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Expanding Small UAV Capabilities with ANN: A Case Study for Urban Areas Inspection

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RLMM, EHS designed the ANN system and performed the analysis of the images. Authors LFF, ACBR, FMC developed and tested the UAV system, wrote the first draft of the manuscript and managed literature searches. All authors read and approved the final manuscript.

Case Study

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ABSTRACT

Aims: Autonomous Unmanned Aerial Vehicles (UAVs) provide an effective aerial alternative for urban areas inspection due to its cost and safety when compared to more traditional methods. The purpose of this paper is to report the development of a system capable of analyzing digital images of the ground and of detecting potential invasion, unauthorized alterations on the ground and deforestation in protected natural areas.
Study Design: The project was developed in collaboration between researchers in the context of the master's program in Science and Technology in Computation of the Federal University of Itajuba.
Place and Duration of Study: Institute of Mathematics and Computation and Institute of Advanced Studies, between March 2012 and July 2013.
Methodology: The Images are captured by a camera mounted on an autonomous electrical helicopter, which overflies the area under inspection. For the processing of the images an artificial neural network technique called Kohonen SOM (Self Organizing Map) will be used. The processing is actually composed of a sequence of steps that seek to collate the final common characteristics of a given image.

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Results: The Kohonen SOM allows grouping the pixels of an image with similar characteristics. In the case of this work, the pixels become widespread in two classes - white and black. After processing, there is a new output image with rearranged colors is produced. The same process can be used for detecting flaws in transmission lines in all three spectrums mentioned in this article.
Conclusion: Today UAVs are already being used in many fields today and will certainly be largely used for urban areas surveillance. The use of the helicopter for land inspection the land showed significant results especially considering the low vibration level produced by its electric motor.

Keywords: Pattern recognition; inspection; UAV; autonomous helicopter; Kohonen SOM.

1. INTRODUCTION

Interest to use Unmanned Aerial Vehicles (UAVs) to collect information has grown initially in the military sector and more recently has reached the civil sector. Then, enabling UAVs to perform low cost autonomous information collection missions has become a challenge.

In many countries it is rather common to find protected areas with restricted use. Aerial monitoring of these areas should contribute to their integrity by detecting invasions, deforestation and unauthorized alterations of the ground and vegetation. The use of UAVs for monitoring purpose has greatly increased in recent years, especially with the miniaturization of sensors. This has allowed the combined use of Global Positioning System (GPS) and Inertial Measurement Unit (IMU) to perform the registration of the location of the images [1,2]. In the last decade the use of small camera equipped helicopters in urban areas has been turned feasible. In [3] visual sensing has been used to estimate the position and velocity of features in the image plane (urban features like windows) in order to generate velocity references for flight control.

The use of UAVs for the inspection of transmission lines has become an attractive alternative to earlier techniques, especially since the space around them is restricted and presents risks of accidents involving human life. A representative work discussing the effectiveness of mini-helicopters for aerial inspection of transmission lines is [4].

UAVs can travel considerable distances, with higher security and much lower cost than other traditional means. For example, crews of manned helicopters have to support fatigue due to extensive hours of work. Then in these conditions, the human eye can often fail on the mission of detecting some particular feature on the ground. An autonomous helicopter is able to capture images from different angles, to process them using for example an ad hoc neural network and concentrate on the locations with the highest probability of spotting irregular activity.

Artificial Neural Networks (ANN) are based on a certain analogy with the organization and functioning of the human brain. There, knowledge is established along the connections between the artificial neurons. Among the many classes of neural networks, the Kohonen SOM neural network belongs to the competitive neural network class with unsupervised learning [5]. In this kind of neural network, to each component of the input signal only the neuron that has the highest affinity with it will be activated. That means that if the input of the neural network is the set of pixels of an image, to each input pixel only one neuron will be activated. The output of the neural network will produce a new image with pixels grouped according to similar characteristics.

This paper describes a new autonomous system that is able to collect and analyze aerial images of the ground with the objective of detecting irregular activity, to identify and to concentrate on most significative areas for further analysis. This type of survey is currently performed by manned helicopters and the area surveying is done by human eye. This former approach is very expensive and, being subject to many errors, cannot be considered sufficiently reliable.

