33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

HYDRO ENVIRONMENTAL AND ELECTRICAL ASSETS MAPPING TOOL USING SWARMS AND MACHINE LEARNING, UAV & USV

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Abstract

This paper describe the development of aerial and aquatic drones, using the swarm and machine learning concept to do the management of these equipment, in order to working together in collaborative and autonomous way to collect data, learn the electrical assets, environmental patterns and mapping our dams and power lines, in shortest time and with more mission frequency compared with the current methodology.

In Brazil, the dams are used to supply water and generate electricity to the population. The monitoring of water resources is very important to check the degradation indices of the areas and maintain the health of rivers and reservoirs.

The power lines electrical assets monitoring process, is very important to keep the maintenance process of their lines updated, to provide energy from the Dams to the Cities.

In the actual days, the current monitoring process has been proved inefficient, due to the lack of technical and financial resources in face of the size of the areas to be monitored.

This paper reflect the actual stage of our development, it is an improvement from the last paper, presented at IEEE Aerospace Conference 2019, were now is considered the use of the aerial drones with Artificial Intelligence for electrical assets monitoring process.

The same considerations of environmental changes are considered here, the robotics systems all the time needed to update themselves according to the dynamic field to perform the mission planned.

The Cities, Dams and rivers are constantly changing due to the human or natural actions, like buildings, storms, winds and etc. For this reason, the operational scenery is all the time changing, which request tools to give certain intelligence to the robotics equipment's allowing the machines to "observe the environmental" and "learn" according to these changes.

Our proposal is an alternative tool, using aerial (UAV) and aquatic (USV) drones, working together to get information about field, in terms of obstacles, the changes in the field between the monitoring process (missions), learn these changes and give certain intelligence to the drones to make changes automatically in their navigation routes under the mapping / monitoring process.

Due the Cities, the Dams size, and their location, in general close to the cities, and considering the lack of resources, the use of swarm concept applied to the aerial and aquatic drones is extremely necessary.

The mission places will be divided by zones, each zone will be defined according to the drone operational envelop (e.g. , the operational range (time and distance) and terrain geography), more than one aerial drone or USV system can be used to mapping the areas, in this case the swarm concept is applied, at squadron setup, to do the management of the drones.

The use of both systems together, for each selected place, will increase the mapping effectiveness, allowing the mapping process of Dams or/and electrical assets in a shortest time, compared to the current methodology, resulting in a complete map of these regions, helping at preventive maintenance process of the Brazilian Energetic Matrix.

Keywords: UAV & USV, Artificial Intelligence, Power lines and Dams Inspection, Management Software, Swarms

1. Introduction

Considering the rate of population growth greater than the respective global infrastructures can support in terms of food and basic infrastructure such as housing, sanitation, power supply among others, cities are increasingly susceptible to the disruptions caused by modern life.

The basis of electric power generation in Brazil comes from hydroelectric power, which stands out among the five largest in the world.

The country has 12% of the fresh water of the planet in conditions suitable for hydroelectric potential, it is estimated at about 260 GW and only 63% of this potential was inventoried. Brazil has almost a continental size and the cities are geographic located over almost all Brazilian territory, demand a complex energetic matrix to supply energy to the customers.

The current water resources situation, when considering the life cycle of the reservoirs, impacted by the population growth and pollution from large cities, the agriculture and industrialization, the lack of adequate treatment and inspection and the lack of skilled manpower to carry out specific surveys on the conditions of the watercourses, contribute to the process of degradation and scarcity of water resources.

The loss of water storage capacity due to sediment deposition and pollution compromises the quality of water for public supply and the capacity to generate energy, fomenting the need to develop methodologies and create equipment capable of monitoring these resources in a more effective.

The modern life changes the customers' way to live, requiring an electrical/electronic dependence due to the use of modern equipment in their homes or work, and together increasing the power consumption and the related supply services.

In this way, the energy supply services and their infrastructure are changing all the time to be customized to the new demands.

For this reason, the Brazilian National Agency of Electric Energy (ANEEL), through the Research and Development Program, is continuously investing resources to improve the energetic sector in Brazil.

In the scope of this paper, this development aims to monitor the Dams in terms of Power generation & water quality, and current power lines infrastructure, proceed with the maintenance process automatization, without the human interference.

The main goal is the use of state-of-art technologies to reduce the working time and costs, using robotic platforms, equipped with sensors, computer vision and Artificial Intelligence procedures in order to give to the authorities a management tool to improving the Brazilian energy services.

2. Development

2.1 System Overview

Here we describe the development of a Multipurpose Hydro Environmental tool using Swarms [29] and [22], UAV and USV to monitor the rivers and dams, and check the health of these places in terms of water quality and the level of siltation, and the development of the application of an Automatic Power Lines Inspection tool, applied at the Smart Cities concept, that use disruptive technology to solve some specifics problems, in this case, the problem of inspection maintenance and the management of Power Lines structure and related asset, where the Drone and the related tools, e.g., management software SIGI, Artificial Intelligence and Computer Vision procedures will help the predictive maintenance procedures, increasing the robustness of the power lines network.

This tool is compounded by an electrical UAV and USV system, composed of aircraft, boat, Command and Control Station, specific payload and field support equipment. The use of these robotic machines will be managed by the management software, according to the each selected mission.

Currently the power lines maintenance process on the field is done by humans in a visual way, the operators uses digital cameras and portable GPS to get information about the structures, like poles, converters, isolators, lines (wires) and etc.

Depending on each region, this process is very slow and it will depend of high skilled technicians on the ground performing the inspection action. Part of their territory has vast areas of vegetation and places with a limited access, becoming it is very difficult for the authorities monitor their areas with regular inspection.

The proposal of this development will be to offer an alternative tool to be applied at the Cities Concept to help the Authorities with problem of maintenance inspection of the Brazilian Energetic Matrix with the focus on the Dams health and the management of Power Lines asset structure, in an automatic way, using Drones to fly over the selected areas and perform to the data acquisition and processing according to the mission profiles, and in a parallel way all systems are monitored by a dedicated software running inside of our Command and Control Station (CCS), to increase the effectives of this technology.

All process is monitored and controlled by the customizable software called by Smart & Integrated Management System (SIGI), an Enterprise Resource Planning (ERP). The SIGI software can do the management of the data, the connection between the sensors (IoT) and to do the analysis of the results according to the authority requests.

Based on the data collected from the interest areas, SIGI software can show real-time situational analysis of these areas and allows that the administrator can optimize resources (material and human) improving the efficiency of resource allocation in these areas. In addition to the development of the management software, the development of sensors to collect the information in the field and update this information to the database of the management software, are considered. The figure 1 shows the basic diagram of SIGI software with the interfaces and relationship between the devices.

