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ORIGINAL RESEARCH ARTICLE

A STEP TOWARDS AUTONOMOUS, BIOMIMETIC, NON-GPS BASED NAVIGATION METHODOLOGY

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ABSTRACT

Global Positioning System (GPS) based navigations have their own inherent weakness; they can be overridden so easily and are not useful inside structures. One method of overcoming the above problem is the use of feature based navigation system. Nature has so much perfected this that copying nature is one of the best approaches available to scientist. In this study, desert ant (Cataglyphis fortis) was imitated. A simple infra-red based active beacons and robot mounted rotating receiver based on TSOP31138 infra-red sensor was implemented using New Three Objects Triangulation Algorithm (ToTAL) in its firmware for the robot pose. The designed robot with the triangulation algorithm was able to compute its pose such that on a grid of 6 m x 6 m, it can home to its base with a maximum error of 14.8 mm.

1.0 Introduction

Ants are an interesting class of organisms, because of the manner in which they carry out tasks, withstanding heat, and the homing skills they possess during foraging. The Desert Ants (Cataglyphis sp.) in particular, navigate long distances, find food, communicate and avoid predators. They care for their family in similar manner as any mammal. When finding a new home, ants take advice from their more experienced brethren who had memorized alternative hive locations. Ants integrate many types of information for navigation, these are: the number of steps, direction of travel, wind, land type, angles of the sun, visual memories of landmarks and smells (Lieff, 2015). Individual ants use diverse information in different situations and can learn entirely new ways to navigate (Lieff, 2015).

Pathwayz (2017) reported that regardless of whether an organism is travelling a shorter distance or extremely long distances, in order to find its way back it must have some method of navigation. These methods of navigation include; Visual Cues and Landmarks, Magnetic Fields, Solar Navigation, Star Navigation and Chemical Navigation.

The Sahara Desert ants refer to any of several species of ant in the genus Cataglyphis that dwell in the Sahara Desert, particularly C. fortis and C. bicolor. The navigational capabilities of these ants have been the subject of scientific investigations (Wehner, 2003; Sahara, 2016). These ants travel over 200m in zigzag patterns while foraging, and when they get their food, they return to their hole in approximately a straight line from the point of pick of meal to the nest. The nest entrance is usually an inconspicuous 5mm hole in the desert floor. The ant does not retrace the zig-zagging path of its outward journey; even if a scent-trail is possible, such a route would be a waste of time and an increased risk. Instead, it runs in a straight line directly back to its nest-hole. It is amazing that the 0.1 mg brain housed in the head of a 10 mg ant accomplishes such feats of navigation.

Biomimetic systems are greatly desired because natural systems are highly optimized and efficient (Afolayan, 2012), such as the desert ant (Cataglyphis sp.). Biologically inspired robots imitate some characteristics of life such as mobility, vision, flying, and navigational methodology. The challenge of developing biomimetic systems is the requirement of a deep understanding of the operation of the living systems being copied (CSN, 2011). In this study, it is the navigational skill of Cataglyphis sp. we intend to copy. The ability of a robot to localize or recognize its location, navigate or move about its environment, are critical building blocks in creating truly autonomous robots. There has been significant progress in this aspect of autonomy, particularly indoors robots as reported by Thrun et al. (1999), Fox et al. (1999), Menon et al. (2007) and Marder–Eppstein et al. (2010). In like manner, field robots in the form of autonomous cars (on streets and highways) are also being researched into intensively (Montemerlo et al., 2008 and Thrun, 2011). In recent years, significant advances have been made in robotics, artificial intelligence and other fields allowing for the making sophisticated biomimetic systems (Bar-Cohen and Breazeal, 2003). Scientists often perform reverse engineering biological specimens in other to copy them either their form or function or both.

This present study is aimed at carrying out static test (triangulation test) on a triangulation algorithm we developed for the robot. This is the very first step in developing a mobile robot that will use landmark (in this scenario, Omni-directional active infra-red beacons) for its autonomous navigation and homing mechanisms. The triangulation algorithm is based on The New Three Objects Triangulation Algorithm by Pierlot and Droogenbroeck (2014).

2.0 Methodology

The approach used in this study involved the selection of a biological model, specifically C. fortis, imitating it functionally (that is not its physical form) and finally building a wheel robot that can roam about and home back to base on the methodology used by the biological model.