2. MATERIALS AND METHODS

2.1 Aircraft

The Mini UAV shown in Fig. 1, is a commercial RC helicopter[1] chosen for its price and performance, range, reliability etc. It has a 1.58m diameter rotor blade, which is powered by a brushless 700MX electric, and has a maximum takeoff weight of 5.2kgs. The base RC platform weighs 3.2kgs with batteries, sensors and flight computers.

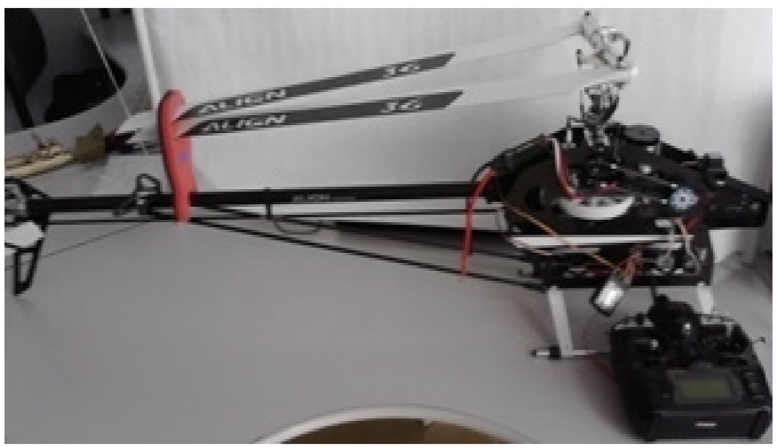

Fig. 1. Chosen helicopter

With the basic configuration for GPS waypoint navigation it has an endurance of 30 min. A 2.4GHz RC link is used for manual flight and a 2.4GHz wireless modem is used to transmit telemetry data to the ground station and operator commands from the ground station. This link together with the omnidirectional antennas used has a line-of-sight range of approximately 5km but if by any means the link is lost an automatic return home procedure will take command of the aircraft bringing it back to visual sight of the operator.

2.2 Autonomous Aircraft

All the sensors used for autonomous flight are included in a commercial integrated device, including an IMU, GPS receiver, magnetometer and barometer, Fig. 2. The device fuses the

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[1] *Align Trex 700e Pro DFC price US$ 1,550,00.*

sensor data with an Extended Kalman Filter to produce a filtered state estimate of position. The onboard flight computer uses the state estimate to generate appropriate commands for autonomous flight in the form of Pulse-Width Modulation (PWM) signals which is converted to Pulse-Position Modulation (PPM) signal through a PPM encoder board. These are fed to the servos via Lisa/M board. This board can select between pilot RC commands or flight computer commands passing through to the servos, allowing to switch between manual, autonomous stabilization and complete autonomous flight.

The current control strategy is implemented using standard techniques. Proportional Integral Derivative (PID) loops control attitude at a high update rate, while outer loops control position and velocity at a lower rate. The PID gains have been tuned for airspeeds up to 10m/s through flight trials and system identification. This control implementation provides reliable hover (within the error bounds of the GPS receiver), and has been used for forward flight with airspeeds of up to 18m/s. Although the controller performs well in winds with fairly constant speeds, it is not yet optimized for gusts and turbulence.

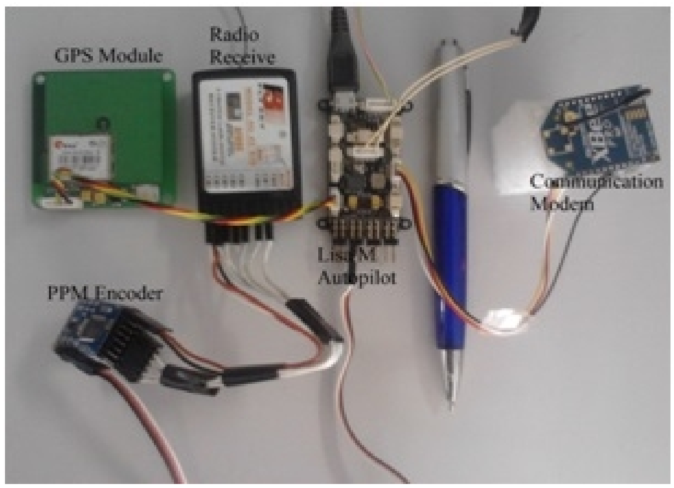

Fig. 2. Hardware embedded in the helicopter.