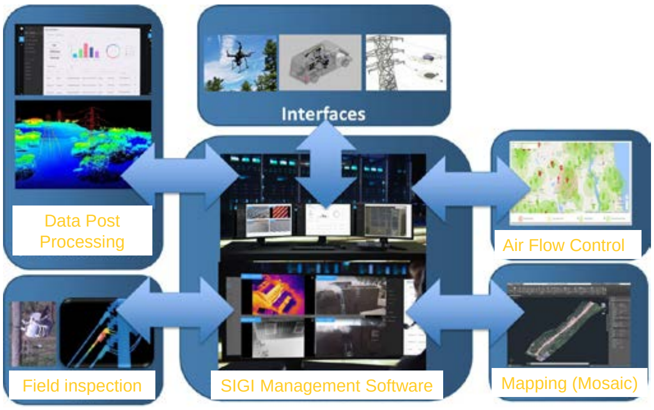

Figure 1 - Smart & Integrated Management System Diagram.

Where:

SIGI main module: This software has the design of an ERP software, with modular concept that allow the customization of the functionalities according to the application. The main block of this module contains the main ERP software, with web access, database, connectivity with Drone software and APP software.

Interface Module: Allows the SIGI connectivity to field Command and Control Centers (C2), such as Camera Monitoring Room, ground crew connectivity, and communicates with any type of infrastructure, whether local or remote, have access to the internet.

Field Module: Represents the devices that will be used in the field, with the collection of information generated by the sensors (IoT), Drones, customized according to the mission profile.

Operational results: The diagram shown in Figure 1 represent the application results, in terms of reports, predictive models and big data, the help the managers to take decision. In this case, operational results will be obtained according to systemic customizations, according to the definition of the object to be managed.

2.1.1 Quadcopter

The BRV-03 Drone, displayed in Figure 2, it was employed at first time for the High Precision Agriculture for the biological control [1], with the small design difference to operated using GPS type RTK-PPK [24] and onboard computer, able to acquire imagens and execute artificial intelligence procedures from the inspected areas [18] and [23].

It is a complete UAS (Unmanned Aerial System) developed by the first author and operates [AN1]in fully automatic mode, from take-off until the landing, monitored in real time from their Command and Control Station (CCS) [4] [15].

The Drone is modular in design and uses a COTS (Commercial-off-the-Shelf) concept for simple maintenance and replacement of components. The airframe is made of composite materials, which makes it very strong and lightweight.

Portable, easy to transport by a backpack, it shall be radio controlled in LOS (Line-Of-Sight) [5] and [21], whose operation can be manually or automatically controlled through a CCS or BVLOS (Beyond Visual Line of Sight). Some features such as automatic and autonomous navigation, takeoff and landing [6] [14] are present in this aircraft.

Flight operation over urban region will demand extra safety procedures to guarantee the safety of the equipment and people on the ground. In this case the system has dedicated emergency procedures, as functions as RTL (Return to Launch Point), automatic landing (in case of low battery and no GPS signal).

Considering the main mission objective, replacement of the field-manned inspection by humans to the automatic way using Drones and Artificial Intelligence with computer vision procedures to improve the effectivity of power lines predictive maintenance process, is considered inside the Drone an embedded computer to execute the dedicated procedures related at the pattern recognition of pylon or poles or other related.

Through to the embedded processing Artificial Intelligence (A.I.), Computer Vision and other routines, the aerial platform can process data internally independent of the communication with CCS, the Drones were able to do small internal data process, like get imagens, geotag and identify the objects, scan/mapping the areas, re-route the mapping and other some function involving machining learning.

The Drone learning process is continuous, for each application/interaction related during the missions the Artificial Intelligence used by the Drones are constantly increasing their capability, in terms of object detection and other parameters. For now, one of the other functions applied at the "Drone Intelligence", with the focus in the recognition of patterns of power lines objects and infrastructure, like, pylon, poles, lines (wires) and etc, to be applied at the management software [30].

Figure 2 shows the BRV-03 used in this application.

Figure 2 - BRV-03, Electric UAV prototype.

The Aerial platform technical specifications are shown in Table 1.

Table 1 - Aerial plataform technical specifications

Model	**BRV-03**
Motor	Electrical
Class	Class 3, by ANAC – RBAC 94
MTOW	4 lbs
Take-off	VTOL
Landing	VTOL
Transport	Case or bagpack
Concept	Rotary wing (Quadcopter)
Navigation	Full automatic
Software interface	Protocol NMEA-183 and proprietary TCP/IP with cryptography

Mission payload	GPS – RTK/PPK 4 X Camera RGB, Thermal camera NIR camera Corona sensor Avoidance collision system Embedded computer (Smart Drone) 4G LTE communication (BVLOS)

The quadcopter platform basic technical characteristics are:

a) Performance and Operational Envelop – It can perform Vertical Takeoff and Landing (VTOL) automatically, flight in high-speed winds over 12 kts and can operated in bad weather conditions, like soft rain, dust and high temperature. The flight time is up to 25 minutes at ISA conditions and no wind with an operational radius of 1.5 km over urban regions.

The VTOL operation is essential for the operation of this system in this scope, due that this system can take off and landing from a truck.

b) Embedded Systems – Based on COTS equipment and considering the modular concept design that allows the customization of mission payload according to each mission profile, the embedded systems for this paper we will consider only the interfaces between the aircraft control and the control of the payload mission equipment [8] and [14].

For a better understand of the aircraft control systems used in this paper, there were widely explored at [4],[6], [15] and [16], and the aerial platform setup consider the Smart Drone Concept at [14], showed at figure 3.

All functions performed by the Drone are remotely piloted or can be presented to be fully automatic, from the takeoff until the landing, through the autopilot [15].

With the addition of an embedded computer, the aerial platform earns the capability of embedded processing data, allowing the internal data processing of procedures of Artificial Intelligence, Computer Vision and other pre-defined routines, executed in an automatic way without the human intervention [14].

Since 2019, our engineering procedures are increasing the embedded data process, changing the boards and optimizing the computer routines to become the drones more powerful is possible at stand-alone take decision process.

In this evolutionary way, in terms of application we used the same developed structure to apply the Swarms concepts and the concept of IoT (Internet of Things) devices for the Drones [23] and [26].

Considering the IoT design, each drone is an IP address and it will be connected with the Command and Control Station (CCS) by dedicated datalinks and with internet using the mobile hotspots, or 3G, 4G or through other kinds of radio communication.

The data links are fundamental to allow the safety communication in two ways and in real time between the aircraft (telemetry), payload (sensors, gimbal control and images) and CCS [9]. In this case, the operational frequency and the cryptography layer are important to keep the communication between the parts protected, trying to keep it free of interferences, hacking or jamming.

All the embedded system shall be accessed remotely via the internet and allows the operator to remotely fly, monitors and control the aircraft and the payload systems through a dedicated CCS.

As described at the beginning of the UAS development [4], the use of COTS equipment as basis for the development of UAS, the same development methodology was used here, on quadcopter, Command, and Control Station and related equipment.

To design and assembly the electronic boards we are using the COTS equipment e.g., a GPS – RTK/PPK, and Inertial Measurement System board (IMU), data link telemetry and video boards, sonar etc. Over the years the development was increased using microcontroller and dedicated software, developed according to the mission requirements.

