# An Intelligent Aerial Manipulator for Wind Turbine Inspection and Repair

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***Abstract*— This study proposes aerial robots utilizing repair operations at height for wind turbines. It is aimed to decrease the risks for human health for a repair operation in risky environments. We address the wind turbine repair problem by proposing a new aerial manipulator that can leverage online detection and decision making. Our proposed system can help to reduce the time and costs for infrastructure maintenance when autonomous aerial robots are deployed intelligently.**

## I. INTRODUCTION

Current robot systems are explored for repairing civil engineering structures through aerial physical interaction using a material deposition approach [2]. However, the aerial robots only operate in an open-loop manner where the aerial worker conducts the operation with a handcrafted trajectory. This type of operation results in an irregularity for the deposited material applied to a structure for the repair operation. In particular; the change in the total mass, unexpected variations in the environment, and the disturbances might move the system out of the desired points. This work aims to address this problem with a proposed feedback mechanism to be deployed by scanning as well as the depositing systems. The test cases for this problem will explore the use of a buildable material with an aerial manipulator. In the initial phase, a material that can be sprayed will be considered with a vision-based approach. When the feedback mechanism is deployed, the proposed approach will extract the shape of the defect to unify with the surface. The information will be gathered by a depth camera and various algorithms including geometric-based and learning-based will be investigated. This information will be evaluated with the desired surface in order to regenerate the trajectory that will be implemented by the repair drone. The system will explore a time parametrization of the space coordinates to repair the 3-dimensional structure. The correction mechanism will incorporate the desired shape, extracted surface geometry, and material flow function. In the final phase, the selected material will be used to demonstrate the proposed system. Fig. 1 illustrates the proposed system and concept of operation.

Different materials can be considered and this can finally offer that the proposed approach can handle both rough and finishing works for the repair operation. Common defect area

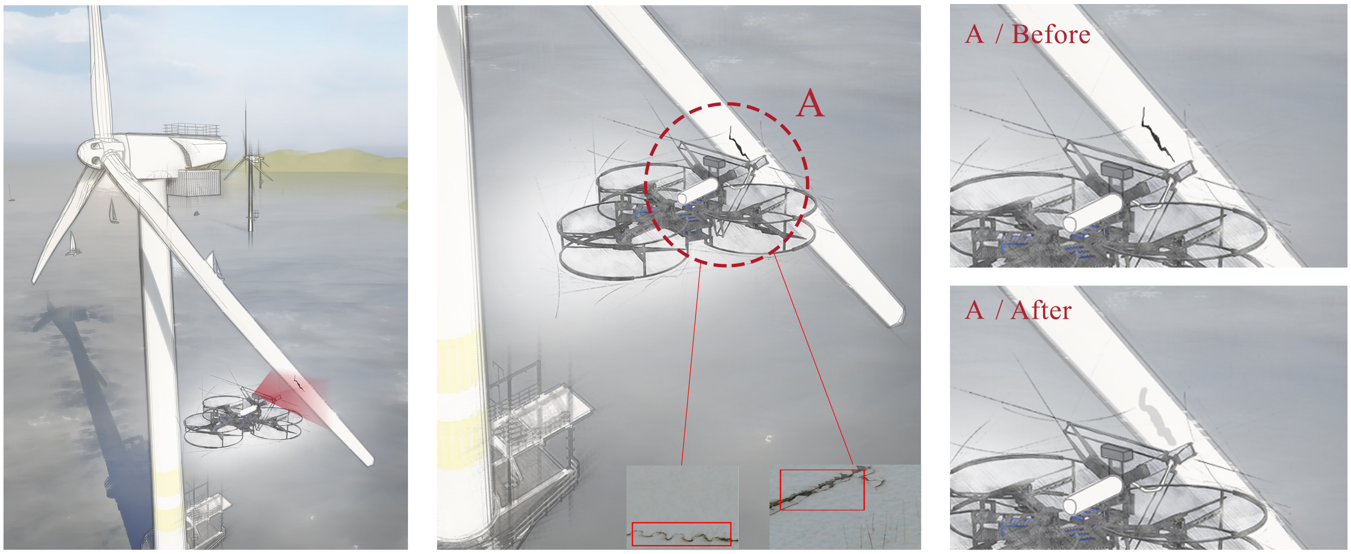

Fig. 1: Aerial manipulator for wind turbine inspection, from left to right: aerial manipulator first scans and detects the faulty region. The second phase is to approach and deposit material with time and path parametrization. Two field images from [1] are also given in the middle. The last stage shows the effect of the repair system before and after it is applied.

