UACIS - Entwicklung eines drohnenbasierten Systems für die zerstörungsfreie Bauwerksdiagnostik

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Abstract. Das Vorhaben Unmanned Aerial Concrete Inspection System (UACIS) steht für die Einführung moderner und höchst leistungsfähiger Drohnentechnologie in die Zerstörungsfreie Prüfung im Bauwesen (ZfPBau). Drohnen werden als Schlüssel zu Effizienz und Effektivität in der Zerstörungsfreien Prüfung (ZfP) identifiziert. Ziel der Entwicklung ist die Anwendung des Systems auf Infrastrukturbauten ebenso wie auf Tragwerke in der Energietechnik. Insbesondere Brücken, Containments oder Kühltürme stehen aufgrund ihrer Altersstruktur, Exposition und begrenzten Zugänglichkeit im Fokus der Bauwerksuntersuchungen. Neben der kontaktlosen Inspektion wird das Drohnensystem zusätzlich in der Lage sein, mechanische Anpresskräfte auf Bauteiloberflächen in fast beliebiger Orientierung aufzubringen. Sonst nur schwer zugängliche Bereiche werden so auch für Kontaktprüftechniken erschlossen und ökonomisch prüfbar. Die zusätzliche Einbindung innovativer Technologien wie insbesondere der Künstlichen Intelligenz trägt neben der Kombination verschiedener Prüfverfahren an einer Drohne dazu bei, vorausschauend instand zu setzen und damit die Lebensdauer relevanter Bauwerksstrukturen zu maximieren.

1 Introduction

Breakthroughs in robotics have led to an increase in the automation of processes in many areas of science and technology around the world. The main improvement brought by this automation often includes a reduction in operation time, improvement of procedure consistency, a reduction of cost as well as a reduction or complete removal of the risk to jeopardize human safety [1], [2]. Yet, the progress in automating NDE (non-destructive evaluation) in the field of civil engineering has been relatively slow compared to other fields, despite the potential benefits.

The main challenge to the automation of NDE is the compound problem between the wide variety of NDT (non-destructive testing) techniques available coupled with the diversity of infrastructures to be inspected [3]. The development of automated NDE is subject to a trade-off between the required development time, range of applications and the expected benefits. In some cases, the flaw's identification process may require multiple complementary NDT techniques to assert confidence in the results which further complicates the development of automated solutions.

Recent promising developments in automated or semi-automated procedures in civil engineering involve Uncrewed Aerial Vehicle (UAV) systems, also known as drones. The application of UAVs in civil engineering has been mainly focused on non-contact inspection procedures such as mapping and visual inspection [3] and several commercial systems already exist. The most recent development involves contact inspection which was made possible thanks to stability and control breakthroughs in UAVs' design. Some recent examples of contact inspection using UAVs include the inspection of pipe wall thickness [4] metal plate [5] and powerline [6].

This publication explores concepts and early-stage developments of the UACIS (Uncrewed Aerial Concrete Inspection System) project, which aims to implement different contact ultrasound-based NDT methods on a UAV for the inspection of concrete structures. In particular, the implementations of impact echo and ultrasonic testing using DPC (dry point contact transducers) are being explored.

2 Towards autonomous and airborne contact NDT

In 2018, eddy current and ultrasound NDT systems were integrated onto a multirotor UAV as part of the AEROARMS project [4]. The project involved the testing of metallic pipes for maintenance application in the field of oil and gas. This research initiative demonstrated the application of a UAV to outdoor contact inspection, but also highlighted the challenges of performing precision measurements under environmental and aerodynamic perturbations. In 2019, an ultrasonic gauge (based on a single crystal probe) was implemented on a multirotor UAV to perform thickness measurements on metal plates [5]. However, the measurement time was limited by the need to re-apply gel couplant on the probe at regular intervals. Most recently in a similar application, a single ultrasonic wheel probe was integrated into a UAV designed by Voliro and used to perform thickness measurements on a metallic plate [7].

So far, the majority of the UAVs used for the integration of contact-based NDT were multirotor systems as opposed to fixed-wings aircraft [4]–[7]. Multirotor UAVs have greater control and stability than fixed wings making them more suitable for contact applications. However, one trade-off with multirotor, compared to fixed wings UAVs of similar weight, is that they are generally more energy consuming and have a shorter flight time. Still, maintaining a static position and constant force against a structure for an extended period of time is a major requirement for most contact NDT systems but the main challenge in UAV design.