2.3 Ground Station

The software used in this project for aerial control is called Paparazzi and it is a free and open-source hardware and software project [6] intended to create an exceptionally powerful and versatile autopilot system for fixedwing aircrafts as well as multicopters by allowing and encouraging input from the community, showed in Fig. 3. Many changes were made in its code for supporting our helicopter. The Paparazzi project includes not only the airborne hardware and software, from voltage regulators and GPS receivers to Kalman Filtering code, but also a powerful and ever-expanding array of ground hardware and software including modems, antennas, and a highly evolved user-friendly ground control software interface.

The versatile Paparazzi Ground Control Station is an operator control unit ground control software for micro air vehicles. It allows visualizing and controlling a micro air vehicle during development and operation. With a flexible software architecture it supports multiple aircraft types/autopilot projects. The purpose of the ground control station is to have a real-time monitoring of an UAV [7].

It allows the user to change in-flight parameters such as the throttle speed, altitude and others. Not only that but it shows flight information like batteries level, current altitude, ground speed, air speed and the top view map. With a simple mouse click the user can change a waypoint location or switch to some other pre-defined route. Fig. 3 shows a screenshot of the interface.

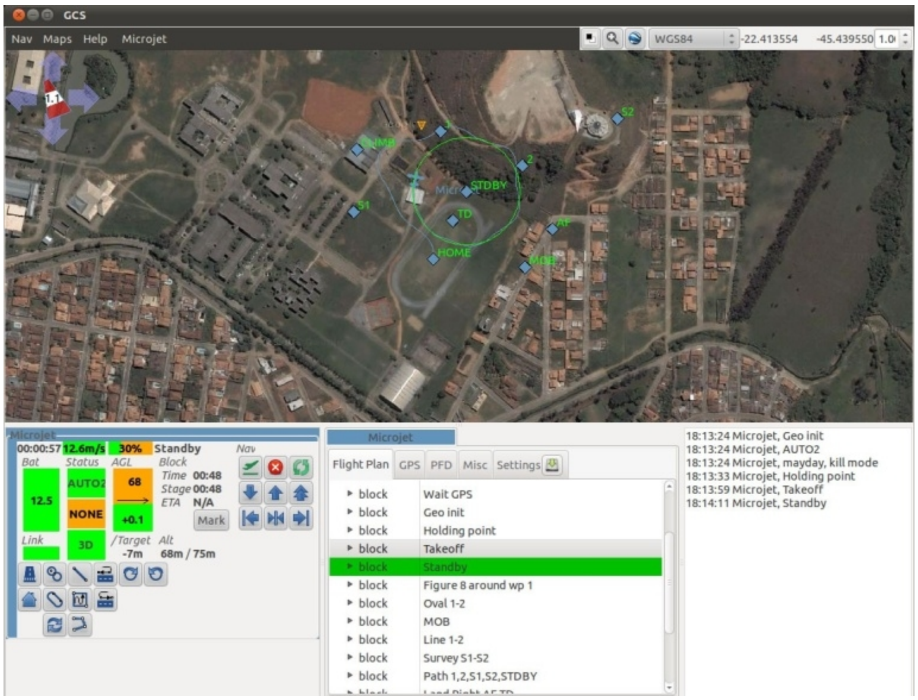

Fig. 3. Ground control station interface

2.4 Image Processing

A system for processing images, see Fig. 4, generally has the following parts [8]:

- Image acquisition: consists of a sensor to acquire the image and a second element capable of digitizing the signal, generating a digital image.
- Pre-processing: has the function to improve the image, seeking to increase the chances of success for the following procedures. Involves techniques for contrast enhancement, noise removal and region isolation;
- Segmentation: divides an input image into parts or objects. It is one of the most difficult automatic processes in image processing. The output of this stage is usually given in the form of pixels, corresponding to the boundary of a region or its constituent points;
- Representation and description: this stage of processing the data is transformed appropriately for the computational processing that follows, being stressed

characteristics of interest. The process of description, also called selection of characteristics, have extracted characteristics that represent quantitative information of interest or which are fundamental in the discretion of classes and objects;

- Recognition: recognition is the process that assigns a label to an object and interpretation involves the assignment of meaning to a set of recognized objects.

