Behavioural And Sensoral Fundamentals For An Autonomous Zebro Swarm

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***Abstract*—Zebro is a six legged robot designed at TU Delft as a research platform on many aspects and especially swarming. The goal of this study is to give Zebro swarming behaviour and because of this behaviour, make it self-sustainable. The behaviour is focused on finding charging stations to ensure survival. It was found that Zebros lose searching effectiveness when making turns on the spot. To ensure Zebros stay together as a swarm and do not collide, different methods were proposed of which not one is more favorable at the moment.**

A BLE113 module was researched for ranging purposes with RSSI. A sufficient filter for the noise on the RSSI signal is not yet operational and measuring distance with RSSI with an accuracy of 0,5m has therefor not yet been confirmed.

***Keywords*—Zebro, swarm, autonomous, design.**

I. Introduction

Zebro was first build at TU Delft in 2010 [1]. The robot was designed as a platform to research many fields and especially swarming robots within TU Delft. The Zebro Project consists of work done by various groups of students and teachers and acts as a basis for different types of research. For this project the Zebro Project demands an autonomous Zebro that can function for a potentially infinite amount of time, preferably within the CyberZoo at Aerospace Engineering. The goal of this project is thus to design a basis for swarming behaviour for Zebro which can be used and expanded to make Zebro suitable for dedicated tasks by following projects.

The basis for swarming behaviour begins with stating the definition of a swarm. This research defines a swarm on a two dimensional plane and uses the following definition: [2]

> *A swarm is a large number of homogeneous, unsophisticated agents that interact locally among themselves and their environment, without any central control or management to yield a global behaviour.*

Secondly, it is suggested that the swarm should have one basic behaviour, because without it, the agents within the swarm would not need to move. The basic behaviour is chosen to be survival, meaning Zebros stay together, do not damage each other and are constantly searching for a power station to recharge their battery. It is assumed this behavioural approach will fulfil the main demand from The Zebro Project.

To move as a swarm, Zebro needs to have at least one sensor with which it can detect other agents. The algorithm for swarming behaviour developed in this research will only use data provided by the selected and tested sensor(s).

II. Design Requirements

The most important requirements for a sensor are:

1) A range of 20 meters to (at least) cover the Cyberzoo.
2) Measure distance with an accuracy of 0,5 meter.
3) Energy usage must be as low as possible.
4) If the module is light weight (<5 gr), The Delfly Project (lightweight flying robot) can benefit from this study in the future.

The Zebro Project wishes to experiment with combined swarms in the future: Zebros and Delfly's. Because of that, the energy and weight requirements for the communication device are stricter than they would be for Zebro alone.

The most important criteria for the Zebro swarm are:

1) Zebros may not collide.
2) The maximum distance of separation between agents is fixed.
3) Decision making must be decentralised.
4) The swarm must be able to operate independent of its absolute location and for an unknown amount of time.
5) The behaviour must be designed for operation in a finite space with unknown dimensions.
6) The path of individual units may not be predefined.
7) Units must be moving at any time, except when out of energy, charging or defect.

These are the main requirements for the swarming behaviour. Two and three together are called *Interactive Behaviour*. What a unit does when it is not avoiding a collision or returning to the swarm is called *Individual Behaviour*.

A last remark: The Zebro Project has a philosophy which states that a swarm robot should be build with as little complexity as possible and still complete its mission. This is kept in mind during this research.

III. Design Solutions

Sensor: Many sensors fit the requirements. Working principles for these devices are sound or radio waves. With sound waves the refresh rate is limited due to the speed of sound. Sending over 343 meters takes one second. Radio Frequency (RF) devices on the other hand are ideal because they are cheap, numerous and send at the speed of light. The sensors are also often suitable for distance measurement with Received Signal Strength Indication (RSSI).

This study examined the possible devices Zigbee, WiFi, Bluetooth and BLE within a literature study. Zigbee and BLE are both preferable devices because they are light weight, use little energy and have a range of at least 20 meters.

Interactive behaviour: To make Zebros have the correct behaviour within the swarm, every Zebro needs to know at least the relative distance to other agents. With this data two approaches were planned. One approach tries to design an algorithm for the individual agents that make up the swarm to have a global swarming behaviour emerge. (bottom up) It takes the requirements for separation and colliding and solves both problems separately. The first is solved by turning 180 degrees on the spot when agents become separated too much. The second is solved by turning a random angle between $90 + arctan\left(\frac{width_{unit}}{2 \cdot D}\right)$ and 180 degrees. Both solutions disregard the fact that area is covered twice. See Figure 1. This is done to simplify the problem. If these solutions look promising later on, constrains can be added.

The other approach uses Matlab and V-rep to generate a matrix containing relative distances and convert these to a mapping of all units with the command `cmdscale`. The simulation with V-rep provides immediate visual feedback on how well this function is performing. The map of all units can be converted to a density map to either attract Zebros to, or repel them from a certain point within the swarm depending on the local density of agents. However, this density plot can be mirrored across all angles and rotated relative to a fixed north. Because of this every agent also needs to know an angle relative to the swarm. This way it can use the information it collects to move towards the place the density plot tells it to move to.