3 Motivations and NDT system selection for airborne inspection

The current UACIS project focuses on extending the development and application of semi-autonomous airborne NDT to the inspection of concrete infrastructures. This project has the ambition of integrating, onto a UAV, NDT methods requiring direct contact between the probe and the inspected structure. These types of NDT techniques often provide information on material properties, geometry, hidden flaws, or inhomogeneity that cannot be detected with a standard visual inspection. Some examples of contact-NDT include UT (ultrasound testing), IE (impact echo), AE (acoustic emission), Eddy current, MT (magnetic particles testing), penetrant testing [8].

The techniques selected for this study include IE and UT using DPC (dry point contact) probes. Both techniques are widely used for concrete inspection and are traditionally performed manually and require a series of point measurements across the surface of the inspected structure. These processes are often time-consuming and arduous for the NDT operator especially when measurements are conducted in areas with limited accessibility (e.g., underneath highway bridges or cooling towers). Therefore, the automation of IE and UT techniques would yield great benefits to the field of civil engineering.

Achieving the integration of contact-NDT on UAVs requires multidisciplinary knowledge and innovative solutions to overcome the main constraints and technical challenges of the project, some of those can be listed as follows: (1) abide by strict weight and dimensional restrictions; (2) ensure full mechanical and electronic integration and communication between the different interfaces; (3) implement wireless real-time data transfer from the NDT-UAV system to ground user's interface; (4) conduct timely probe actuation and signal acquisition consistent with contact onset between the structure and the NDT-UAV system; (5) define noise attenuation and signal processing strategies to enhance the signal to noise ratio, obtain reliable data and attenuate environmental disturbance including from the UAV itself.

4 Concrete NDT systems integration on a UAV

4.1 Description of the selected UAV system

The UAV used in this study is a commercial robot developed by ©Voliro Airbone Robotics and was specifically designed for applications requiring contact with a structure [7], [9]. Their tiltable rotors design generate thrust vectoring that allows 3D navigation whilst maintaining the UAV main body and payload at a fixed orientation. The UAVs can target a specific measurement location from any angle and maintain a constant contact force of up to 2kg for a minimum of 5s when the payload arm is perpendicular to the measurement surface. The measurements can be performed semi-autonomously and are assisted by features including onboard FPV (first person view) cameras and 6 Lidar sensors as shown in Fig. 1. The removable UPI (universal payload interface) is designed to be easily interchangeable and to facilitate the integration of NDT systems. The UAV can supply up to 12V to the payload as well as receive, store and transfer via Wi-Fi data from the payload. The main constraints in NDT system integration onto the UAV are weight and size related. The maximum payload weight that can be integrated is approximately 800g and the positioning of the payload should not obstruct flight, cameras' line of sight or extend beyond the propeller's arm guards.