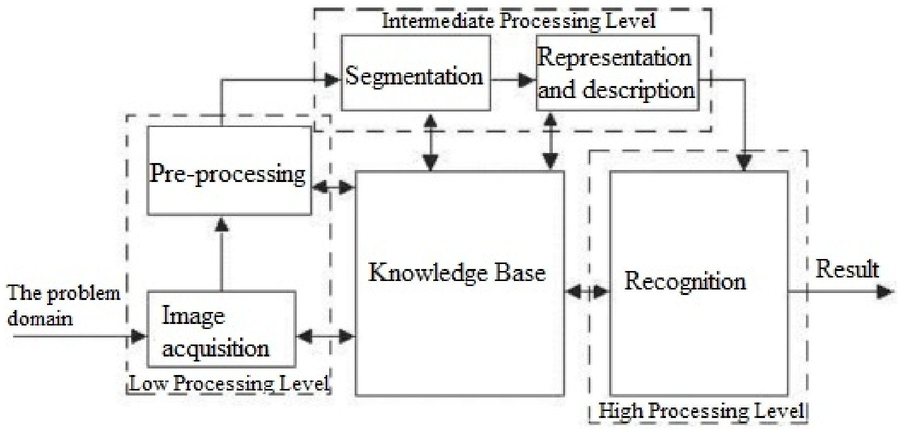

Fig. 4. Image processing division

This paper presents the development of a system for classification of digital photographed images shot from a set comprising a camera[2] coupled to a support, provided with vibration absorbers the whole in turn is mounted on an electric mini-helicopter. Images are georeferenced and the whole process of imaging is performed in a ground station that receives the photos sent by the mini-helicopter and saved in a hard disk for further processing. It allows one image to be inputted and generates a new output image where the pixels are grouped according to similar features.

2.5 Kohonen Self-Organizing MAP

Kohonen Self Organizing Map (SOM) is a map or matrix with non symmetric dimension, where each element represents a neuron, [9]. Neurons are interconnected and maintained relation to each other, even influencing each other. Each neuron or set of neurons represents an output and is responsible for a particular function. This feature is analogous to the brain where different information is controlled by different parts of the brain, such as speech, hearing and vision. The artificial neural network resembles other brain aspects such as: knowledge acquisition from the environment through a learning process and connection strengths between neurons - the synaptic weights - which are used to store the acquired knowledge.

The goal of SOM is the classification of the input data as the knowledge that neurons acquire. The topology between input and output is always kept, since the notions of neighborhood between neurons are not altered.

[2]*A Sony FCB-EX980SP camera that employs a 26x optical zoom lens combined with a digital zoom funcion, this camera allows to zoom up to 312x.*

The synaptic weights are initialized randomly and during learning such weights will be updated at each iteration of the algorithm. The intention of this phase is to find the neuron that has the closest characteristics of the input. Thus, after a process of iteration only one neuron is activated, however their neighbors also suffer a small influence.

2.5.1 SOM Kohonen Algorithm

1. Randomize the map's nodes' weight vectors
2. Grab an input vector
3. Traverse each node in the map
   3.1 Use Euclidean distance formula to find similarity between the input vector and the map's node's weight vector
   3.2 Track the node that produces the smallest distance (this node is the Best Matching Unit, BMU)
4. Update the nodes in the neighborhood of BMU by pulling them closer to the input vector
   4.1 $W_v(t+1) = W_v(t) + \theta(t)\alpha(t)(D(t) - W_v(t))$
5. Increase t and repeat from 2 while $t < \lambda$

Where t denotes current iteration, λ is the limit on time iteration, W_v is the current weight vector, $D(t)$ is the target input, $\alpha(t)$ is a monotonically decreasing learning coefficient and $\theta(t)$ represent the amount of influence a node is distance from the BMU has on its learning, usually called the neighborhood function, and is learning restraint due to time [10].

The topology of Kohonen SOM network is shown in Fig. 5. This network contains two layers of nodes - an input layer and a mapping (output) layer in the shape of a two-dimensional grid [10,11].

