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Thermographic Drone NDT: Concepts, Case Studies

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UNIVERSITÉ LAVAL

NDT in Canada
NDTiC 2022
Canada's NDT Vision - Inspection Excellence
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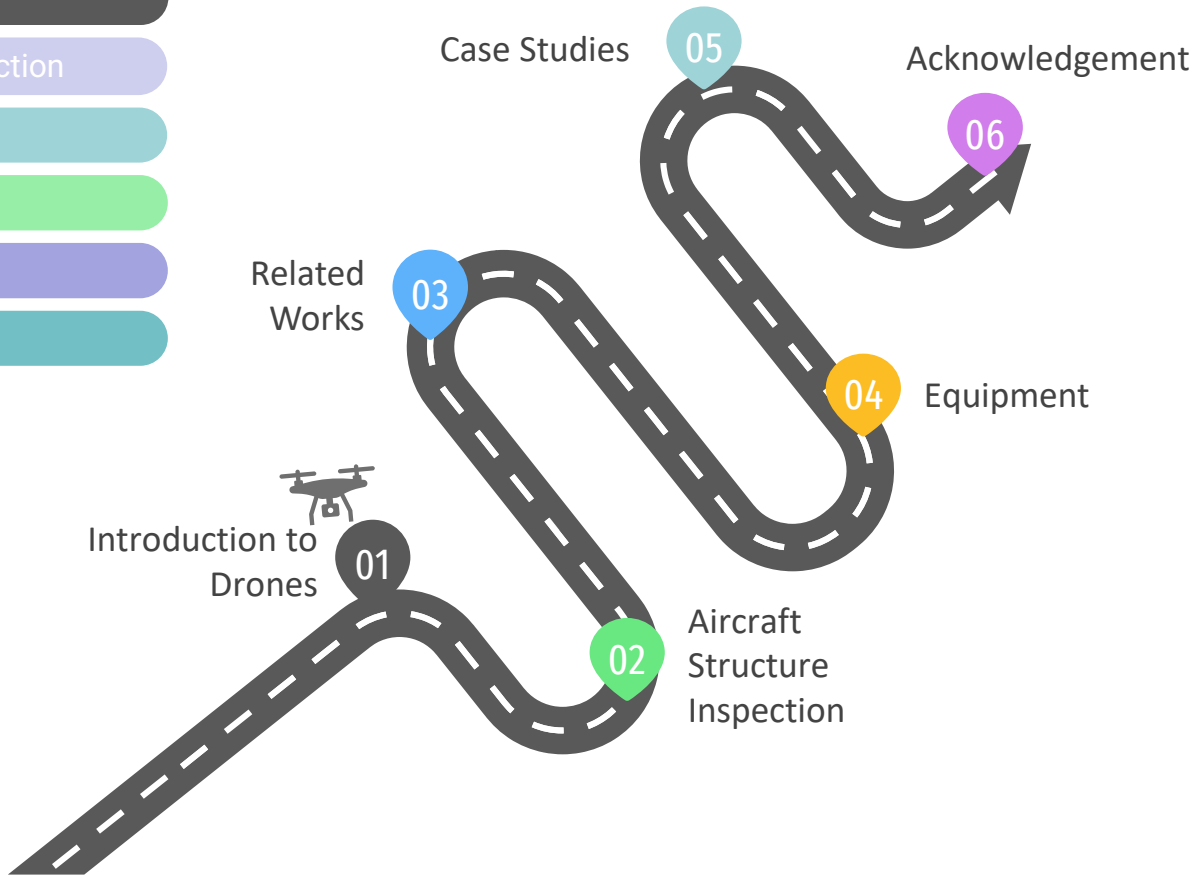
ABSTRACT

- **Idea**: Inspection of large structures using a drone
- **Case of aircrafts**: Recent aircrafts incorporate and high content of composite materials such (CFRP) in wings, fuselage, etc. that require proper inspection to detect and assess severity of embedded defects present at manufacturing stages such as porosities and in-service defects (delaminations and disbonds).
- **Other applications**: Many other fields could benefit from drone inspection, for instance civil engineering in the case of large structures sometimes difficult and dangerous to reach.