2.1 Selection of biological model

The desert ant (Cataglyphis fortis) was selected for the study. The skills demonstrated during foraging and homecoming (homing) by the ant were demonstrated in the various navigational mechanisms it employs. In this study the landmark based homing methodology was approximated by using Omni-directional active infra-red beacons as the fixed landmark.

2.2 Imitation level and strategy

The desert ant uses the orientation of the various landmark features in its surrounding during homecoming to locate the hole to its nest on the ground. We plan to use active infra-red beacons and sensors for imitating the landmark and its detection augmented with ultrasonic sensors for obstacle detection and avoidance. Together, they will give the robot pose (position and orientation) at any instance.

2.3 The robot design

The robot (Figure 1) is a four-wheeled device designed to imitate one of the Desert Ant navigational capabilities – feature based navigation. On it is mounted with two ultrasonic sensors, a rotating infrared receiver sensor, a motor driver and control circuit comprising of ATMEL ATMEGA328P-PU microcontroller and the other basic elements. The motor driver circuitry is based an L298N Dual H-Bridge Motor controller; it allows the robot to move forward, backward, left-forward, right-forward, left-backward and right-backward. It allows for the braking or slowing down of the robot as well. The top mounted servomotor serves the purpose of rotating the infrared receiver sensor. The ultrasonic sensor is mounted at the front for object detection using timed reflected echo. Echo coming back after 4000ms implies there is no object in front of the robot. The microcontroller (ATMEGA328P-PU) controls the Servomotor, the IR Receiver Sensor and the Ultrasonic Sensor as well as the drive motors. The active beacons (Figure 2) are a group of three (3) Infra Red LED transmitters mounted radially outwards so as to transmit Omni-directionally. They are referred to as being active because the signals they send out are coded and each beacon is managed by a built in microcontroller. These codes are detectable by the rotating Infra red receiver sensor mounted on the robot as it moves about. The robot is powered by four (4) ICR18650 2000-mAh 3.7-V Li-ion rechargeable dry cells.

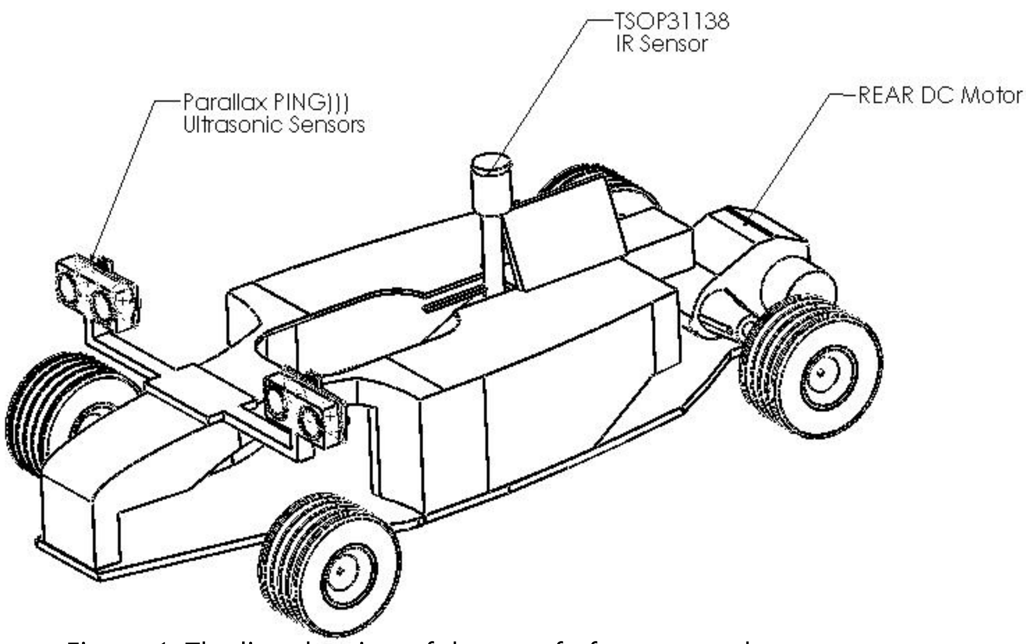

Figure 1: The line drawing of the proof of concept robot.