Considering the mission requirements, for this development were used a GPS, type RTK/PPK with real time update and closed loop methodology between the Command and Control Station and the aerial platform. The use of this kind of GPS in a closed loop is to guarantee the geographic precision with real time corrections, in terms of latitude, and longitude, necessary to mapping procedures and to define exactly the specific geographic position of the lines, poles and related infrastructure [7] and [24].

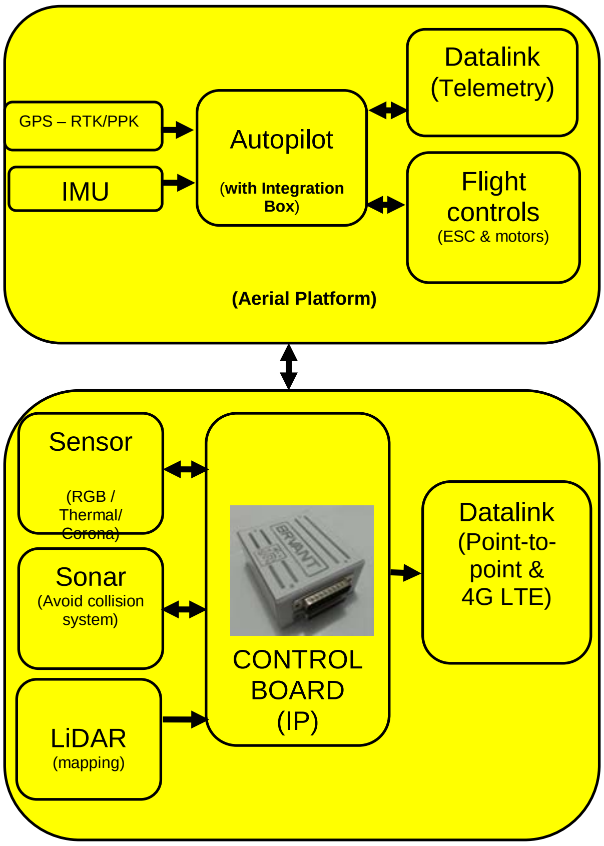

Figure 3 - The onboard equipment integration diagram.

c) Customized Payload – Considering the modular concept design, the embedded payload allows the replacement according to each mission profile.

The main module of the customized payload are:

- *Cryptography* - The cryptography module is a software able to encrypt or decrypt data from the mission planning, telemetry and video. This module reads in real time the data from the telemetry and video link apply the cryptography process and transform the data in the "secure information" to transmit point-to-point [20].

- *Embedded Image Processing* - Based on the OpenCV open source library [13], it was developed some software modules to process the imagens in real time digital. This technic is known by Digital Image Processing (DIP) [10], [11] and [12].

- *Artificial Intelligence, Machine learning* - Based on Neural Network, Specialized Systems, Inference Machine and other A.I. technics using matlab [27] and TensorFlow open source library [28], this module is applied to swarm control (if available), to learn and to define the field samples to train the A.I technics to recognize, from the collected images, the patterns according to the mission demands.

- *Internet of Things (IoT)* – Each aerial platform and the payload control board works as webserver to collect the data from the other IoT sensors. This module allows the internet communication between the robotics platforms to the IoT network.

According to the mission requirements described above, the drone will be used as an aerial tool, in the Smart City concept for flights over the power line's structure, mapping (scanning) the places, getting visual information from the devices and identifying the specific devices according to maintenance process, in a visual way.

For now, the payload customization shall consider the use of a large scale of imagery sensors to get from the field the specific information by the maintenance demand process. We are considering the use of thermal camera, RGB camera and other sensors related with the corona effect over the power lines.

The use of RGB camera with zoom control and integrated GPS, allow to take and geotag pictures in high resolution to make mosaics. The thermal camera is capable to take thermal pictures and the corona sensors will create a visual way to check the corona effect over some part of the power lines.

The amount of each sensor and the installation position will be defined according to the inspection object. All controls shall be done by the CCS in real time or, if the operator wants, the aerial platform shall perform the mission according to the pre-defined routines.

This equipment is totally controlled by the payload computer and remotely by CCS, point-to-point or via 4G, allowing to the operator pre-program actions during the mission, as sample, the exact position to take pictures, the RTL command, or other actions according to the mission profiles.

Through the Command and Control Station (CCS) software the operator can change the imagery type, take pictures, make videos, adjust the zoom and have a full gimbal control (if available).

Figure 4 shows the picture from each imagery sensor.

Figure 4 - Thermal, (2) Corona effect & (3) RGB (visible)

c.1) Computer Vision and Artificial Intelligence: The use of Computer Vision and Artificial Intelligence running inside the Drone to do the visual inspection and infrastructure pattern recognition of bolts, poles and others uses the same concept derivate by the development presented at IEEE 2018 [14], here in a bigger scope, considering various patters according to the mission requirements.

The Smart Drone concept [14] and [23], were became able to install safety procedures and intelligence inside of the UAVs, decreasing the Command and Control Station dependency to perform the missions, due the procedures of artificial intelligence installed inside of the platforms, for this work is related the use of this kind of intelligence to increase the orthodoxy inspection methodology, improving the maintenance ways with the use of technology.

For this contribution, there are COTS regular RGB camera, COTS thermal camera, and in some cases sensors like, LiDAR and to measure the corona effects. It is considering an embedded image processing, based on the OpenCV open source library [13], with the customization of some software modules to process in real time digital thermal image. This method is known by Digital Image Processing (DIP) [10].

According to the mission requirements, the Machine Learning rules are defined and applied to the DIP.

The embedded Artificial Intelligence, Machine Learning process are based on Multi-Layer Neural Network, to learn and define the field samples to train the neural networks to recognize the part-to-part of the infrastructure, from the collected images, performing the image compare of patterns, according to the maintenance rules previously defined [30].

Figure 5 shows the machine learning diagram, based on Neural Network and respective input and output data.

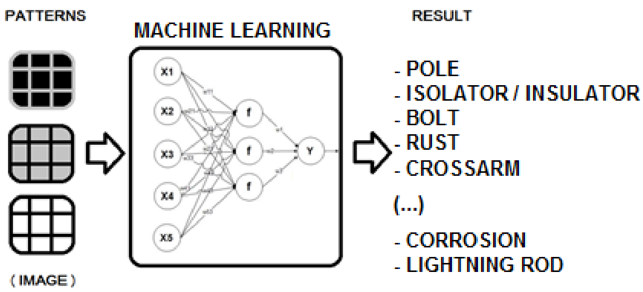

Figure 5 - Machine Learning diagram, based on Neural Network.

Where:

(1) The patterns represent the pixels from a selected region of an image.

(2) The process represents the Neural Network (Artificial Intelligence) during the Machine Learning process.

(3) The result represents the desired result, used at the Machine Learning process to train the Neural Network. In this case, the results are the electrical asset from the power lines structure.