INTRODUCTION TO DRONES

OUTLINE

- Introduction To Drones
- Aircraft Structure Inspection
- Related Works
- Equipment
- Case Studies
- Acknowledgement



NON-DESTRUCTIVE TESTING

In past decades, industries surrounded us with large structures that most of them depend on each other to function correctly. The **operational safety**, **production cost**, and **capacity of the industrial sites** depend on their continuous operation. So, inspection and assessment of systems are essential for early detection of any problem, possibly with minimum interruption in the operation which can be addressed by **Non-Destructive Testing (NDT) solutions**.

Non-Destructive Testing commonly is being adopted for

01 Cost and time reduction

02 Increasing profits

03 Maintaining quality level

04 Providing better production design

05 Ensuring product integrity and reliability

06 Monitoring the manufacturing process

07 Avoiding failures, accidents, and saving human lives

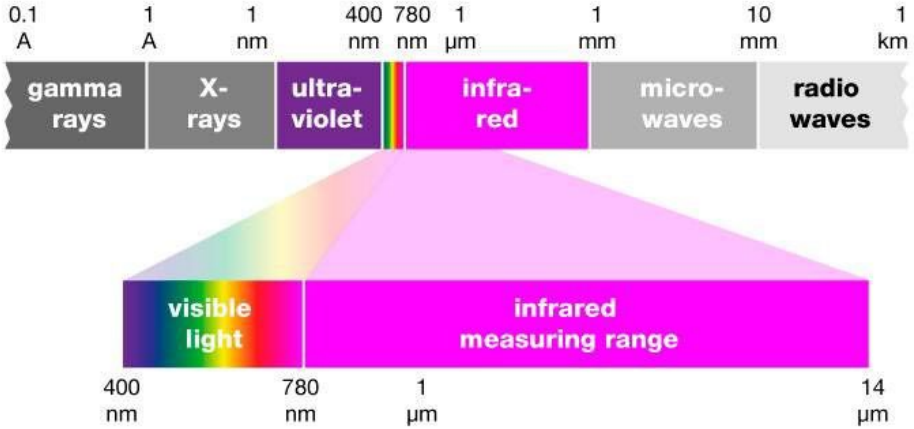
08 Ensuring customer Satisfaction

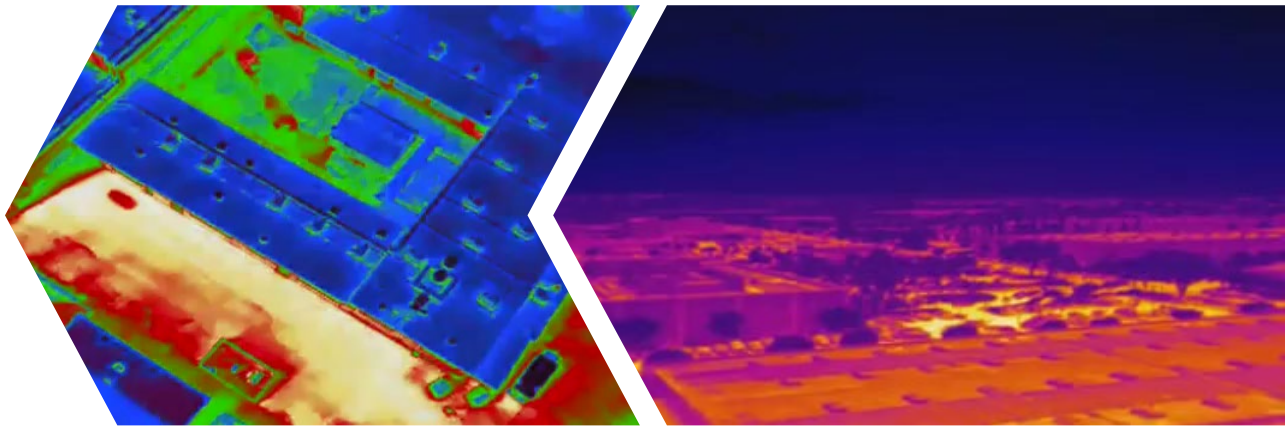
THERMAL NON-DESTRUCTIVE TESTING

THERMAL-NDT

IR thermal vision is the capability to detect and measure by artificial means, the IR radiation that all bodies with temperature above 0 K emit.

