Technique for the Visualization of Information for Refueling a Swarm of UAVs Using Genetic Algorithms in a Virtual Environment

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***Abstract*—This work is centered upon the study and development of an algorithm for finding the best sequence for refueling, in order to minimize the risk of a Lack of Fuel situation within the swarm elements, based on the distance that each element should cover, as well as the autonomy needed for this function. An approach was sort through the theory of evolutionary algorithms, specifically the genetic algorithm, selection methods, crossover and mutation of individuals in a population, development and the use of Virtual Reality to present results.**

I. Introduction

Technological advances have given the world a number of different technologies, many of which have had a high impact upon human development. The use of the computer in contemporary society is indispensable, as it is used in fundamentally every aspect of daily life, a prime example being the act of communicating with the banking system, which uses the internet for carrying out a diverse range of services.

One of the historical innovations of technology has been long distance communication. Communication is the act of transmitting information from one person to another. This represents a basic human necessity that being the approximation of distant communities. In prehistoric times, information referred to imminent danger, search for prey, etc. Native tribes relied upon the use of smoke signals or drums for communicating with others, whereas the great conquerors and generals on the battlefield had to establish a communication system manned by messengers.

Telecommunications are different to visual presentations, in that they use electrically processed signals in order to transport information. Telecommunications were truly set down in 1844, when Samuel Morse transmitted the first message through a line between Washington and Baltimore (Morse code). More than 30 years have passed since the telegraph was the only form of telecommunication. This system accompanied the pathfinders into virgin territories and even after the invention of the radio transmitter, it remained in use due to its intelligibility even in the presence of noise and low intensity signals [1].

The evolution of Morse code went on to become the telephone, a system that transmits sounds by electric cable over long distances. Shortly after, this was substituted by radio signals, which in turn improved the sound quality transmitted over long distances. During the 1990's, with the appearance of corporative networks based on open systems, it became possible to interlink diverse technologies to computer networks, besides their very own integration with mainframes and minicomputers. Finally, the standardization proposed by these corporative networks permitted this diversity of computers to communicate between themselves even with the diversity found in Hardware and Software, which was the main reason for the incompatibility that made communication in a number of scenarios impossible [1].

A. Basic UAV Concepts

An unmanned Aerial Vehicle (Figure 1) includes any type of aircraft that does not need an on-board pilot to be controlled. These aerial vehicles are controlled at a distance by means of electronic or computerized devices, under human supervision and governance, or be it, without intervention from Programmable Logic Controllers.

Fig. 1. Unmanned Aerial Vehicle

The UAV was initially projected for military purposes. This type of aerial equipment was conceived, designed and constructed for use in highly dangerous missions, in the military intelligence area, in artillery shoots, for aerial support to infantry troops and cavalry on the battlefield, control of cruise missiles, along with urban, coastal and border patrolling and environmental activities.

B. Basic Swarm Concepts

A swarm (Figure 2) implies a grouping together of individuals, a term originally applied to bees. However, taking into consideration the term “swarm”, technologies based on unmanned aerial vehicles have been developed, with strategies designed for the transmission of signals to wireless networks in certain remote areas, where they have come to be known by the term UAVs or drone swarm [2].

Fig. 2. Swarm of UAVs

Aerial Robotics is an area that has attracted academic interest, when it comes to its application in swarm intelligence. In this type of application, each agent in the swarm is represented by a flying robot. The robots are used to execute complex activities or those that when executed in a distributed manner, offer relevant benefits. In this context, robots are physical entities, micro controlled electronic devices, or micro processed. These may contain actuators and sensors for interacting with the environment in which they find themselves. It should be noted that the decisions made by these agents are of a very simple nature, providing a space where intelligent swarm algorithms can be implemented into robots with low computational power.

C. Virtual Reality and Visual Simulations

The use of simulations can be essential in a number of cases as for example, projects that demand interactions, and for the representation of complex models in applications for which its information can be visualized in three-dimension animation. This avoids the necessity for the development of methods with different solutions for each problem of a specific theme. This is a discipline that offers the replication of a physical system and shows itself to be useful when it comes to areas of study, such as computer graphics and virtual reality. Simulations can be seen as a “motor” that moves these technologies, as with virtual reality. Finally, through simulations (creation and execution of a model for analysis), one can create the infrastructure necessary for other areas of science [3].

Virtual reality can be used for the visualization of events, properties and behaviour present in a simulation. At the same time, a simulation can integrate virtual reality technology, in order to demonstrate specific behaviour or patterns. In general, a VR system looks to reproduce features present in the real world. These self-same features should be obtained through simulations that can be produced in a virtual reality software, thus defining actions over specific objects or over the whole environment. The physics, movement and collision between objects exemplifies the simulation of behaviour presented in the virtual environment. It is therefore possible to validate real models before their implementation into the physical environment. This allows for an economy in resources and time by dispensing of tests that occur in the real world [4].