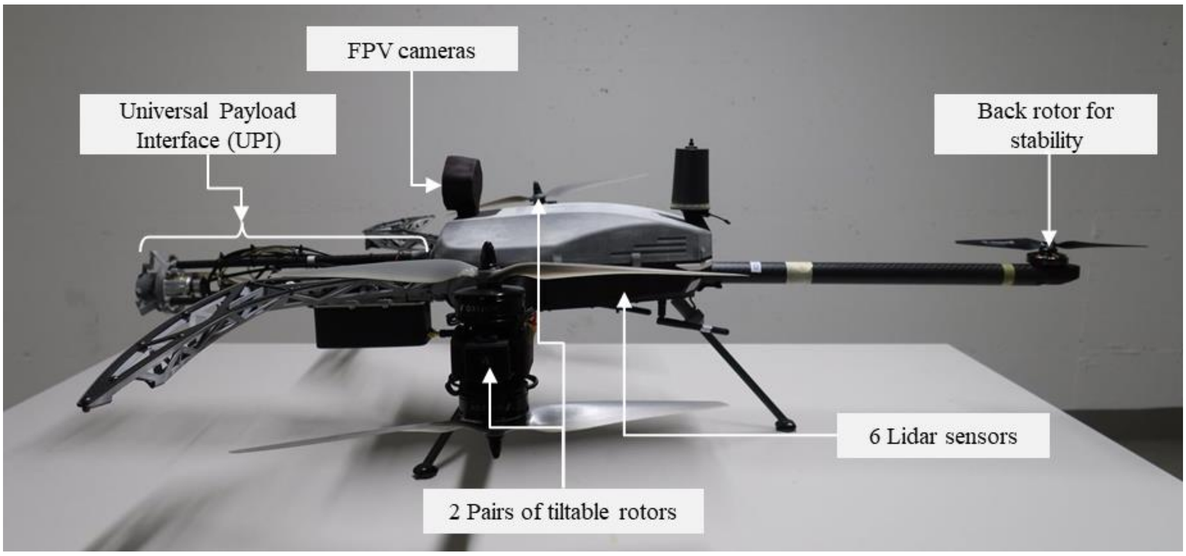

Fig. 1. Picture of a UAV designed by Voliro Airborne Robotics (picture supplied by Voliro).

4.2 Airborne impact echo inspection concept

IE is an NDT system widely applied for concrete inspection that uses an impactor and a single probe to respectively generates acoustic waves from impact stress in the structure and record an acoustic waveform signal [10]. Generally, the impactor can be a manually operated hammer or small steel ball impactor or an automated solenoid impactor. The probes can consist of an accelerometer or piezoelectric sensor. Traditionally, the probe is held by the operator against the surface of the inspected structure at approximately 3cm to 5cm from the impact location. Each impact provides a single A-scans containing information about repetitive waves reflections within the structures. Data are generally collected into a measurement grid and each A-scan information is converted into a frequency spectrum. The spectrum is used, in combination with knowledge of the wave speed, to identify backwall thickness, tendon duct locations and the presence of delamination and other flaws.

In this study, an impact echo system with an automated solenoid from Olson Instruments is partially disassembled and mounted onto the UPI (universal payload interface) of the UAV. A schematic of the different components is shown in Fig. 2. A special spring holder was designed to carry the approximately 500g impact echo probe and the impactor, as shown in Fig. 3. The spring holder was specifically designed to be stiff enough to carry the Impact echo system's components straight whilst being flexible enough to act as a suspension between the UAV and the NDT system. Fig. 4 shows the mechanically assembled IE system onto the UAV.