IR vision is aided by computer sciences to process the acquired information.





- https://www.youtube.com/watch?v=zfRaq2d0kZg
- https://www.youtube.com/watch?v=yxdrIhvGImE

THERMAL NON-DESTRUCTIVE TESTING

THERMAL-NDT

Observation Setup

- Reflective mode
- Transmission mode

Inspection Configuration

- Point Inspection
- Line Inspection
- Surface Inspection

Definition of Thermal Non-Destructive Tesing

Thermography is the process of acquisition and processing of thermal information collected by a thermal imaging system. The inspection of industrial components can be done by observing the component's radiation pattern and identifying possible faults or problematic components by searching for any distortion or unexplainable pattern in the thermal images.

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Types of Active Thermography

Active Thermography — An energy source must produce enough emission to differentiate the region of interest and the background.

Passive Thermography — Ordinarily applicable in the scenarios where the region of interest has a lower or higher temperature than the background.

Pulsed Thermography (PT)

The specimen is stimulated by pulsed heat.

Step Heating (SH)

Similar to PT but using long pulses for specimen stimulation.

Lock-In Thermography (LT)

Periodically modulated heat into a specimen while monitoring the surface temperature modulation

Vibro-thermography (VT)

Use mechanical vibrations to generate hot spots in the areas where possible defects are located

TYPES AND CLASSIFICATIONS

According to **U.S. Department of Defence**, UAVs are classified into five categories [1]:

Category	Size	Maximum Takeoff Weight (lbs.)	Operating Altitude (ft.)	Airspeed (knots)
Group 1	Small	0 - 20	< 1200 AGL *	< 100
Group 2	Medium	21 - 55	< 3500	< 250
Group 3	Large	< 1320	< 18000 MSL **	< 250
Group 4	Larger	> 1320	< 18000 MSL	Any airspeed
Group 5	Largest	> 1320	> 18000	Any airspeed

* AGL = Above Ground Level
** MSL = Mean Sea Level
Note: if the UAS has even one characteristic of the next level, it is classified in that level.

DRONES

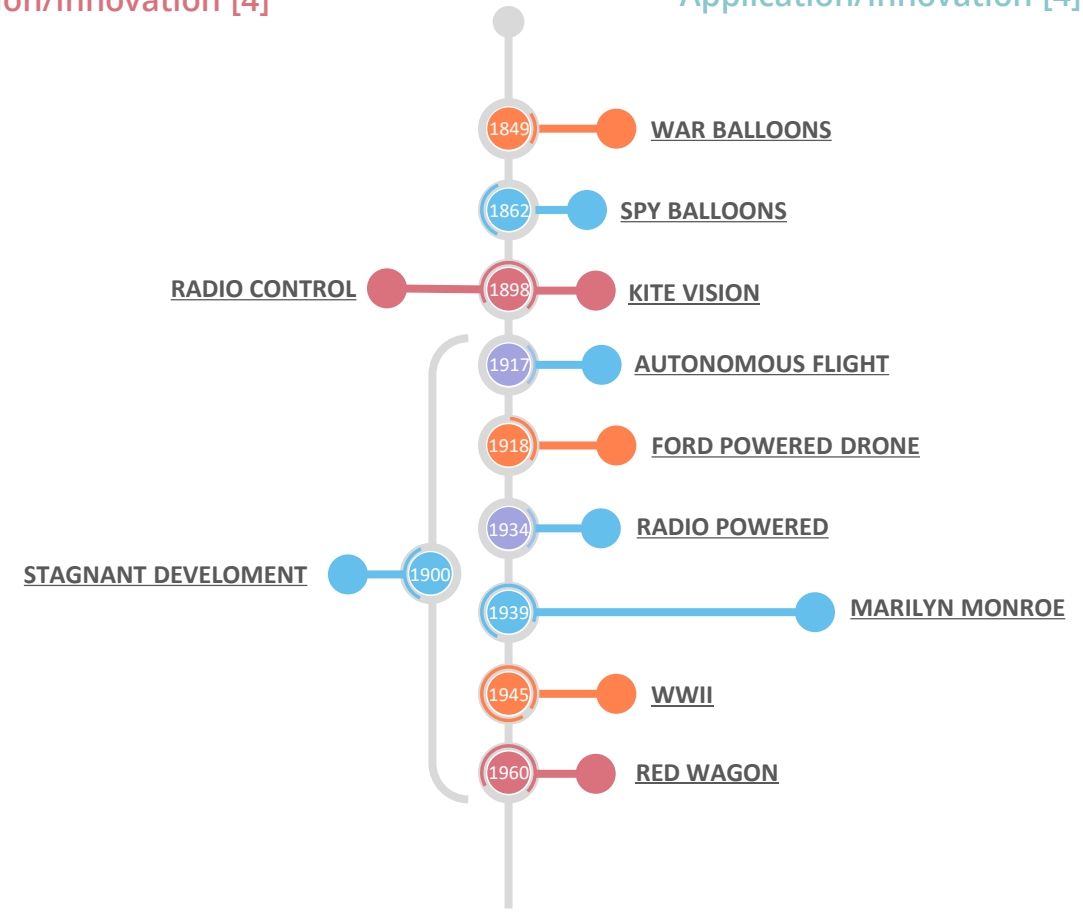
Bekmezci in [2] demonstrates the **types** of drones as:

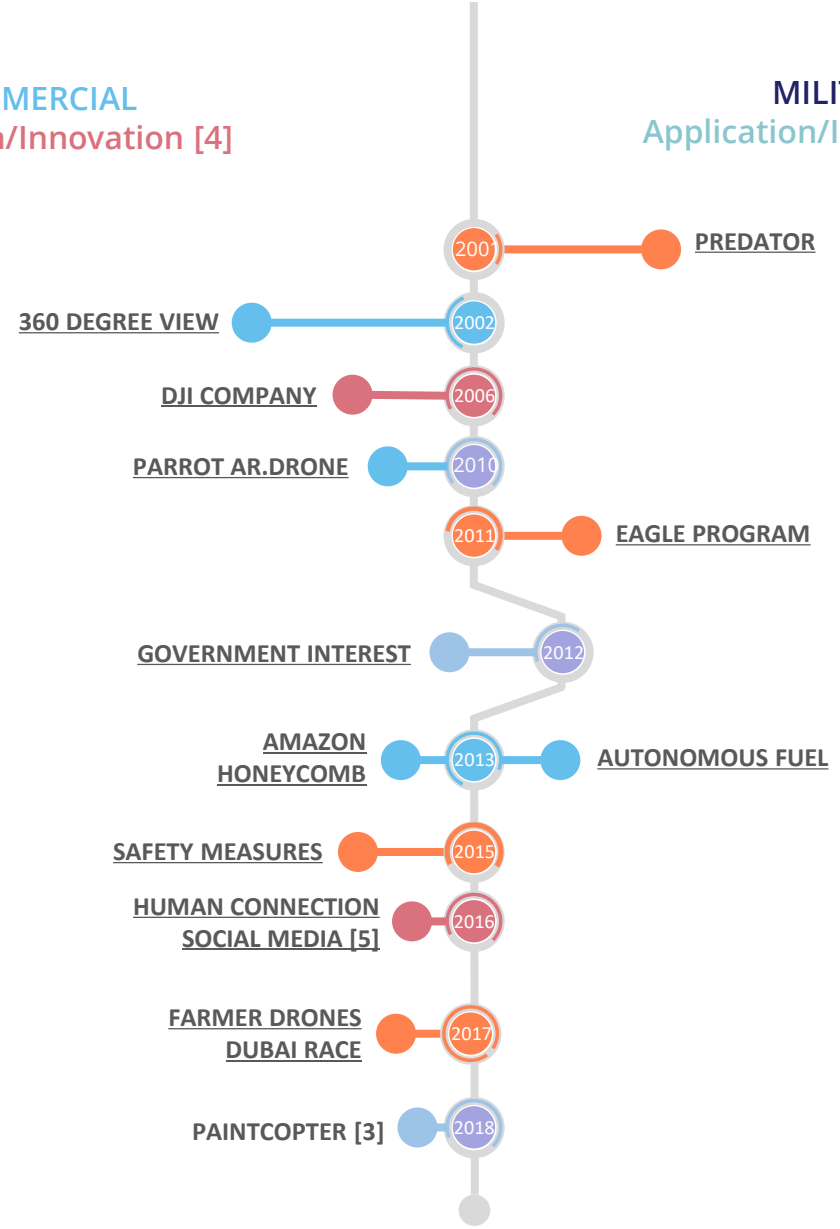
HISTORY TIMELINE

DRONES

COMMERCIAL
Application/Innovation [4]

MILITARY
Application/Innovation [4]





DRONE-ENABLED INSPECTION

HOW IT CAN HELP?

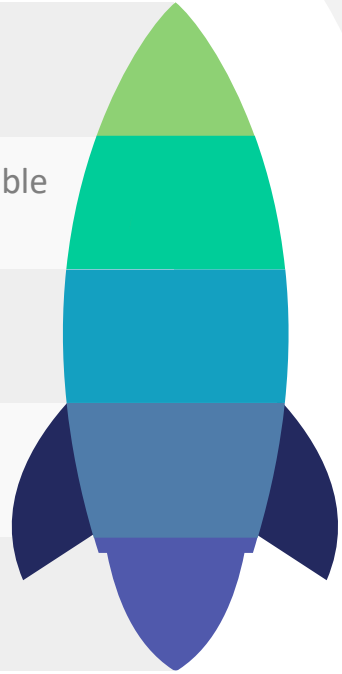
Large areas

Remote and inaccessible locations

Hard-to-reach or dangerous sites

Replace inspection using manned aircrafts

Repeated inspection



Benefits of using drones for Inspection of Large Structures

- Easy and free positioning
- Quick deployment or launch
- Flexibility to suit a majority of inspections
- Low insurance costs
- Little to zero downtime for equipment and systems

Advantages

- ▲ Frequency
- ▲ Consistency
- ▲ Safety
- ▼ Cost
- ▲ Coverage
- ▼ Time
- ▲ Accessibility

CHALLENGES AND LIMITATION OF DRONES

WHAT CANNOT DO?

- Vibration & Sudden Motions
- Limitation in Payload
- Limitation in Flight time
- Vulnerable to Weather Changes
- Needing Well-Trained Pilot
- Effect of Drone's Propellers

CHALLENGES OF INSPECTION

WHAT CAN BE DONE?

CHALLENGES	DRONE SOLUTIONS
Remote or **hard-to-access** areas	Provide **mobility** and allow inspection regardless of its **design** and **location**.
Inspection of specimens with high **structural complexity**	Drone's **flexibility of maneuver** let comprehensive, **reliable** and **accurate** data collection and inspection from **different aspects**.
Repetitive equipment **setup** and initial **calibration** in case of large specimen	Drone's **fixed setup** reduce inspection **time** & **cost** and lead **regular inspection** and more **accurate** results
Manual inspections can cause **property damages** and human **injuries**	Due to **autonomousity** of the drones: (a) Reduce **number of personnel** and inspection. (b) Reduce the future **incidents**. (c) Executing more **preventive inspection**.
Inspection **costs** and **time** is one of the key factors which can force industries to less **regulated commitments**.	Autonomous flights can reduce **cost** of **human resources**, **accommodation**, **equipment transfer**.

