Spectral Evidence of Ice on Aircrafts – The SEI Project

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Abstract. The general objective of the SEI project (reference call: MANUNET III 2018) is to experiment spectral sensor fusion techniques of data acquired by UAVs (Unmanned Aerial Vehicles) during aircraft preflight inspection. In General Aviation, an important safety issue regards the presence of ice on the aircraft's fuselage and wings. Ice on the wings can cause loss of lift and stalling, which in most cases would result, during take-off phase, in airplane's fatal crash. Another important aspect to consider is the high amount of de-icing liquid usually involved in the process incurring in high costs and considerable damage to the environment. This is not a typical industrial scenario, but the project addresses important aspects related to the manufacturing sector: it has to accomplish specific tasks following a design process; it involves human operators (labour) collaborating with machines and tools; it includes the usage of semi-raw materials (glycol fluids) to accomplish a service; it sees serialization of the process that could be invoked at any needed time. Moreover, it targets safety issues both for operators and machines regarding reliability of results at the end of the process, it is order-based and comparable to a discrete manufacturing process.

Keywords: Artificial vision technologies, Augmented reality, Robotics, UAVs, De-icing, Safety.

1 Introduction

The SEI (Spectral Evidence of Ice) project is intended to provide a novel solution to aviation-related problems associated with detection of ice during pre-flight inspection. Common conditions include: (a) crews unable to see the ice due to poor lighting conditions or the transparent nature of clear ice, (b) ice hidden from view, (c) crews not able to physically reach the ice during a tactile wing inspection. When looking for clear ice, the undisputable detection method is a near visual examination combined with a "hands on" check of the wings. An important impact of a UAV de-icing inspection will be a completely safe and reliable procedure to detect ice and to report the results of de-icing actions both to ground de-icing operators and to the airplane crew.

Another benefit of the proposed method is a significant reduction in defrosting time, depending on aircraft size, extent of frost coverage and ambient conditions. For a standard de-icing procedure, pre and post inspections made by UAVs is expected to result up to 30-35% time savings. This reduced time will lead to greater efficiencies in the use of de-icing and other airport facilities. At remote de-icing facilities, where aircraft are de-iced with engines running, reduced engine runtime will in turn lower the fuel burn and its related carbon emissions at a similar percentage and will therefore lower aircraft's operating costs significantly.

Furthermore, the human physical intervention will be reduced thus limiting the safety risks for its health or the physical challenges a de-icing worker is required to deal with (e.g. operating in extreme cold climate, physical/age issues, etc.). This is a completely new field as the deployment of UAVs for inspection operations is emerging in the very last years.

2 Project Objectives

In order to deliver the envisioned solution, the SEI project will address a set of four objectives. The first three are Technological Objectives (TOs), which are related to specific technological needs that will allow to technically achieve the expected results; the fourth one is a Market Objective (MO), which aims at increasing the project's impact on the market.

2.1 Technological Objective 1: Mission Awareness and Advanced Sensing

The system is based on a methodology to assign different tasks to the UAV, with obstacle avoidance, in a time efficient manner, complying with the requirement of finding an exact schedule, allowing the UAV to fly autonomously. The scheduling system should react to uncertain events (e.g. breakdown, fuel/battery depletion, etc.), which could happen during the UAV's operations. The SEI project is proposing a metaheuristic approach which assigns tasks to UAVs with an objective of minimizing the makespan. Advanced sensing functionalities will be attained through an Ultra-Wideband localization system, providing global positioning data, together with an onboard hyperspectral camera for ice detection, and acoustic sensors. The overall information will be logged on a database system which will provide relevant information to the operator for ultimate decision making. Means for validation will be based on the following KPIs (Key Performance Indicators):

- Minimize the makespan by up to 30%
- Positioning precision down to the order of magnitude of centimetres.

2.2 Technological Objective 2: Human-System Interface

The SEI project aims at designing and developing an innovative and user-friendly control and vision interface, supporting remote access from portable devices. AR (Augmented Reality) technology will be used, superimposing virtual/real information to the real environment. This will enable the operator(s) to assess, query, interpret, adjust, and control the mission execution in real time and in a cost-effective way. Means for validation will be based on the following KPIs:

- Increased interface responsiveness (< 0.5 sec)
- Maximized user friendliness.

2.3 Technological Objective 3: Ice Detection Accuracy

Ice detection will be done by a hyperspectral camera. This sensor can be installed on a UAV with a specific gimbal able to compensate vibrations, so it can be used in movement conditions. The hyperspectral camera exploits the characteristics of radiance, and it will be used, as a first instance, to define the spectral signature of different airplane components and surfaces: frost, clear ice, fresh snow, etc. During inspections, this knowledge will be used to detect the ice along the airplane. By combining the information deriving from the positioning sensors and the data acquired by the hyperspectral camera, it will be possible to obtain detailed information both in the spatial domain and in the spectral domain. This enables the ice detection and localization along the surfaces of the airplane.