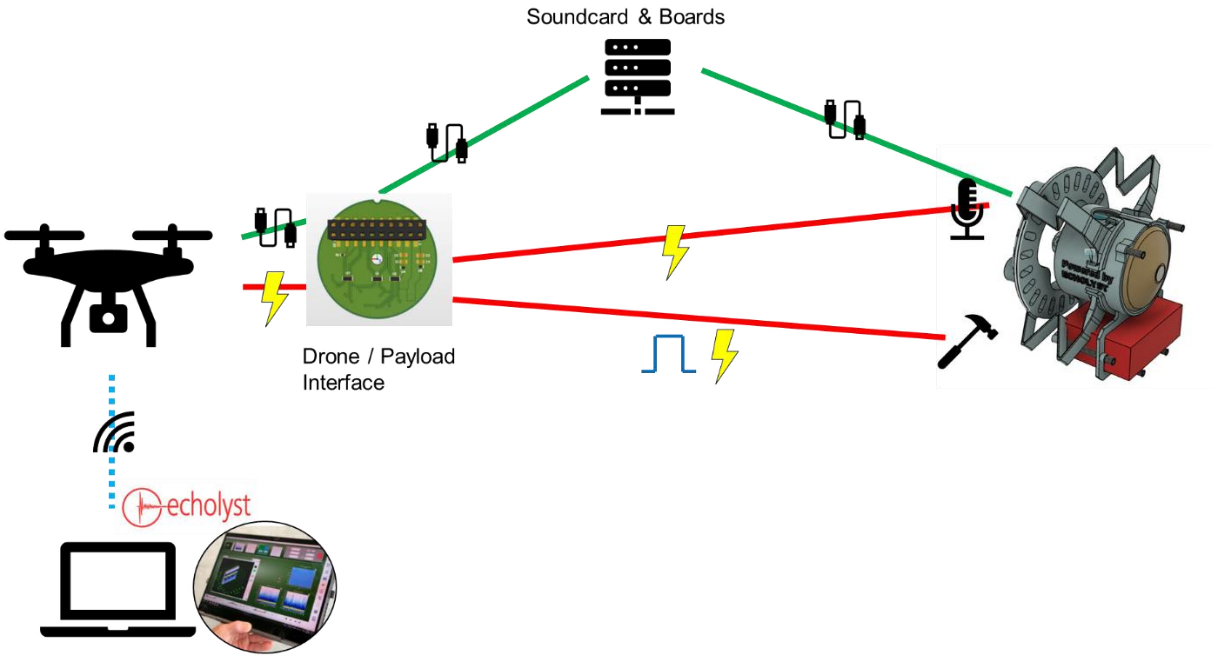

Fig. 2. Schematic of the components integration and interfaces connections of the impact echo UACIS system

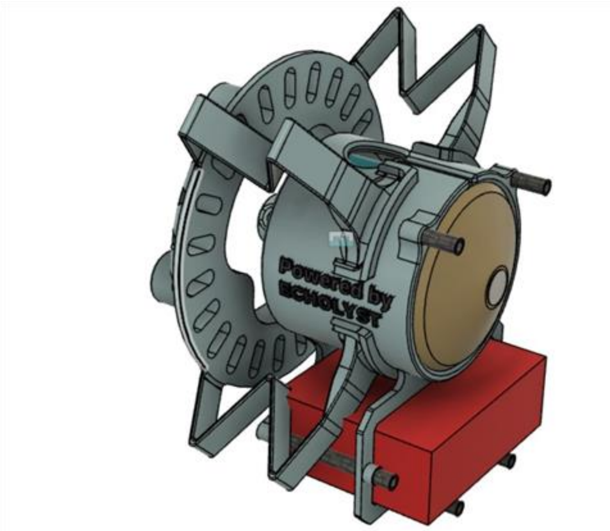

Fig. 3 Schematic of the spring holder (grey) carrying the impact echo probe (beige) and impactor (red)