AIRCRAFT STRUCTURE INSPECTION

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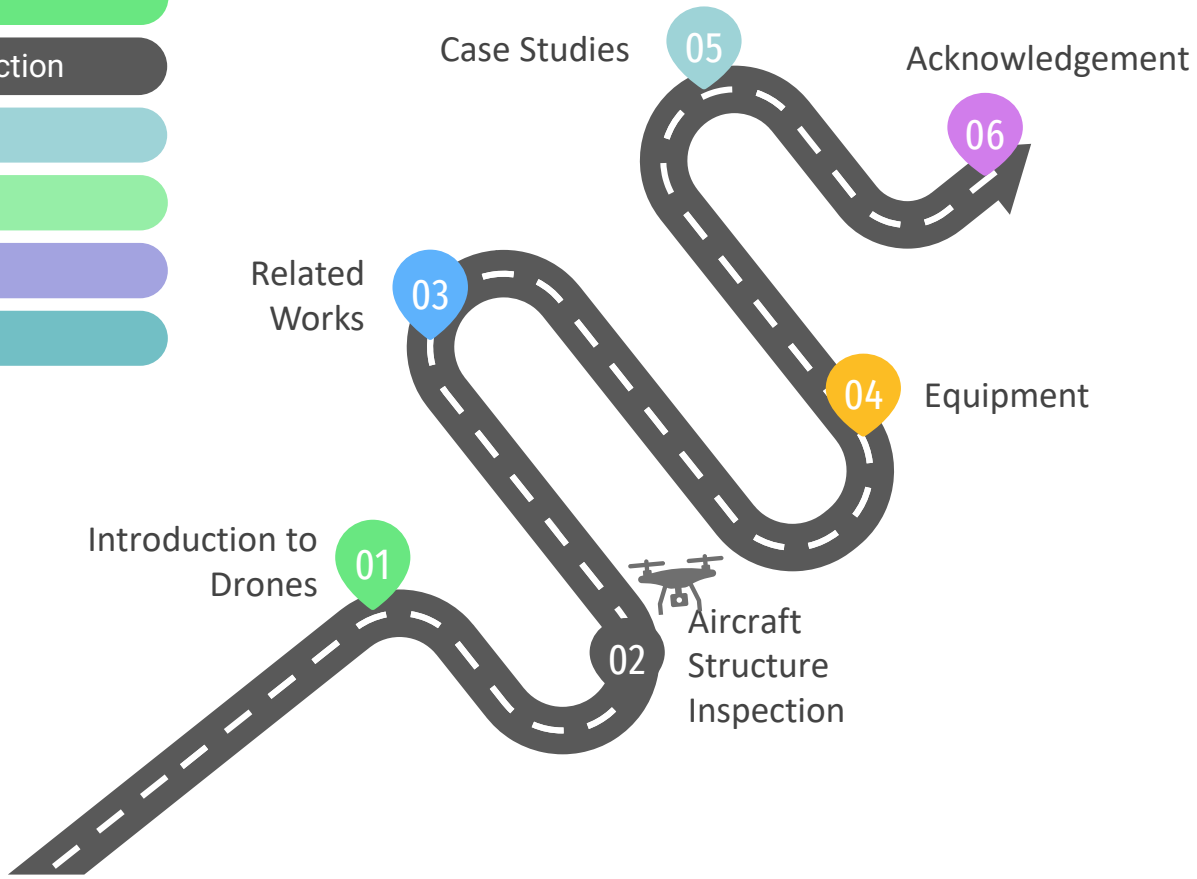
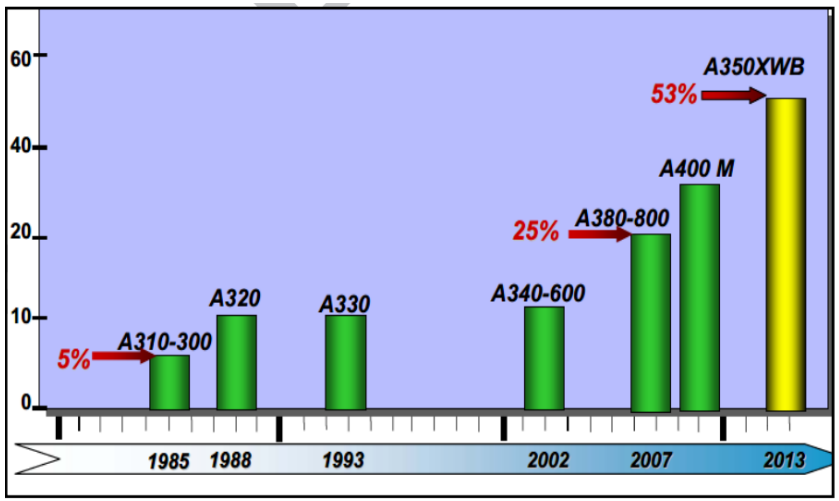