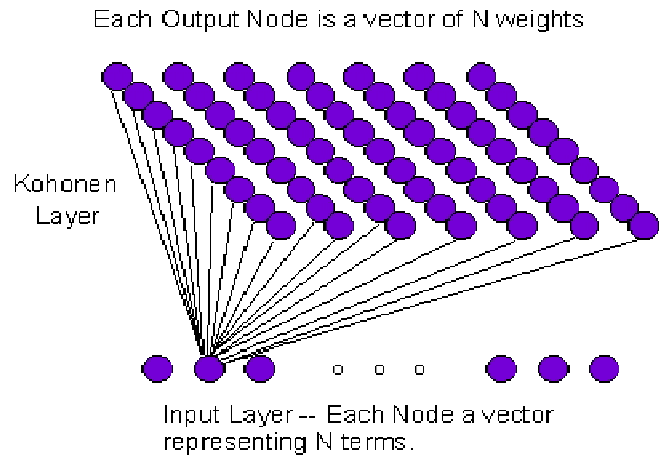

Fig. 5. Kohonen SOM topology

3. RESULTS AND DISCUSSION

A JAVA software that implements Kohonen SOM was developed. It allows one image to be inputted and generates a new output image where the pixels are grouped according to similar features.

For the processing some parameters must be set. These parameters are linked to which type of sensor to capture images is being used. For example, the optimal parameters for images captured by an UAV are not the same as satellite images. These parameters are:

- Number of iterations: how many times the algorithm will be repeated. Typically the higher the number of iterations the higher is the quality of the processing. However, after a certain point the number of iteration starts to damage the quality of the output image. Thus, an intermediate number should be fit so that the quality is not compromised.
- Rate of learning: learning rate interferes with the updating of synaptic weights. A very small learning rate requires a higher number of iterations to converge to the desired result. However, a very high rate causes oscillations and also hampers convergence.
- Number of neurons: each neuron represents a class, ie, a distinct characteristic. The number of neurons must be placed according to how the user wants to have some generalization in the grouping of neurons. The smaller the number of neurons more generalist will be the grouping. A very high number of neurons will tend to cause the output to copy the entry, which is not desired.

To test Kohonen SOM and better understand its operation some tests were made using aerial images of a city. Table 1 below shows the parameters used in the configuration.

Table 1. Kohonen SOM test

Test #	Number of Iterations	Learning Rate	Number of Neurons
Test 0	3	0.000001	2x1
Test 1	4	0.000001	2x1
Test 2	5	0.000001	2x1
Test 3	6	0.000001	2x1
Test 4	7	0.000001	2x1

The sequences of steps taken to implement the tests are:

1. The images were converted to grayscale.
2. An adjustment in brightness and color tone of the images was made.
3. The image is processed by the software that uses a Kohonen neural network.

Below we can see in the Fig. 6 to 9, an example of test number two.

Fig. 6. Original image captured by the UAV

Fig. 7. Image after the application of step 1

Fig. 8. Image after brightness change from step 2

Fig. 9. Image after all 3 steps

The tests were made using only two neurons, one representing the color white and the other representing the color black. Steps one and two correspond to a pre-processing, which assist the image processing done by Kohonen SOM in step 3. The pre-processing makes it easier to the final process recognize which color is closer to white and which closer to the black. The brightness adjustment was performed using an image editor to reduce the image contrast.

In order to facilitate the representation of clusters obtained from the processing of Figure 6 by the Kohonen SOM, there are used two distinct colors that represent each neuron. In Figure 9, the grouping in black represents the shadows of the buildings and the treetops, and the white color represents other details of the image, as the lawn next to the highway and the roofs of houses.

4. CONCLUSION

Kohonen SOM allows grouping the pixels of an image with similar characteristics. In the case of this work, the pixels become widespread in two classes - white and black. After processing, there is a new output image with the colors rearranged. The processing result is an image capable of being quickly compared with other prior images stored in the ground station. The same process can be used for finding faults in transmission lines in all three spectrums mentioned in this article.

UAVs are already being used in many fields today and will certainly be largely used for transmission line inspection, future works include but are not limited to improvements on the autopilot system for a better stability on gusty conditions and the usability of an airplane instead of a helicopter for other uses that require long and faster distances travelling.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

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