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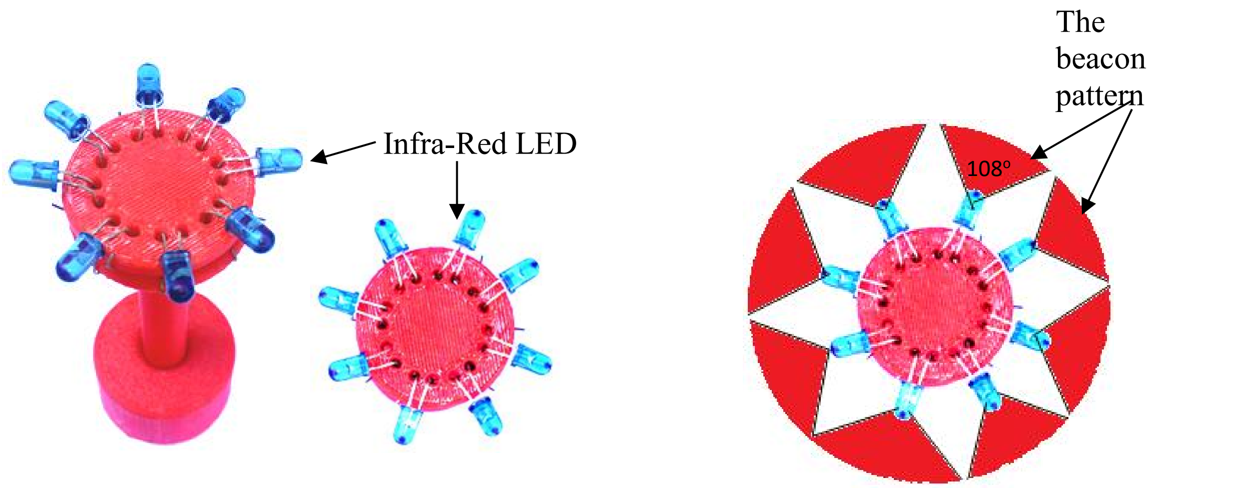

A B C

Figure 2: The beacon with 8 infra-red LED round about its periphery. (A) Isometric view (B) Top view (C) The transmission pattern of the beacon, each is at 180o angle.

2.4 Control algorithm

The control algorithm for the navigation of the robot presented in this study is based on the Three Objects Triangulation Algorithm (ToTal) shown in Figure 3 as a flowchart. This algorithm satisfies biological plausibility defined by Vardy and Moller (2005) as the likelihood of an algorithm existing in biological model. Furthermore, it is required that the algorithm be constrained to share some set of properties known to exist in the model animal in its implementation. The navigation algorithm we have built into the robot use simple landmarks and memorize their locations relative to its own pose. This information is noted at the beginning of operation and it is then used to find its track back when it desire to do so just like the desert ant does.

3 Experimental Verification of the Built-In Algorithm

The test for the triangulation algorithm of the robot at different coordinates was carried out by placing the robot and the beacons on known coordinates within the 6m x 6m experimental grid area. The robot was switched on and connected to a computer (HP 250 G3 Notebook) via a USB port so as to record the robot computed triangulation output (from its firmware). The computation of its coordinates was based on the information obtained from the infrared sensor and the active beacons and using The New Three Objects Triangulation Algorithm built into its firmware. The experimental setup is shown in Figure 4. The test was carried out three times, whereby, for each fixed and known beacon position, the robot was placed at ten different positions and was allowed to search for the positions of each of the beacons and thereafter compute its position relative to those of the beacons. Using Figures 5 and 6; for the first experiment, beacon1 was placed at (0, 0), beacon2 was placed at (1, 0) and beacon3 was placed at (0, 1). The coordinates are given in metres. Also, for the second experiment, beacon1 was placed at (0, 0), beacon2 was placed at (1.5, 0) and beacon3 was placed at (0, 1.5) and lastly, for the third experiment, beacon1 was placed at (0, 0), beacon2 was placed at (2.0, 0) and beacon3 was placed at (2.0, 0), with the coordinates all given in metres. As the robot positions were statically altered, the actual coordinate (randomly selected) was recorded and the robot estimate of its own coordinates computed using the triangulation algorithm. Furthermore, the distance to the goal (GDa) (in straight line) was measured and also computed (GDc) with the algorithm.