MOTIVATION for AIRCRAFTS : COMPOSITE INSPECTION by IR THERMOGRAPHY

- Using thermography for inspection of aircraft components is well-suited for the inspection of **composite materials**, having **low reflectivity** and **high emissivity**.
- Thermography is suited for inspection of composites since the energy absorbed in this material, **release much slower** than traditional metallic materials [32].



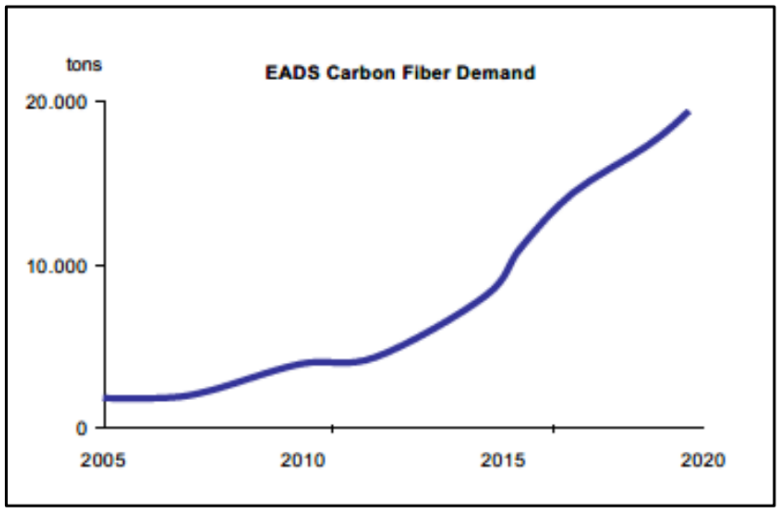


Figure is adopted from our publication [32] :

- Left figure shows the use of composites in Airbus aircraft since 1985.
- Right figure shows the demand by tons from 2005 to 2020

UAV-IRT FOR INSPECTION OF LARGE COMPOSITE AIRCRAFT STRUCTURES

CHALLENGE

In order to deploy a **heating source** and IR camera with the drone, they should be connected to the internal battery which can **decrease the flight time enormously**. Moreover, the additional equipment can decrease autonomy of the drone.

SOLUTIONS

Separating the heat source from the drone and operate it independently from a grounded power supply.

Having the UAV permanently **connected to a power cable**, which will assure a constant power supply.