Figure 6 shows the Machine Learning result for an isolator part identification using RGB camera.

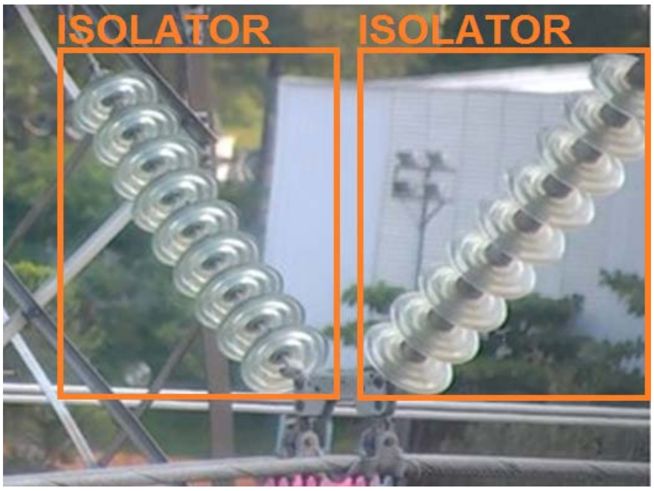

Figure 6 - Visual inspection, isolator identification

2.1.2 USV Boat

The USV boat prototype, displayed in Figure 7, is a complete USV and it can be operated by a remote control or in fully automatic mode. The USV is monitored in real time from their Command and Control Station, using a full duplex transceivers where the station can remotely and in real time send commands to the boat and the other robotic devices (drones) involved at the mission, can received data from them and do all management necessary to perform the mission [4] [9].

The USV is modular in design for simple maintenance and replacement of components. The flotation devices are made of ABS plastic and the other parts are made of composite material, which makes it very strong and lightweight.

Considering the system customization according to each mission profile, the boat was developed with ample compartments for systems installation and payload packaging. In this case, we can increase the boat autonomy installing more batteries, we can change the payload computers and sensors according to the mission, and etc.

The boat design, in terms of dimensions and natural stability was considered a model with the same characteristics of a catamaran boat [6] and [9]. The catamaran boat has some operational characteristics very important for our operational scope, it has very low draft, natural stability in high and slow speed, and the avionics + payload compartment can be located at the center of the boat, between the two-flotation devices and installed outside of water line.

The boat basic configuration has an electric power plant motor, located at boat stern, one actuators for the boat direction (similar to aircraft rudder functionality), one Speed Control (ESC) used to manage the motor throttle.

Portable, easy to assemble and to transport, the boat can be operated by radio controlled in LOS (Line-Of-Sight) whose operation can be manually or automatically controlled through the Command and Control Station, or in BVLOS (Beyond-Line-of-sight), using the quadcopter as relay of communication. Some features such as automatic functions and autonomous navigation [6] are present in this boat, for example, the automatic navigation by waypoint, and the follow me mode and return to launched point (RTL) in case of emergency.

Figure 7 shows the boat prototype used in this application.

Figure 7 - USV boat prototype.

The USV technical specifications are shown in Table 2.

Table 2 - USV technical specifications

Model	**BRV-USV**
Motor	Electrical
Class	Aquatic drone
Weight	300 lbs
Range	2 km (LOS) and 8h (BVLOS)
Transport	Truck
Concept	Modular
Navigation	Automatic
Software interface	protocol NMEA-183 and proprietary
Mission payload	Default camera (RGB) Thermal camera NIR camera High resolution camera (34 Mpixel) Sonar scanner LiDAR AIS Transponder Customized Sensors Avoidance collision system Embedded computer (Smart Drone Concept)

The USV platform basic technical characteristics are:

a) Performance and Operational Envelop – The boat typically operates at a cruising speed of 6 knots for scan the deepth of the dams or rivers.

In manual or automatic mode, the maximum speed is 12 knots that allow the operation in calm or hard waters. The boat can be operated in severe weather conditions, like hard rain and high temperature; it can perform missions up to 8 hours.

The operational range will depend of the geographic position of the boat and the Command and Control Station; in general, the boat will be operated at a maximum radius range of 2 km from the Command and Control Station.

Using the drone (quadcopter), as communication relay, this radius range can be improved up to 8 km, in this case the quadcopter will be the communication bridge between the Control Station and the boat, this communication is in real time, able to transmit for both point imagens, telemetry date and commands from the Command and Control Station to the boat.

b) Embedded Systems – As done with the quadcopter and the other developments related during the years, the USV boat has the same modular concept design, that allows the replacement of mission payload according to each mission profile. The embedded systems are following the same direction, they are divided by two groups, the boat control and the boat mission equipment (payload).

The basic control is the group of electronics equipments that keep the boat navigation through the deflection of the primary navigation controls (directional rudder), and throttle [9].

As the same related with quadcopter there are installed inside to the boat an inertial system (IMU), capable to measure the pitch, roll and yaw angles from the ship.

The automatic control is a group of electronics equipments that keep’s the boat navigating automatically on a route, defined by the mission profile. In this case, an autopilot system is used to navigate the boat and the other board is used to integrate the payload control with the navigation scope.

The mission equipment group is the group of electronics equipments responsible for mission devices, e.g., payload control, imagery sensors, mission data link, underwater sonar and their integration.

All the embedded system allows the operator to remotely navigate monitors and control the boat and its systems through a Command and Control Station.

Figure 8 shows the boat embedded systems diagram.

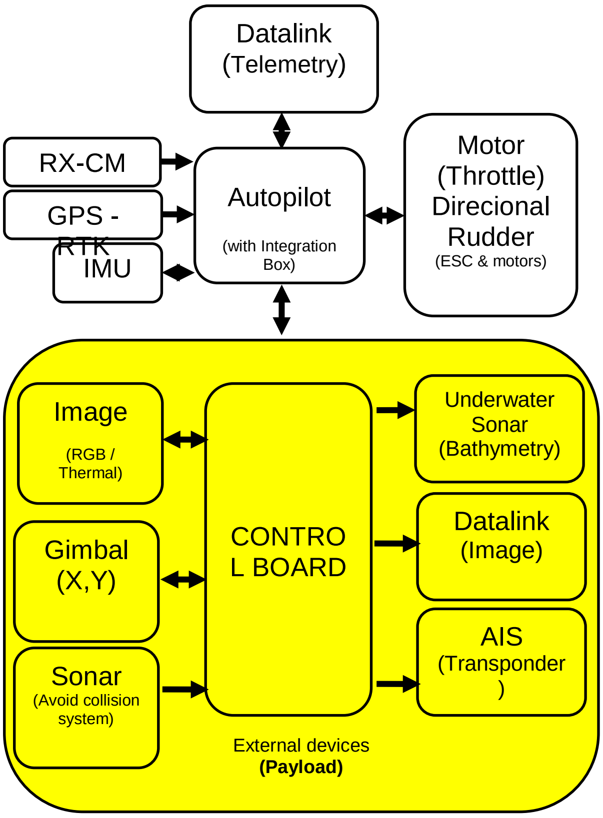

Figure 8 - Boat: The onboard equipment integration diagram.

c) Payload - In general, the boat's main mission is to follow the trajectory (route / path), previously created by the Command and Control Station, during the stage of mission planner, and mapping the areas according to the mission pre-defined.