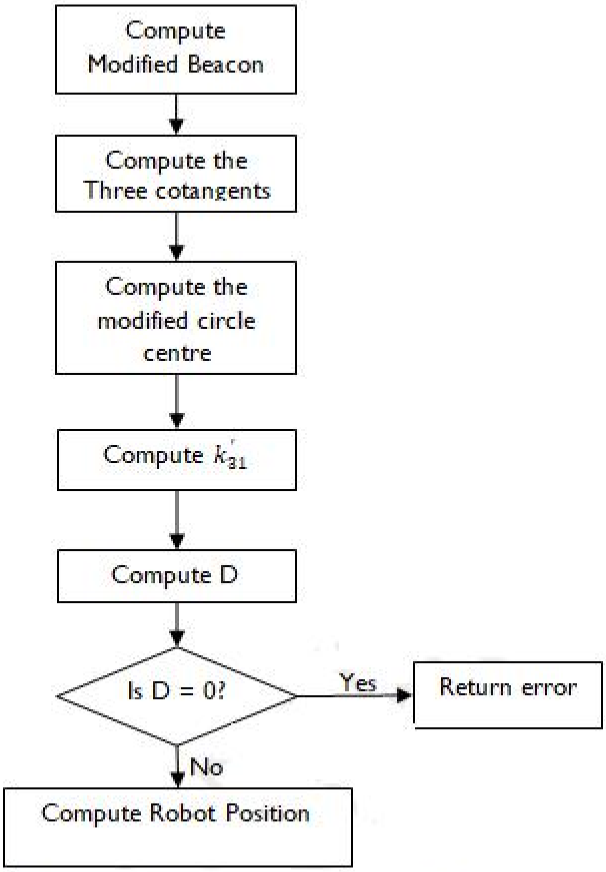

Figure 3: The flowchart of the Triangulation Algorithm

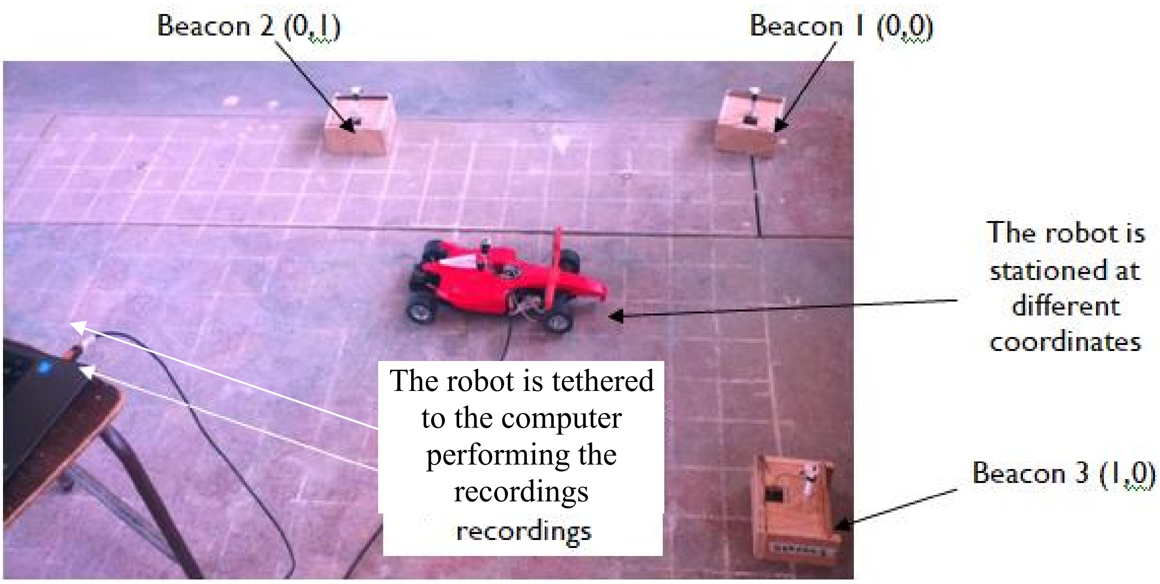

Figure 4: Experimental setup for the test on triangulation with a fixed beacon coordinates and different robot position. This Figure is for experiment 1beacons coordinates while the robot position is at (0.5, 0.5) coordinates.