2.4 Market Objective 1: Improvement of environmental impact

In the case of de-icing, all chemical formulations currently approved for aircraft de-icing can have environmental implications. A lean application of de-icing fluids, deriving from the exact detection of aircraft contaminated areas, could save about 50-60% of these fluids, with a huge positive environmental impact. Means for validation will be based on the following KPI: 50% reduction in de-icing fluid consumption.

3 The SEI Approach

3.1 The Proposed Solution

To speed up the de-icing procedures and save/reduce the use of de-icing liquid, our solution is based on the use of UAVs. At least one UAV will be used for analysing the surface of the aircrafts with dedicated adequate sensors. Navigation and path planning to the inspection area around the aircraft will be performed autonomously and in short time by the UAVs. During the inspection, acquired data will be transmitted to a central data collection and analysis center to be processed, as shown in Fig. 1. Collected data will be stored, analysed and displayed through an augmented reality device for a human operator, enhancing its capabilities to determine the appropriate de-icing procedures. As a result, the process time will be decreased significantly by accurate and in-time human guidance to the UAVs. Furthermore, the human physical intervention will be reduced thus limiting the safety risks for its health or the physical challenges a de-icing worker is required to deal with.

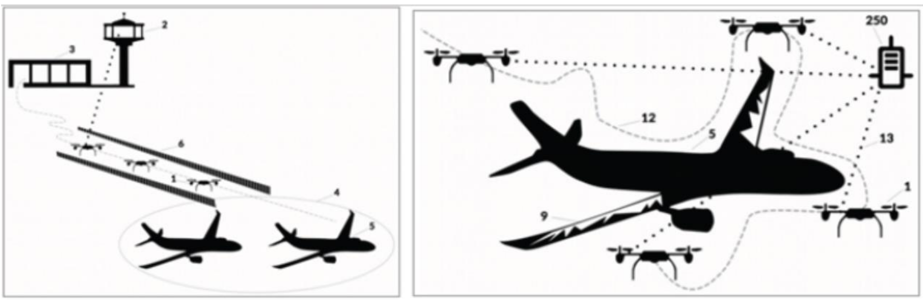

Fig. 1. De-icing activities for general aviation: (left) path planning and target identification; (right) swarm configuration [2].

3.2 End-User Involvement and Multidisciplinary Approach

The end-user involved in the experimentation will simulate the application of the spot de-icing method supported by the UAV. It also endorsed this methodology, to be applied in its de-icing operations, and to be leveraged as international best practice. Since the beginning of the project, the end-user will be involved to assist R&D partners in deploying the methodology at the technical level. The project will therefore benefit from a multidisciplinary approach that will include de-icing operators, aircraft pilots, and de-icing trainers. The proposed patented method and system will be based on the following main 4 steps: (1) Request for de-icing operations, (2) Aircraft scanning, (3) Ice detection and (4) Feedback to the operator.

Request for de-icing. A human robot interface, based on a Graphical User Interface (GUI) installed on a PC, will be used to provide the request for inspection. Initially, at least one UAV will receive the request for inspection of an aircraft that is located in a given inspection area or target area. The request for inspection may also comprise information that identifies the position of the target area requested, providing coordinates or GNSS (Global Navigation Satellite System) position.

Aircraft scanning. Once the target area is reached, the UAV makes a survey of the aircraft autonomously, being in communication with a control unit, to identify the position of the aircraft and detect its shape. During this step, high precision is not required, and consequently a single UAV could make a scan, via a SLAM (Simultaneous Localization and Mapping) mechanism [1]. Once the approximate shape of the aircraft is known, the system can determine the path that the UAV should follow.

Ice Detection. Ice detection will be done by a hyperspectral camera. The spectral image gathered by the hyperspectral camera contains detailed information both in the spatial domain and in the spectral domain. This enables determination of the ice along surfaces of the airplane and it will be possible to derive a substantially continuous spectrum for each pixel of the image, thus making possible detection, identification, and quantification of the substance in the image in the highest possible detail. Using classification methods, it is possible to analyse the spectral evolution of the individual pixels to recognise and select different materials or to enable high-resolution colorimetric measurements.

Feedback to the Operator. To map the data, the SLAM system may again be used, which hence enables association of the data detected by the sensors with corresponding position data. Consequently, a number of information layers may be associated to the 3D model of the aircraft. In particular, each layer corresponds to the projection of data (possibly processed) of a particular sensor or of combined data from a number of sensors that represent various characteristics of the aircraft, such as the layer of ice on the aircraft, the damaged areas of the aircraft, the thermal profile of the aircraft, and the visual appearance of the aircraft. These layers may be displayed separately or in superposition by an operator. In this case, the de-icing and/or anti-icing operations may be performed by a human operator, who avails itself of a display device to identify the contaminated areas of the aircraft.

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