
6. The third basis unit vector is given as:
   - $\widehat{e}_z = \widehat{e}_x \times \widehat{e}_y$
7. Distance between the point P1 and P2
   - $d = \|P2 - P1\|$
8. Get the signed magnitude of y component of vector P1 to P3
   - $j = \widehat{e}_y \cdot (P3 - P1)$
9. The location of the robot K can then be given as:
   - $P = P1 + x\widehat{e}_x + y\widehat{e}_y + z\widehat{e}_z$ where,
   - $x = (r_1^2 - r_2^2 + d^2) / 2d$
   - $y = (r_1^2 - r_3^2 + i^2 + j^2) / 2j - (i/j)x$
   - $z = \sqrt{r_1^2 - x^2 - y^2}$

Fig. 5. Trilateration localization algorithm.

the robot to detect the floor color. In our experimental setup we plan to differentiate the GPS accessible area from GPS denied area by giving different colors to the tiles of the arena. To simulate the information provided by GPS in real Khepera IV robots, one of two techniques will be utilized. If the experiments are conducted in the lab the Vicon system will be used to provide the localization information. Otherwise or in addition markings in the arena and the downward facing sensor will be used.

3) Description of Task: In the environments described in II-1, the swarm will be tasked with locating and providing an absolute localization for a point of interest in the no-GPS region, as shown in Figures 2 and 3.

III. Proposed Experiments and Expected Outcomes

1) Trilateration Algorithm: For localizing a robot in a GPS denied environment, we intend to use the Trilateration algorithm. This algorithm essentially computes the intersection of three spheres. We start with a robot K in the GPS denied environment. This robot is surrounded by the neighbour robots who HAVE access to GPS information as shown in Figure 4. The neighbours broadcast their own location and distance to the robot K periodically. From all the available neighbours, select broadcasted information from 3 robots who themselves are located at points (P1, P2 and P3) with distance (r1, r2 and r3) respectively from robot K. Here, P1, P2 and P3 are 3x1 vectors and r1, r2 and r3 are scalars. With this information, the robot K can compute its own location by the algorithm shown in Figure 5. This algorithm can then be repeated for all of the neighbour triplets of the robot K. The resulting location from all such triplets is then combined to get the absolute position estimate.

2) Proposed Experiments: The experiments will be carried out in the simulation with following assumptions:

1. No communication delay between robots when receiving range and bearing broadcast information.
2. Robots perform perfect motion (no wheel slip)
3. During early trials, GPS information (absolute location) will be kept binary (either robot knows its position through GPS or doesn't). Later, noise will be added to the available GPS information and the localization accuracy will be tested.

Initially, we plan to test the above algorithm in a static environment. We will position one robot in the the GPS denied environment and three robots in the GPS accessible environment. The robots are stationary and the performance of the localization algorithm will be checked for such a configuration.

Next, we plan to move the GPS denied robot keeping the GPS accessible robots static.

Finally, we plan to move both, the GPS denied robot and the GPS accessible robots with a sample velocity and check the robustness of the algorithm.

Finally, the goal test case would be this: A single robot in the GPS denied area tasked to find the stranded robot (indicated by red LEDs). There may be multiple robots in the GPS accessible area, some of which will be stationary and some moving. The GPS denied robot will then use broadcast information from its neighbours to localize itself and search for stranded robot. The rescue robot tries to go towards the red light of the stranded robot. When it reaches within a set proximity of the stranded robot, the location of the stranded robot is known.

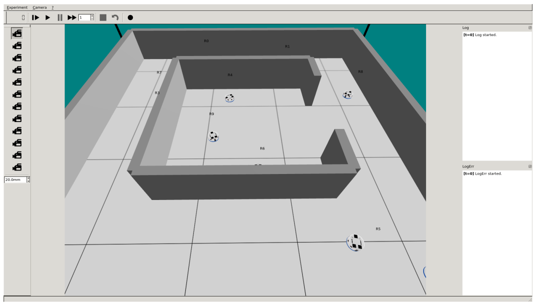

Fig. 6. Walled Arena.

As a future work, this location information can thus be relayed back to the team of robots that transport the stranded robot out.

In all of the above test cases, the first type of parameter variation that will be analyzed is the effect of the number of robots on the localization of a point of interest in a no-GPS region.

The second type of variation that will be analyzed is the effect of the fraction of moving robots to static robots on the location estimate of the GPS denied robot.

To evaluate the performance of the techniques developed the parameters of the experimental set up will be varied along different dimensions. Each of these have different expected outcomes.

Provided there is time our reach experiment is to include walls in the arena as show in Figure 6.

3) Expected Outcomes: Since the probability for multiple robots in the GPS region being in view of robots in the no-GPS region increases with the number of robots, since the arena is of fixed size. It is expected that increasing the number of robots will improve the accuracy of the localization of the target of interest until a saturation point. There should be a saturation point since the robots will start to both obstruct each other and interfere with the maneuvering of each other.

IV. Weekly Schedule

The proposed schedule of work is shown in Table I. The days with activities indicate the start of that activity as the focus of the team and the estimated initial completion of the previous activity. There will likely be need for revision of the earlier components of the project once later stages start, but these milestones are ordered as such to structure the work flow.

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TABLE I
WEEKLY SCHEDULE

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week of April 2	Prepare Experimental Setup		Algorithm Development				
Week of April 9	Algorithm Verification		Running Experiments				
Week of April 16						Prepare Demo	
Week of April 23	Demo Day 1		Demo Day 2	Report Writing			
Week of April 30		Report Due					