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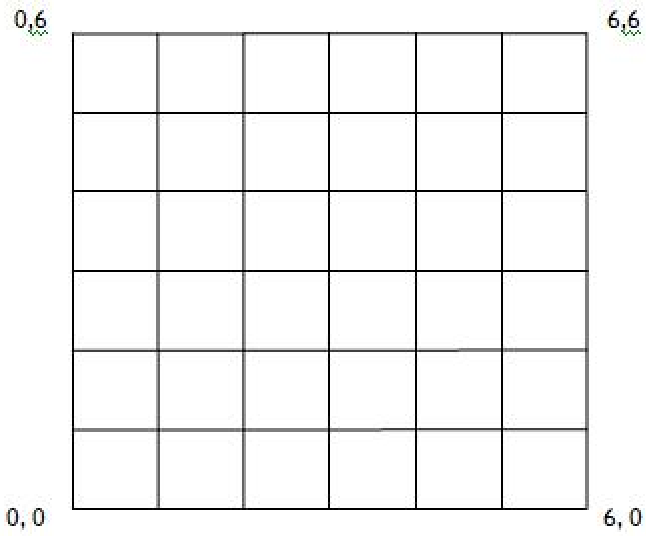

Figure 5: The Experimental grid design and it coordinates nomenclature

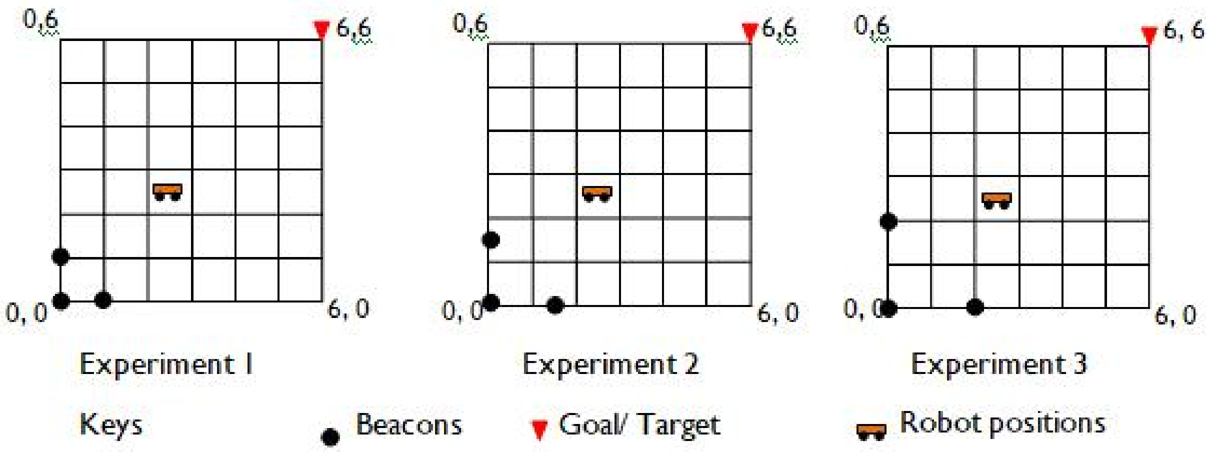

Figure 6: The beacons positions. The robot positions refers to the robot actual coordinates

4. Results and Discussion

The goal coordinates are the reference coordinates, fixed at (x=6, y= 6) in meters. The robot actual coordinate and its computed coordinate's results for the three experiments are presented in Tables 1 to 3. Plots of absolute deviation from the goals for the three experiments are shown in Figures 7, 8 and 9. They all appear to be random. We could only attribute these random variations to be due to the components (especially the infra-red sensor) warming up in order to accommodate the changes in the ambient temperature. They were actually not compensated for in our design. We expect a steady variation, not sharp and unpredictable one. Experiment 3 (Figure 9) has the least varying response which corroborates our idea since the infra-red sensors were already very warm by the time the 3rd experiment was being conducted. However, the absolute variation of the goal computed from the actual goal is encouraging as the worst case is 0.015 m (ignoring the outlier in the first experiments). It means the robot will miss its target by maximum of 0.015 m (15mm) if homing from the corner of the 6 m X 6 m grid. This result is an improvement when compared to GPS based systems whose precision is in the order of 3-5m (Ping-Ya, 2000; Andrew, 2017). However, on a relative scale, there is need for a lot of improvement; a low orbit GPS system has 1:300,000 best error value to orbit height (1500km) ratio whereas, our system has 1:400 error to target (6m ahead) ratio. The limitation is obviously in the triangulation sensing device used – ie the infra-red sensor and the rotary scanner minimum angular resolution.