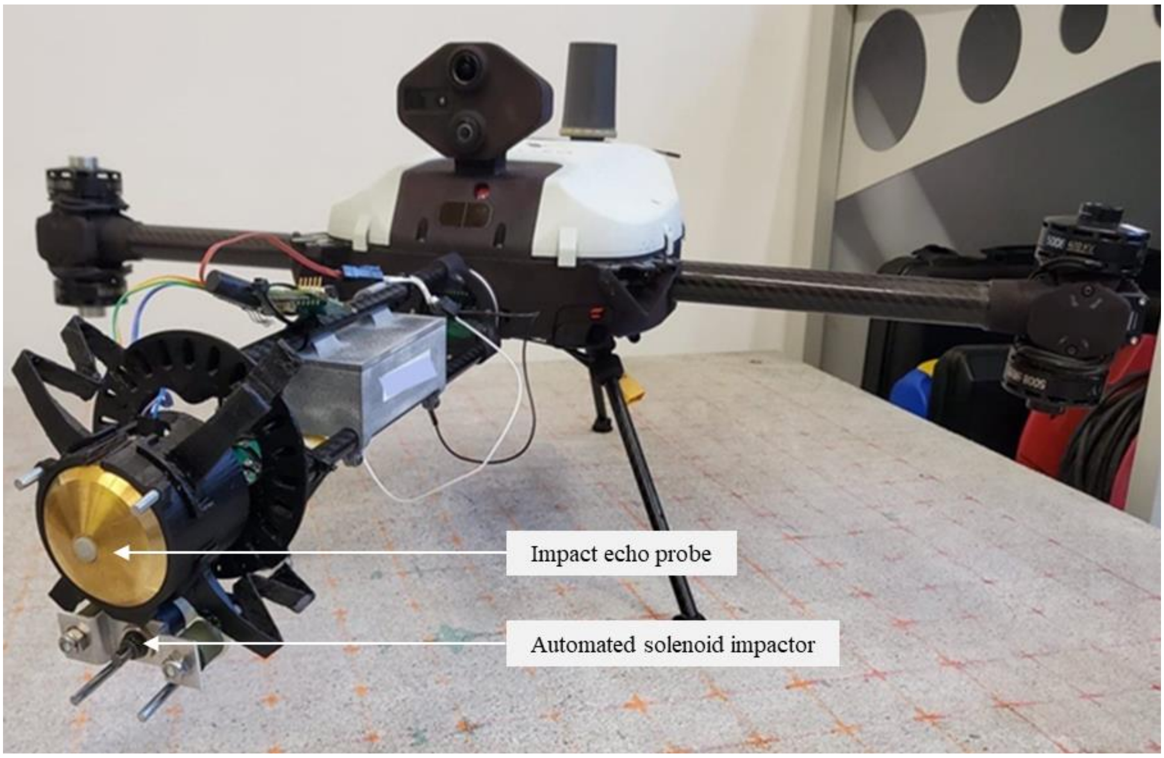

Fig. 4. Picture of the mechanically assembled impact echo probe and impactor on the UAV.

4.3 Airborne ultrasound inspection with DPC transducers concept

Dry point contact (DPC) transducers are a type of transducer used for ultrasound testing of concrete. DPC can generate ultrasound and received signals from ultrasonic waves propagating in a structure. The main advantage is that they do not require any couplant and allows different measuring configuration such as pitch and catch or pulse-echo. These transducers are often arranged into an array configuration with different DPCs working successively as emitters or receivers. The collected signals can be used to perform 2D and

3D image reconstruction of the inspected structure using image reconstruction algorithms such as the total focusing method with full matrix capture [11].

The transducers selected for this study, as shown in Fig. 5, are S1802 shear waves DPC transducers supplied by ACS-Solutions GmbH. Those transducers have a central frequency of 50kHz, each of them weight approximately 19g. The prototype involves the integration of 8 DPC transducers. The OEM board, provided by AOS, will enable different pitch and catch measurement configurations, including the possibility to actuate simultaneously multiple DPC transducers. A schematic of the components' integration is shown in Fig. 6.

Fig. 5. Example of commercial shear waves DPC transducers (extracted from acs-international.com)

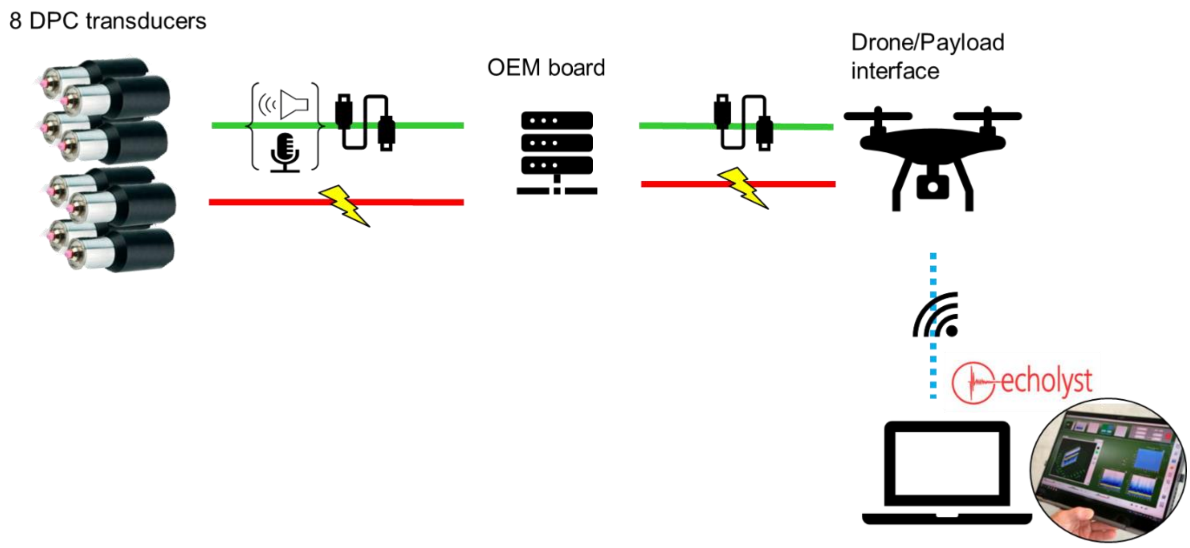

Fig. 6. Schematic of the components integration and interfaces connections of the ultrasound UACIS system

5 Conclusion

This publication shows the early concept and development of the UACIS system. Future works will consist in finalising the full integration of both the impact echo and ultrasound system onto the UAV as well as conducting experimental data collection on a concrete block.

6 References

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