The payload control board inside of the boat is the same of quadcopter payload control board, described above. The difference is only the software packaged installed inside.

To increases, the navigation accuracy a 9DOF Inertial System (IMU) and a GPS-RTK [3] and [7] is used. The GPS – RTK is a Real Time Kinematic Positioning system, by satellite, the navigation technique used enhances the precision of position data derived from satellite based on positioning systems (GNSS), such as GPS, GLONAS, Galileo and BeiDou.

The GPS-RTK is very useful to give to the boat navigation more accuracy in compared to the quadcopter; we are talking about 5 cm in navigation error.

Considering 5 cm of navigation error, the points collected by underwater sonar will be considered with an error of position (Latitude / Longitude) of only 5 cm.

Comparing to the quadcopter, that use the photography camera to take aerial pictures over the mapping areas, the aquatic drone (boat), use the underwater sonar with bathymetry technology to mapping and determine the underwater topography of the dams, lake or rivers. This technology result in a mesh of point of the depth of the underwater places that will be post processed to create the polygons representing the underwater topography. As done with the aerial pictures where is used a GIS based [18] software to geotagged the pictures and create the maps, the same methodology is applied to the geotag the underwater map, created by the bathymetry process.

The data links are fundamental to allow the communication in two ways and in real time between the boat, the quadcopter and other robotic devices (telemetry and commands), payload (control, images and sensors parameters) and the Command and Control Station. In this case, the operator all the time can monitor and if necessary change the navigation and/or payload parameters remotely and in real time, using the Control Station.

As described above with the concepts of the quadcopter, for the Boat the same development methodology used. We are using COTS equipment to build the "avionics systems", e.g., a GPS, and Inertial Measurement System Board (IMU), data link telemetry, video boards, underwater sonar, RX Control Module (RX-CM) etc.

For the monitor process of rivers and dams, and to check the health of these places, in terms of water quality and the level of siltation, some equipment's as underwater sonar, high precision GPS (RTK – GPS) and other kind of sensors are requested.

2.1.3 Swarm concept

As described above, due the characteristics and the size of the places, in general hundreds of thousands of square acres to mapping, one more quadcopter and boat will be necessary for mapping these areas.

Considering the boat characteristics in terms of performance and operational envelop, we are talking about one boat covering an area of 8 square acres per mission of 8 hours. In this case we will need use more boat for mapping more areas according to the mission requirements.

The same consideration is applied to the drones, flying over the cities or over the Dams, the flight time and the geographic conditions will demand the use of more than one equipment per mission.

The areas will be divided in zones, each zone will be employed one or more squadron of swarms. Each squadron will be compounded by one quadcopter, which shall be the leader of other quadcopter or the boats, or vice-versa.

Each boat can communicate with the other boat to manage the mapping process and the quadcopter will control all boat of their squadron. In case of the use only the boats for perform the mapping process; one of them will be elected the leader of the squadron.

The actual swarm architecture can be showed at figure 9.

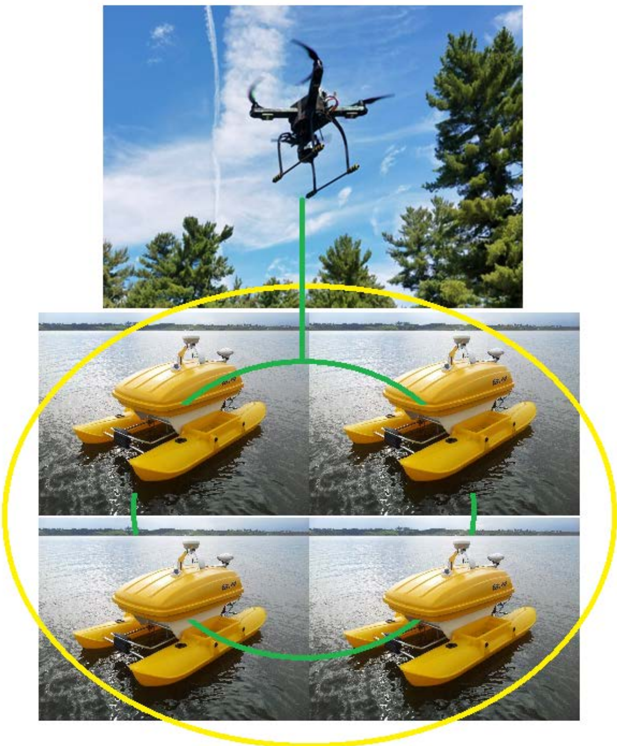

Figure 9 - Swarm architecture for mapping application (Squadron).

In this development, the use of swarm concept applied for the quadcopters is used to help the aerial machines self-organizing to mapping the mission areas and / or, in some cases, control the robotic boats.

As done in [23], for the first approach was used the method of mesh network communication and the control method by hierarchical coordination.

Each squadron will be defined to mapping a pre-defined area, according with the mission planning management, by Command and Control Station Software.

Figure 10 shows the swarm drone coordination model.

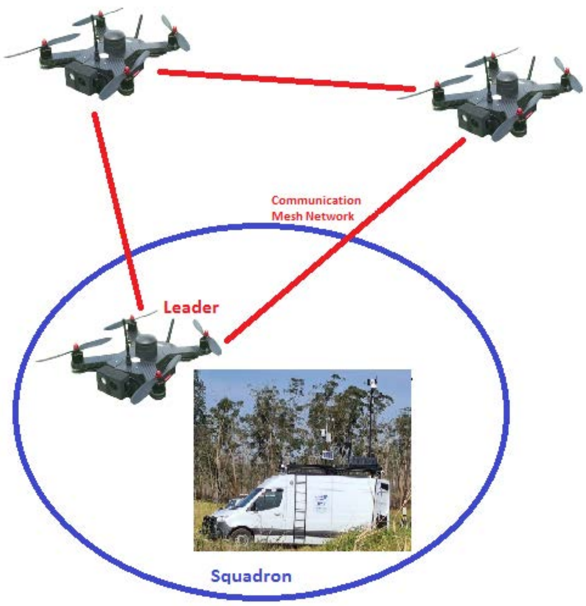

Figure 10 - Swarm drone coordination model by hierarchical coordination.

2.1.4 Command and Control Station & Field Portable Devices

The Command and Control Station (portable, VAN vehicle or situation room) at all mission stages are used as a remote supervisor.

All information related to navigation and payload status is shown on a specific and customized screen, the real time the current aircraft position, the planed mission (path and waypoints), real time video and sensors status, where the operator can manage the aircraft's route to correct its position, and make changes, if necessary.