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is leading edge due to the erosion that can lead to coating cracking, debonding, cracks in composite, material loss and surface roughening [3]. The material choice for this operation includes protective tapes, protective coatings (applied with brush or casting), epoxy and polyurethane fillers [3]. Our proposed system will represent real material deposition with similar build characteristics. The developed system will be cost-effective and safer to conduct repair processes at height for infrastructure systems using a buildable material and vision-based mechanism.

Fig. 2: COAST lab: pictures from Coastal, Ocean and Sediment Transport lab at the University of Plymouth to represent the conditions for an offshore turbine.

The current state of the art in drones with repair capabilities is blind to changes associated with the material deposition. For instance, even most of the commercially available extrusion systems could continue adding the material without taking the volume shape into account. The first stepping stone is based on the detection of the point and identifying the characteristics of the object. This stage will explore the defect characteristics including a gap, discontinuity, and irregularity. After the data collection to characterize the structural problems, the repair drone will utilize mission planning. Depending on the identified problem, this could be filling a gap, or depositing the material to remove the irregularities on the structure. After deciding on the characteristics of the surface and the shape, the repair drone will deposit the material. The loop will continuously be closed with visual identification and feedback to inform the next actions. The initial experiments and demonstrations will be conducted in the COAST laboratory of the University of Plymouth. The images from the laboratory to represent the real conditions are given in Fig. 2.

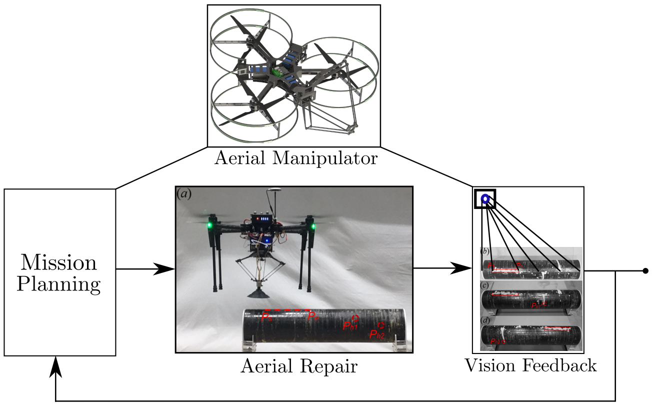

Fig. 3: The proposed approach for the closed loop aerial repair system [4]. The first block processes the feedback from the vision pipeline to compute the repair actions for the aerial manipulator.

## II. METHOD

The overall system diagram is illustrated in Fig. 3. The base platform in this work is described in [5] and the aerial manipulator version is illustrated at the top of Fig. 3. This high payload platform can carry up to 7.3 kg with a maximum flight time between 10–34 mins. The initial data confirm the accurate tracking of the setpoint trajectories. The onboard sensing includes the Intel Realsense T265 tracking camera, the D435 depth camera, and Ouster OS-1 Lidar. The vision system will first explore the collected and available datasets for the crack inspection. Prominent defect classes include crack, erosion, lightning damage, and broken vortex generator. With a supervised learning approach, a real time estimation of the defect will be implemented. After the detection, the time parametrization of the path to deposit the material will be computed.

## III. DISCUSSIONS AND FUTURE WORK

The field implementation of our proposed system requires to include safety loops to provide a reliable system. The proposed platform will explore the relative navigation to add an additional collision avoidance loop considering optical flow sensors [6]. In order to consider variable conditions and the changes in the data stream, an adaptive learning approach will be considered as future work in this application [7].

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