It is in this context that VR was used, as this work involves a system yet to be confirmed, and as previously seen VR can be used in the simulation of models that already exist, as well as those still to be implemented. Therefore, by means of Virtual Reality, it was possible to create an ideal scenario for the execution of our proposal, thus reinforcing the viability of implanting a UAV system, under the proposal laid out in this work.

II. Motivation

A large number of companies, industries and residences are connected to the global computer network, as are administrative and bank services, along with others, which have migrated to technologies where being connected is vital full time. However, even with the expansion of the worldwide communication network, there are still a number of locations that find themselves isolated, without any form of communication. This may be due to some kind of network problem or a lack of resources [5].

The problem concerning the lack in communication in certain areas has caught the attention of companies such as Google; this company is testing the use of drones, in order to take internet connection to remote locations. As previously explained in 1.A and 1.B, UAVs and drones are unmanned aerial vehicles, which possess flight autonomy without the need for a human on-board. By equipping these UAVs with data transmission technology and pre-programmed routes, it is possible to take the internet to various locales of the world using swarm technology [6].

One should identify a runtime for each UAV, signal limit, refuelling time and the spatial configuration, in order that the signal is transmitted uniformly. This study has as its objective the use of a Genetic Algorithm for the simulation and solution of the refuelling order of UAVs, in terms of priority. This priority definition will take into consideration the distance between the equipment and the base, together with its battery life.

Summarized in Figure 3, is the manner in which the swarm will actuate. A data signal is emitted to a specific location in the environment, this communication is given through a wireless signal as there exists a minimum distance at which the signal and the connection between each machine is successful. If this minimum distance is violated, the connection is lost or the quality of the signal can negatively influence the network.

Each individual in the swarm possesses a battery with a different load level, if the battery load is close to running out, it will be necessary to order the UAVs, so that the individual with the lowest load is the first to be refuelled.

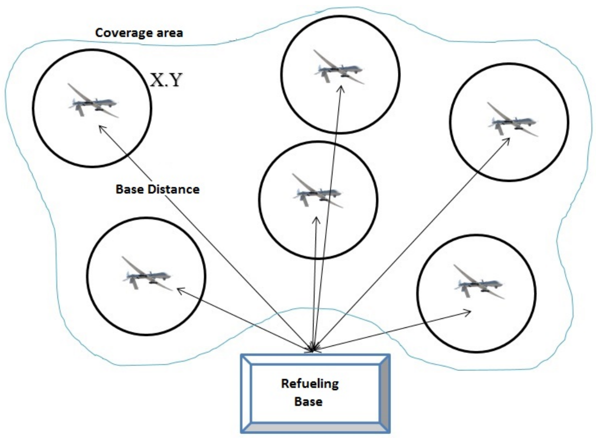

Fig. 3. Diagram Swarm UAV for Refueling

Taking into consideration the distance the UAV is from its refuelling stop and the time it has left in terms of battery load, an algorithm will be developed that simulates the ordering and refuelling of the UAVs, along with a virtual reality system for visualizing each GA process.

The GA software (Genetic Algorithm) will be able to:

- Order the UAVs in order of greater refuelling necessity, taking into account distance and battery load;
- Call in UAVs for refuelling;
- Show the real time movement of the UAVs in a virtual reality environment.

III. Development

In this chapter, the processes for the Genetic Algorithm will be highlighted, along with the simulator in a virtual environment as a solution to the problem proposed herein.

A. Chromosome Model for the Genetic Algorithm

In Genetic Algorithms, the chromosome carries a solution, where for each problem there exists a type of chromosome model, which in turn possesses various representations, some of which can be characterized as the following:

- Binary: Represents a chromosome with binary values, such as 0 and 1 or true or false;
- Real Numbers: Represent a chromosome of real numbers, such as 0, 3, 4, 1.2, -0.3;
- Numerical: Represents a chromosome with numerical values, such that they cannot be altered.

In the case concerning the proposed problem, each UAV possesses an identification ID [0, 1, ... N], where the software recognizes the object for which it will modify the position and visualization information. In this manner, the following chromosome was modelled:

This chromosome possesses the identification for all UAVs; each gene from this chromosome possesses a weight, which

TABLE I
Chromosome with Numerical Genes

3	1	4	9	5	2	0	6	8	7

was defined as Zero Fuel Stalling. This weight is calculated when the UAV is added to the swarm. However, the calculation is the relationship between the distance until the base and the battery load level.

To each gene, there is attributed a risk value, this attribution is made through the ID given to the UAV on a table, this table is created when the UAVs are added to the swarm, the table is dynamic and therefore able to add or remove any ID.

B. Chromosome Fitness

The fitness of the chromosome is an evaluation of how adequate it is as a solution to the given problem, in this case we wish to minimize the risks posed from the UAV crashing through lack of fuel, hence the lower the fitness value, the lower the risk of crashing.

The function for evaluating fitness is:

$$Fitness = \sum_{i=0}^{n} (R_i - R_{i+1})$$

Such that:

- R= Risk of crash
- i= ID of the UAV

The algorithm tends to order the genes with the highest risk of crashing into the first positions of the chromosome; this allows the most vulnerable UAVs to head the refuelling chain.