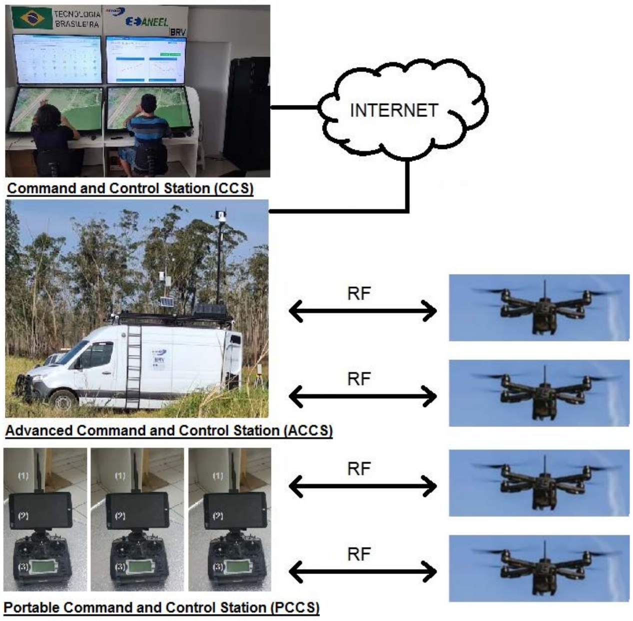

Figure 11 - Command and Control structure.

For the Smart Cities concept, considering the local conditions, in terms of geographic structure and air space access, controlled by our local laws, there are three Command and Control layers to monitor and control the aerial platforms missions over the cities [30].

The Command and Control Station (CCS) [25], is a complete Situation Room with the main objective of perform the control of one or various Advanced Command and Control Station (ACCS) and their equipment's in real time over the field.

The communication between the Command and Control Station (CCS) and the ACCS, is done by a security and encrypted way, point-to-point or via 4G LTE.

The ACCS are compounded by vehicles (VAN or truck) used to control the aerial platforms or the field IoT devices, in real time, creating a local infrastructure to operate the systems according to the mission demands. Through the ACCS the aerial platforms or field IoT are controlled remotely, or the Command and Control Station (CCS), can monitor the mission status involving these equipment's, where the ACCS are used as communication relay.

Inside of the Command Control Station (CCS) and the ACCS there is a software package that remotely and in real time allows the drone and the mission full control, called by Smart & Integrated Management System (SIGI) software [23] and [25].

According to [25], the SIGI software has two layers that represent the operational hierarch, the module 1 (layer 1), represents the macro field operation and, the module 2, the individual Command and Control of the ACCS or the devices (layer 2).

Layer 1 represents the Smart & Integrated Management System (SIGI), compounded by devices and software based on the Enterprise Resource Planning (ERP) concept. This component of the system is located at a dedicated infrastructure and allow the full control of all equipment working at the city, as illustrated by figure 1.

Figure 12 - Command and Control Station with Smart & Integrated Management System (SIGI).

Layer 2 represents the Drone Command and Control Station, in this paper called Portable Command and Control Station, this layer represents the interaction between the field operation and the Drones during all mission stages and in real time.

All missions performed or action on the field will be planned and the management will be performed by the SIGI. The operators (UAV or USV or both) will receive their equipment with the missions/orders pre-defined to execute on the field. At any time (if the SIGI manager want), the process on the field shall the modified, cancelled or the Drones shall be controlled remotely by the SIGI, this this case characterizing the BVLOS operation [5].

a) Portable Command and Control Station (PCCS) – To support the robotics platform, the IoT devices and give to the operator the real time situational awareness, the field Command Station is a component of vital importance.

As done with the robotics platform and IoT devices, the Control Stations are composed of COTS equipment, equipped with device interface to support real time full control of the platforms and IoT devices, according to the software package and mission profile selected.

The Command and Control Station (CCS) has the expansion capability, to increase the number of equipment-controlled simultaneity and in real time, e.g., two or more ACCS and respective aerial platform and/or IoT devices.

Figure 13 - Advanced Command and Control Station (ACCS).

Due the software architecture, here defined by the modular concept, the connection of other equipment according to the mission requirements is possible, e.g., the SIGI platform, that inside has a secondary moving map display, communication radio transceivers, PCCS and GPS – RTK/PPK correction for improve the "target" position [2], [3], [19], [24] and [25].

This version of the Portable Command and Control Station and/or Advanced Command and Control Station are an IoT devices and have the IoT capability and high precision GPS – RTK/PPK, real time closed loop positional correctional, showed at figure 14 and 15.

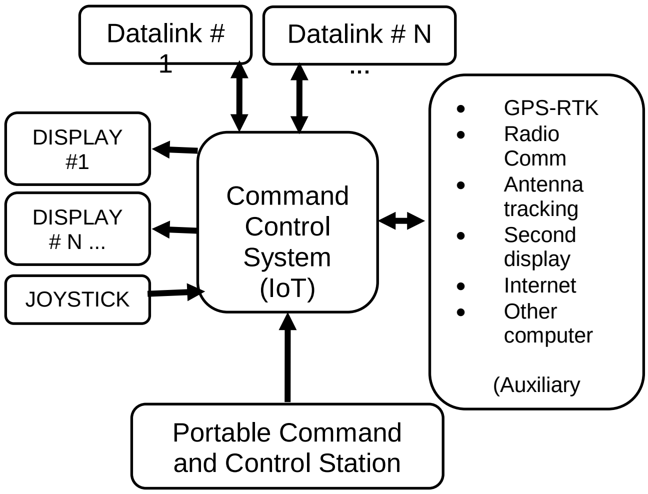

Figure 14 - Portable Command and Control Station block diagram.

Figure 15 - Portable Command and Control Station (PCCS).

Where:

(1) Datalinks, video and telemetry.

(2) Tablet computer with software and expansion ports.

(3) Remote Control for manual operation.

Since from the improvement of embedded data processing applied to the Aerial platforms, making them more “Smart”, [14] and [23], due the development of the flight boards and the implementation of the Smart Drone concept. The robotics platform become more independent from the Command and Control Stations, due the safety procedures and intelligence inside of the UAVs and USVs, decreasing the Command and Control Station dependency to perform the missions, guided by the procedures of artificial intelligence installed inside of the platforms.

The natural tendency was the development of the Command and Control software design based on modules with the basic actions/architecture based on the specifications above.

Each Command and Control Station, based on the field or on the complex infrastructure works as a “State Supervisor”, giving to the platforms and the sensors a kind of threshold to operate without any action from the supervisor. This non-centralized data processing allows the process distribution of small components, with low data throughput, in segregated modules representing each additional function from the main software.

As described previously in [14] and [25], additional software modules can be used together with this software, for example, dedicated mapping procedures, machine learning (A.I related), monitor the mission planning path according to each equipment, the cryptography, infrastructure integration modules and GPS corrections. These software modules increase the functionalities of the main software, helping at customization of the robotic system according to the application requirements, reducing the work dependency of the Command and Control Station.

3. System Works / Experimental Results

For the regular use of the aerial Drone as a Service Tool together with the Smart Cities concept, it will depend on local regulation laws for the Drone operation and some power lines inspection customization process, considering from the actual and orthodoxy methodology process to the new process using aerial platform and some computers advanced techniques.