Table 1: Experiment 1: The Robot Pose; Actual and Measured Coordinates

Repeat	Actual Coordinate(m)		Computed Coordinate(m)		Distance to Goal(m)	
					Actual	Calculated
	x_a	y_a	x_c	y_c	GD_a	GD_c
1	0.34	0.34	0.336	0.300	8.0328	8.0353
2	0.74	0.46	0.739	0.457	7.6393	7.6420
3	0.58	0.73	0.571	0.737	7.5597	7.5617
4	0.54	0.65	0.542	0.650	7.6442	7.6426
5	0.34	0.93	0.334	0.938	7.5987	7.5983
6	0.79	0.95	0.799	0.950	7.2558	7.2491
7	0.22	1.25	0.231	1.252	7.4814	7.4716
8	0.64	1.70	0.701	1.722	6.8717	6.8104
9	1.50	1.25	1.530	1.212	6.5468	6.5505
10	0.10	1.11	0.123	1.131	7.6630	7.6321

Table 2: Experiment 2: The Robot Pose; Actual and Measured Coordinates.

Repeat	Actual Coordinate (m)		Computed Coordinate(m)		Distance to Goal(m)	
					Actual	Calculated
	x_a	y_a	x_c	y_c	GD_a	GD_c
1	0.30	0.42	0.306	0.417	7.9766	7.9748
2	0.79	0.95	0.789	0.959	7.2558	7.2503
3	1.55	0.94	1.545	0.980	6.7384	6.7120
4	1.83	1.83	1.821	1.821	5.8973	5.9098
5	0.40	2.22	0.411	2.228	6.7564	6.7426
6	1.35	0.30	1.356	0.301	7.3561	7.3513
7	0.99	1.03	1.000	1.031	7.0570	7.0492
8	1.00	1.37	1.004	1.374	6.8145	6.8089
9	1.15	0.95	1.150	0.964	7.0018	6.9922
10	1.64	2.24	1.632	2.213	5.7574	5.7815

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Table 3: Experiment 3: The Robot Pose; Actual and Measured Coordinates

Repeat	Actual Coordinate(m)		Computed Coordinate(m)		Distance to Goal(m)	
					Actual	Calculated
	x_a	y_a	x_c	y_c	GD_a	GD_c
1	1.00	0.58	0.998	0.577	7.3740	7.3773
2	1.49	1.25	1.479	1.261	6.5500	6.5497
3	0.48	1.32	0.478	1.319	7.2369	7.2389
4	1.38	1.65	1.377	1.669	6.3456	6.3350
5	1.84	1.53	1.837	1.543	6.1063	6.0988
6	0.87	1.56	0.863	1.561	6.7846	6.7888
7	0.74	2.05	0.726	2.044	6.5780	6.5928
8	0.75	1.35	0.749	1.346	7.0132	7.0162
9	1.35	1.60	1.317	1.619	6.4018	6.4126
10	0.27	1.86	0.264	1.865	7.0691	7.0710

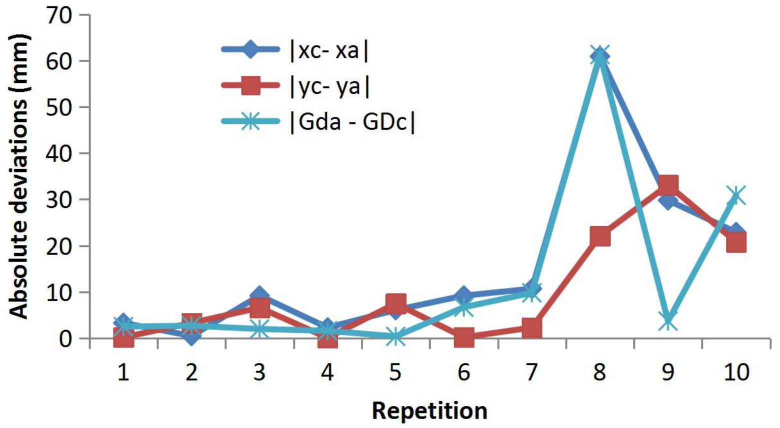

Figure 7: Absolute deviations of the coordinates computed by the robot (Experiment 1)