C. Development of the Code

The GA was developed using the C# programming language, based on the criterion for Object Oriented Programming, where basic interface graphics were used for the tests. The following classes were programmed:

- TableUAV: a set of UAVs possessing position, the distance until the base and battery load level;
- Individual: The class based on the TableUAV, which may be a solution;
- Population: The class with a set of individuals, a solution set;
- Fitness: The class that calculates the fitness of each individual;
- PMX: The class that contains crossover types for numeric representations;
- GA: The class that executes the Genetic Algorithm.

D. Development of the Virtual Environment

In order to carry out development tests, the authors opted for the use of a basic interface to streamline and facilitate the visualization of raw data. In Figure 4, the working procedure for this interface is shown:

- Button Get Dist/Risk; return to distance screen;
- Button Alter Dist; alters the distance of the UAV;
- Button Create Ind; creates any random individual;
- Button Create Pop; creates an initial population;
- Button Evolve; evolves into another generation each time it is pressed.

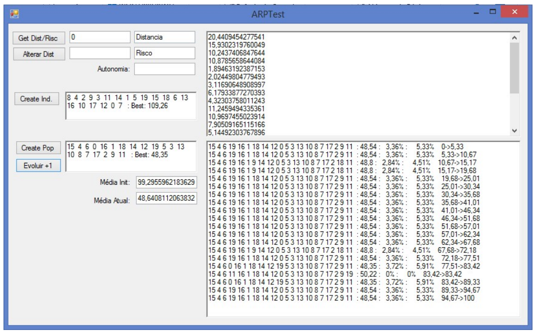

Fig. 4. Basic Interface of GA

On the right-hand side of the screen, the text boxes show the evolutionary progress each time that the button is pressed. In this manner, it is possible to analyse every individual, along with their fitness values. However, this interface does not present a good visualization for the end user, and with this being the case, the authors developed a more interactive interface in a virtual environment for simulating UAV refuelling.

In Figure 5, the interface with the virtual environment is shown, where the UAVs are distributed across the scene in a defined position, each of which possesses a different battery load, this therefore creates a scenario of multiple position ordering possibilities.

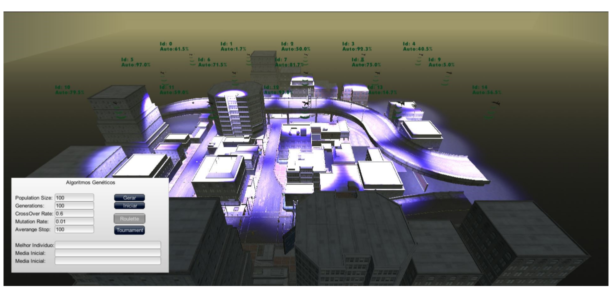

Fig. 5. Virtual Environment for Simulation Supply to ARPs

Above each UAV, there exists a text with identity information and the percentage of battery load left. The blue light shows the area covered generated by the emitter of the wireless signal, as one can see in Figure 5. The left-hand side presents the GA configuration menu, as population size, generation limit, crossover and mutation rates, best individual, initial and final average.

IV. Conclusion

Genetic Algorithms are always used when a particular mathematical problem possesses an impractical analytic resolution, or be it; it is to a certain extent difficult to obtain analytically. However, by studying a UAV refuelling ordering case in relation to battery load level and distance until the base, one can confirm that GAs can always be used with the aim of optimizing diverse values of a heuristically generated population.

In general, the data generated by artificial intelligence systems are complex and impossible to be interpreted by laypersons; these therefore become specific data for computer scientists. However, using the virtual simulation environment, the complex results are transformed into visual information of easy understanding.

The sampling results were taken across the simulated environment, which clearly exhibits the UAVs being selected for refuelling. One also notes that the raw data for the UAV refuelling order became more intuitive and easier to understand, where a pseudo present vision of the real environment is given.

References

[1] POAKIS, John G.; SALEHI. *Communicating Systems Engineering : Masoud. Introduction and History of Communications Systems*. Pretice Hall Professional, 2006.

[2] Fortmann, F.; Ludtke, A. *An intelligent SA-adaptive interface to aid supervisory control of a UAV swarm*. Industrial Informatics (INDIN), 2013 11th IEEE International Conference on , vol., no., pp.768,773, 29-31 July 2013 doi: 10.1109/INDIN.2013.6622981

[3] FISHWICK, Paul A. *Computer Simulation: The Art and Science of Digital World Construction*. USA: Universidade da Flórida, 1995.

[4] KIRNER, Claudio; KIRNER, Tereza. *Reality and Augmented Reality Applied to Simulation Visualization*. Simulation and Modeling: Current Technologies and Applications. New York: IGI Publishing, p. 391-419, 2007.

[5] VERMESAN, Ovidiu; FRIESS, Peter. *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems*. River Publishers, 2013.

[6] GOOGLE. *Internet Para Todos Fornecida por Balões. Patrocínio: Banco Cidade*. GOOGLE LOON, Disponível em: http://www.google.com/loon/. Acesso em: 19 fev, 2015.