For the explanation simplification of all process, we are consider three phases, were the first is related with the local area mapping, the second with the directly inspection process, flying the Drone over the mapped areas collecting data and the last, the third is the collected data, processing and management process, showing the results according to the mission profile.

Figure 16 shows all related processes.

Figure 16 - Automatic Power Lines Inspection Sequence Diagram.

For the Aerial Inspection process, initially, a quadcopter or the Advanced Command and Control Station (ACCS) is used to map some pre-defined places. These places will be defined through the data collected by the SIGI (the management software) and pointed as an “action to do it” to Command and Control Station Software (SIGI), creating the mission path to mapping in aerial way these places.

In general, the pre-defined places/areas to be mapped will be selected by the user interaction on the SIGI software considering the authorities database (registered past events or in the case of new events).

The figure 17 shows the selected area to be mapped, considering the local field infrastructure, data provided by the Power Line Company.

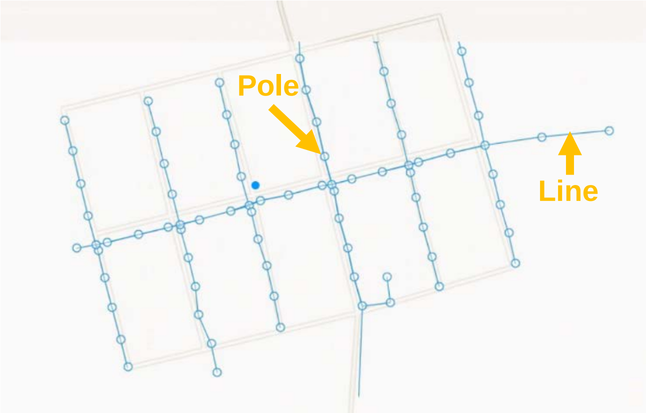

Figure 17 - Field local infrastructure, (1) Poles and (2) Lines.

The figure 18 show the selected area to be mapped, considering the Dams inspection, using the Boat or the aerial Drone.

Figure 18 - Quadcopter or Boat, mission profile.

Figure 19 shows the selected area to be mapped, considering the local mapping by the VAN vehicle (ACCS), in this case the Power Line Company does not know the area, it is a new registered place [30].

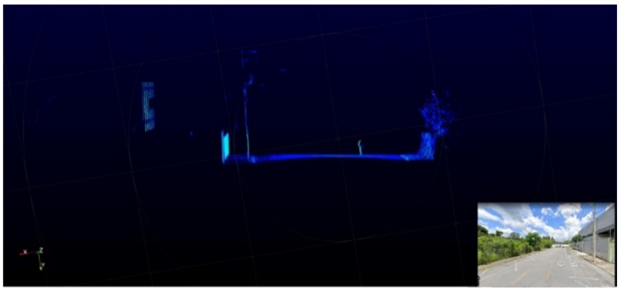

Figure 19. VAN vehicle mapping (ACCS), (1) Poles and (2) Lines.

In this stage, considering both mapping processes, the SIGI software knows the area to be inspected, a mission path is created, considering the mapping process for the Dams, and /or, power lines and their infrastructure. At this stage the drone flight altitude, range and flight time are considered, creating the mission path for only one aerial platform or another, according to the swarm concept.

Figure 20 shows the mission path profile created by the SIGI management platform and illustrated by Command and Control Station Software.

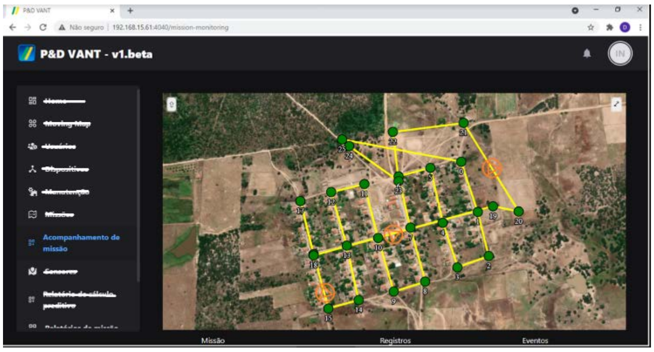

Figure 20 - Quadcopter, mission profile, swarm operation.

After the first step, the field mapping process, the mission path profile is created, this information will be used to send one or more quadcopter to fly over the defined areas, taking aerial pictures, to make high-definition digital maps and to collect images from the local infrastructure, such as the pole, isolators, bolts, lines and others. When the use is the Drone Boat, in this stage, we collect data from the Boat sensors, e.g., bathymetry, surface pictures and other related.

This mapping process, the 2nd stage, is very important because through the aerial pictures, we will be able to create a water surface map, considering the real situation of the aquatic plants or, a macro map (mosaic) of the exactly place and geographic position of the infrastructure (poles and lines path), and if necessary, it is possible to correct the Power Lines Company's database with this new information from the mapping process.

The regular use of the UAS or USV as a Service Tool considers that the platforms are launched automatically, enters cruise mode executing the mission routines and lands or stop automatically.

The automatic navigation functions are triggered in all mission stages.

During the mapping process stages, in automatic or remote-controlled manner, the operator can select the imagery sensor type according to the best fit to the mission demand, and the data collected by the cameras are used to train the neural networks, in order to identify the local infrastructure, in terms of parts as pole, bolt, isolator, lightning rod, or the environmental changes, over the water surface.

Figure 21 shows the identified infrastructure parts, e.g, isolator, bolt and pole, after data processing.

Figure 21 - Aerial mapping result, after the data processing.

This stage of the mapping process is very important, using aerial pictures we will be to create a macro map of the dams, rivers or lake surface, identify potential obstacles, as sample, the aquatic plants, called by macrophytes, advanced siltation areas or other objects shall be an obstacle for the boat navigation, during the mapping process, as related in figure 22.

Figure 22 - Aerial mapping result, after the data processing.

After the aerial mapping process, the pictures are post processed and is created a GIS based map [18] and dedicated maintenance database with all information collect at the mission.

With all information obtained during the flight, 3rd stage, as well as the aircraft navigation data, images and other related data, are stored in the Command and Control Station and monitored and managed in real time by the SIGI, thus creating a database for future reference.

Considering the Machine Learning process, in all three stages, the system will be learning every single mission, with field infrastructure geographic position correction or through the parts patters acquisition, processing and recognition, making the maintenance process smarter.

For the surface and underwater mission, using the USV, the boat will navigate through the mission path, collecting data from the sensors at specific points (georeferenced coordinates), and using an underwater sonar, with bathymetry technics, it will measure the depth of the reservoir.

Figure 23 shows the result of underwater mapping through the bathymetry technics.