To determine the angle relative to an agent or the swarm the following methods can be thought of:

- Trial and error - A unit checks if it is getting closer to the swarm or an agent while moving and determines its heading from it.
- Time based - Performing trilateration with RSSI measurements taken at different points in time.
- Internal reference - Creating a plot of where all agents are with only knowing relative distances.
- External reference - Creating a plot of where all agents are using three fixed reference points.
- Radar - A modified BLE113 module is able to determine RSSI and direction towards other agents.

Individual behaviour: Algorithms based on behaviour seen in nature are Brownian Motion and Lévy Flights. They define an angle (A) which an agent will turn and a distance (D) which it will move. A simple form of Brownian Motion has a fixed (F) D and a 50% chance of turning 90 degrees left or right after which the process repeats. Lévy Flight is an adapted Brownian Motion where D and A are both random (R) [4]. The probability of D is represented by a Lévy distribution and the probability of A by a uniform distribution.

This study introduces and studies the following generalised behaviours: RARD, FARD and RAFD. RAFD, for example, means an agent will turn a Random A then move a Fixed D after which the process repeats. The random component can be drawn from any kind of distribution. To find a charging station effectively and ensure the highest rate of survival, the swarm should not cover any area more than once while there is still area undiscovered. The swarm should also cover as much area in as little time as possible. Zebro is assumed to use the same amount of energy per time, no matter the circumstances. Because turning and moving forward does not happen at the same time, area is lost. See Figure 1.

IV. Design Concept

Sensor: After comparing specifications of the different sensors, the BLE113 module is the preferred sensor. BLE is more power efficient [3] and the protocol allows reading RSSI without having a connection. This happens when the module is in advertisement mode. This is beneficial because one BLE module can potentially detect an infinite amount of other modules and their RSSI this way, instead of being restricted to 8 connections.

The module currently works with an external Micro Controller Unit (MCU) from T-minus Engineering [5] which is interchangeable with other MCUs. With this setup RSSI measurements were done. One set of measurements was done indoors between zero and two meters with ten centimetre increments. A second set was measured outdoors between two and twenty meters with two meter increments.

The measurements clearly show that RSSI is noisy. Indoors even more than outdoors. This noise needs to be filtered in order to reliably estimate distance between two modules. This project did not succeed in reliably filtering the RSSI to establish an accuracy of 0,5m. According to [6], [7] this should be possible at least within one meter distance. The measurement data for two to twenty meters follows the logarithmic function of the Free Space Path Loss Model [8], but it is at the moment unclear if this is enough for a reliable distance measurement.

Interactive behaviour: With the second approach the choice for determining the angle is the External Reference method. This is the most reliable method and can be easily implemented. A base with three stationary BLE modules can be placed at the site where Zebros need to swarm.

Choosing between approach one and two for the best design concept is not yet possible because for both approaches more simulations need to be done to prove their effectiveness.

Individual behaviour: The best concept for this mode is also unknown because more simulations are needed. It is know that units should turn while moving to increase effectiveness.

V. Discussion

Sensor: The results from literature and experiment are a proof of principle. Future work should be focused on developing a filter for the RSSI data. It is suggested to stick to the simple Free Space Path Loss Model because of the limited calculating capacity of an MCU.

Interactive behaviour: Both approaches deserve more research. For the first (bottom up) approach it needs to be proven that the methods successfully keep the swarm together and prevent collisions.

For the second (top down) approach it needs to be proven that the algorithm can be executed locally.

Individual behaviour: It is very hard to prove what individual behaviour will result in what global behaviour. It is suggested this can not certainly be deduced and therefor needs to be extensively tested to gain insight.

References

[1] *http://www.robotics.tudelft.nl/?q=research/zebro-six-legged-robot*, Last viewed: 15-12-2014.

[2] X. -S. Yang, Z. Cui and R. Xiao, *Swarm Intelligence and Bio-Inspired Computation*, Elsevier, May 2013.

[3] *http://www.digikey.com/en/articles/techzone/2011/aug/comparing-low-power-wireless-technologies*, Last viewed: 15-12-2014.

[4] M. Jamil and H. J. Zepernick, *Lévy Flights and Global Optimization*, Elsevier, May 2013.

[5] *http://www.t-minus.nl/products/flight-computers/*, Last viewed: 17-12-2014.

[6] Y. H. Lee, K. W. Ho, H. W. Tseng, C. Y. Lo, T. C. Huang, J. Y. Shih and T. H. Kang, *Accurate Bluetooth Positioning Using Large Number of Devices Measurements*, IMECS, March 2014.

[7] O. Katircioglu, H. Isel, O. Ceylan, F. Taraktas and H. B. Yagci, *Comparing Ray Tracing, Free Space Path Loss and Logarithmic Distance Path Loss Models in Success of Indoor Localization with RSSI*, Wireless Sensor Network 2, June 2010.

[8] G. Mao, B. Fidan, B. D. O. Anderson, *Wireless Sensor Network Localization Techniques*, Elsevier: Computer Networks 51, November 2006.

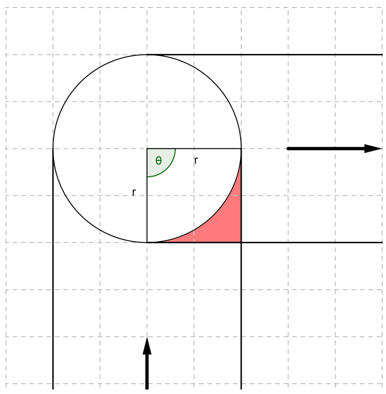

Fig. 1. The effect of turning without moving on the area covered.