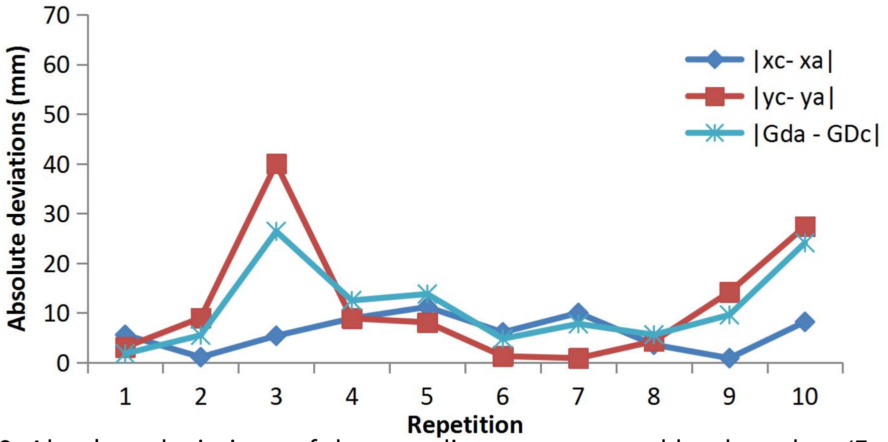

Figure 8: Absolute deviations of the coordinates computed by the robot (Experiment 2)

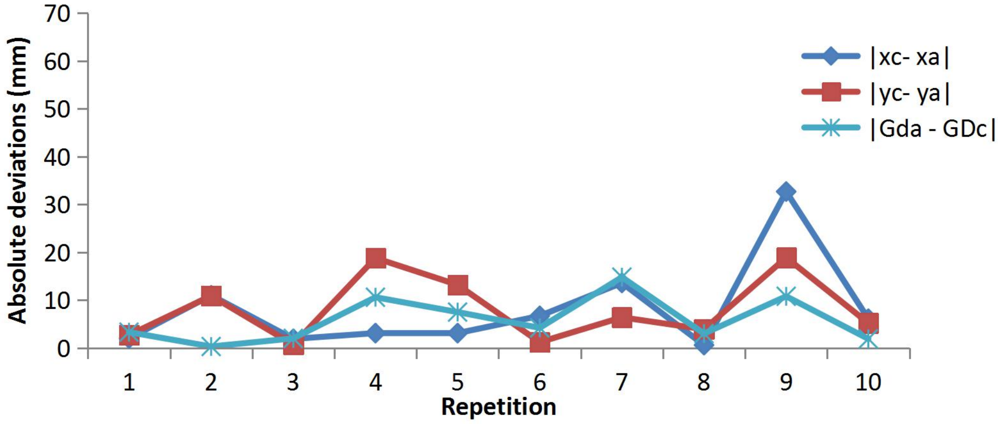

Figure 9: Absolute deviations of the coordinates computed by the robot (Experiment 3)

5. Conclusion

In this paper, a preliminary work on a robot based on desert ants (Cataglyphis fortis) was reported. The built-in triangulation algorithm known as The new three-object Triangulation Algorithm was found to be simple and require less computation, with ability to aid the robot to home in with a maximum error of 14.8 mm (or 15mm approximately).

The limiting factors observed is due to the infra-red sensors (TSOP31138) used, itneeds warming up before stabilizing so as to get a repeated reading. However, the transmitter LED mounted on the beacons had no problem.

6. Recommendations

This study being a preliminary work, we are recommending the use of fast acting infra red sensors or any alternative directional sensing system with high signal to noise rejection ratio. Also, a mobile platform should be used perhaps with a long range sensors like Laser based tentacles for open terrain experiments.

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