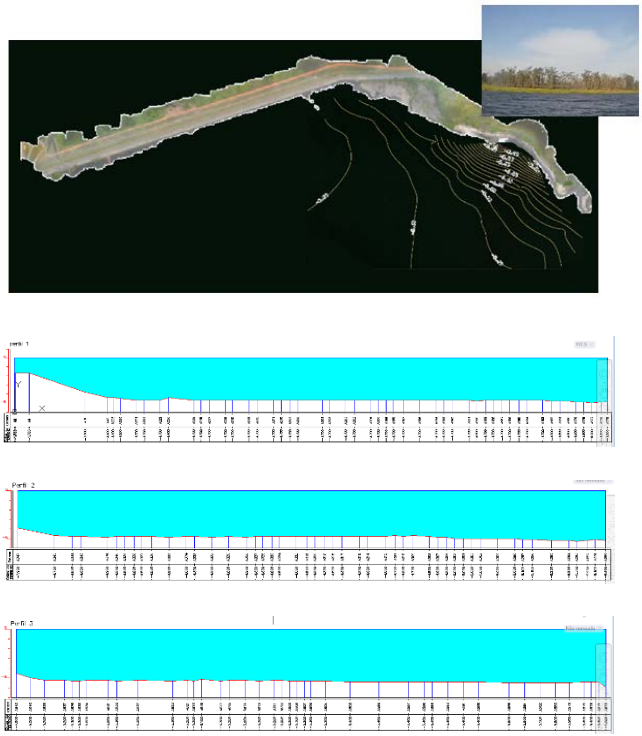

Figure 23 - Boat mission with the points collected by underwater sonar and a depth, graphics representation (topography).

All information obtained during the mapping process, for both systems (aquatic and aerial), images and other related data, is stored in the Command and Control Station, thus creating a database for future reference.

4. Conclusions and Results

This paper report the development of some research and development project, working together at the considering the use the Drone as Services, applied at Smart Cities concept.

The Grants related are from the ANEEL R&D program, with NEOENERGIA Group, EMAE Group and IBRV Institute, grant # PD-00040-0024/2020 and # P&D 00393-0012/2018, for partial support in this development.

In complementary way, the third R&D project was a partial supported by FAPESP and FINEP, grant # P&D 2019/13442-8 and 2018/10036-6.

The projects related to the ANEEL R&D Program were used for the development of a complete system to monitor the Brazilian Energetic Matrix, since the Dams, were the energy is generated until the customers house.

The maintenance process of their resources is very important to keep the health of the systems.

Considering the continental dimensions to monitor theses resources, the technology is the best way to improve the actual and orthodox inspection methodology.

During the present work, it shown that there is the possibility the use of aerial and surface robotics as a service tool applied at Smart Cities concept to provide to the authorities an alternative and disruptive tool for the Dams and the power lines maintenance process.

Some relevant factors must be considered in this development:

This development is a conceptual demonstrator project with partial results.

This proposal has the focus to be an alternative tool to help the authorities at the hydrologic and environmental inspection over the Dams, and at the power lines inspection over urban regions, using robotic platforms as a service tool together with the Smart Cities concept.

According to the Dams and cities sizes, urban conditions or power lines network, this technology shall be an alternative to measure the health of the "cities" in terms of energy supply, automating power lines maintenance processes, increasing their operational safety and robustness.

UAVS (Quadcopter)

Using an Unmanned Aerial Vehicle, it is possible to install customized payloads to allow the aerial "patrol" over the Dams, and/or the power lines infrastructure area, with a visual inspection in real time and using the automatic functionalities of UAV platform.

The quadcopter has a very important function. It will fly at first time at pre-defined areas to mapping, creating the 1st layer of the map, where will be used at GIS application.

The second main importance factor, using the GPS – RTK/PPK technology is the geographic position upgrade environmental conditions, and / or of the poles and lines path, updating the actual database with the suppose new position or creating new infrastructure register at the Power Lines Company database, for future use.

The flight over the places will increase the effectiveness of the maintenance visual inspection process, considering the easiest way for these flying machines to get the aerial pictures from selected areas.

USV (Boat)

The boat (USV) is the robotic platform responsible for the 2nd layer of the GIS map, the underwater topography of mapped areas. The boat operation is the same of the quadcopter, the boat will follow a mission profile path and during the navigation will collect data from the embedded sensor, e.g., temperature, level of siltation etc.

The boat-embedded systems are similar to quadcopter embedded system, but the difference is the type of sensors used to do the underwater map and get information about the water quality.

All process related to the measurement of water quality and the level of siltation, defined by bathymetry technology are previously defined inside of boat-embedded computer.

Due the boat cruise speed to perform the bathymetry (using an underwater sonar), and considering the size of the places to mapping, more than one boat shall be using to mapping the area.

Smart Drones, embedded processing and Swarms concept

The use of an embedded board to data process inside of the quadcopter and the boat, shall reduce the throughput and the dependence of the datalinks during the mission. In this scope, the cryptography process is fundamental to protect the data, video and telemetry.

Tools developed, to solve some mission issues, as sample, the object tracking, Digital Image Processing (DIP), GIS tools and some concept of swarm's algorithms, with the embedded data processing become very efficient to increase the "intelligence" of these robotic platforms.

For our application two type of swarms, the aerial – represented by the quadcopters and the aquatic or surface, represented by the boats, are considered. All of them shall be used to mapping the areas together or in separated.

The use of one or more aerial platform at same time, as described above, the swarm's concept, will depends on local laws, but this kind of operation increases the mapping effectives when used the technic of area saturation in these places.

The mission profile and the equipment development were driven by the regulatory laws, as ICA 100-40 and MCA 56-3 (Issue by Brazilian Air Force) and RBAC 94 (Issue by Brazilian National Agency of Civil Aviation). In these terms, the flight profiles and the aerial system safety procedures were considered.

The use of Digital Processing Images (DIP) and GIS tools in conjunction with a high precise UAV navigation system are fundamental to increases the systems precision on mission plaining.

Command and Control Station and IoT devices

Through the Command and Control Stations, in the situation room, or in a portable setup or inside of a van vehicle, full control of the aerial platform and the related sensors is possible, in all mission stages and in real time. With the improvement of the IoT capability, the aerial platform, the payload and the Command and Control Station shall be monitored remotely by the SIGI.

Final conclusion

As described at this paper, the employment of this development as a proof of concepts for the improvement of the Brazilian Energetic Matrix, it is possible, demonstrating that it is possible to use this kind of system, applied to the Smart Cities concept, to perform the Dams and power lines' inspection over field and urban regions, monitoring all stages of the Energy generation and distribution. This can reduce the costs and improve the time and human factor effectivities at the maintenance process, giving the managers a new management system able to the reads the real situational worthiness maintenance scenario from the Brazilian Energetic Matrix.

5. Acknowledgements

Thanks to NEOENERGIA Group, EMAE, ANEEL Agency and IBRV Institute, grant # PD-00040-0024/2020 and # P&D 00393-0012/2018, for partial support in this development.

To FAPESP and FINEP, grant # P&D 2019/13442-8 and 2018/10036-6, for partial support in this development.

Thanks to all researchers.

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7. Copyright Statement

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