- http://titanvine.com/2015/06/12/easyjet-to-use-drones-for-aircraft-inspection/

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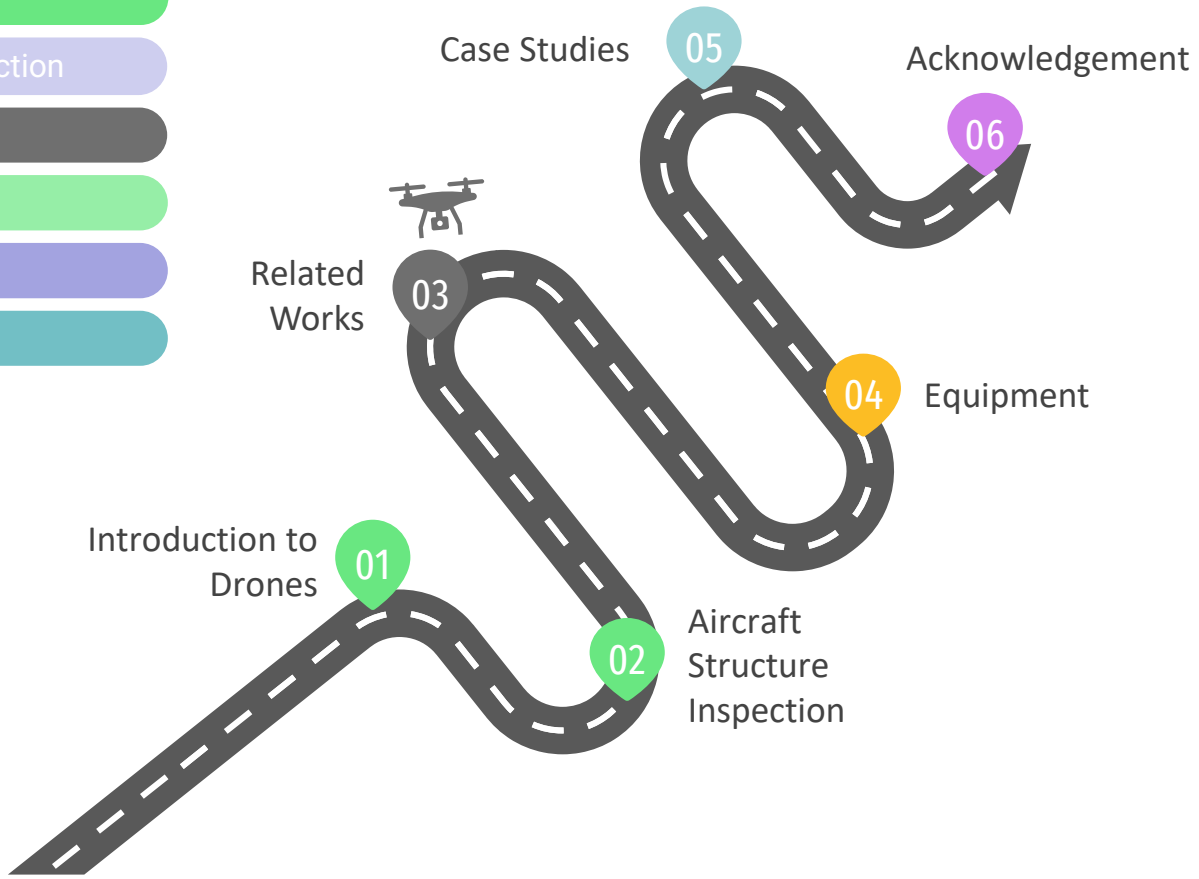

DRONE & DRONE-BASED INSPECTION

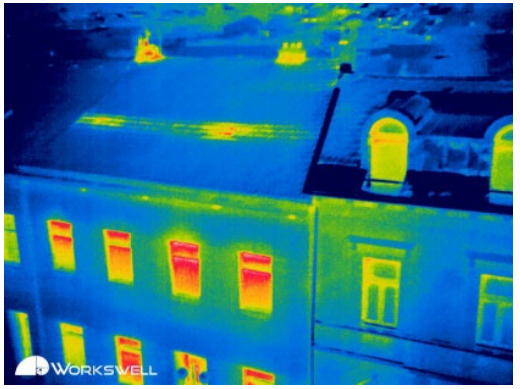

Image courtesy: Workswell Infrared (missing insulation)

General UAV applications:

- Precision agriculture [34],
- **Traffic analysis** (electric, thermal, etc.) [35],
- 3D mapping/modeling [36],
- **Archeological** exploration [37].

Passive thermography and UAV applications:

- The observation of thermal phenomena without the use of external energy stimulation
- **Building inspection** (e.g. detection of air leakages, moisture or humidity) [38];
- **Precision agriculture** (e.g. monitor nutriments levels or lack of water in crop fields;
- **Quality assessment of large structures** (e.g. inspection of photovoltaic panels farms, wind
- turbines) [39].

Active thermography and UAV applications:

- **Stimulating the structures** to be inspected with a controlled energy source and to use data **Processing** to improve defect detection and characterization [40].
- **Large structures** can be inspected using a dynamic configuration. This is the so-called line scan thermography (LST) [41], where the camera records thermograms right after heating.
- Improvement active IR UAV inspections based on the automatic detection of the thermal scene using e.g. references targets, excitation source closer to the inspected object and aboard the UAV [42].

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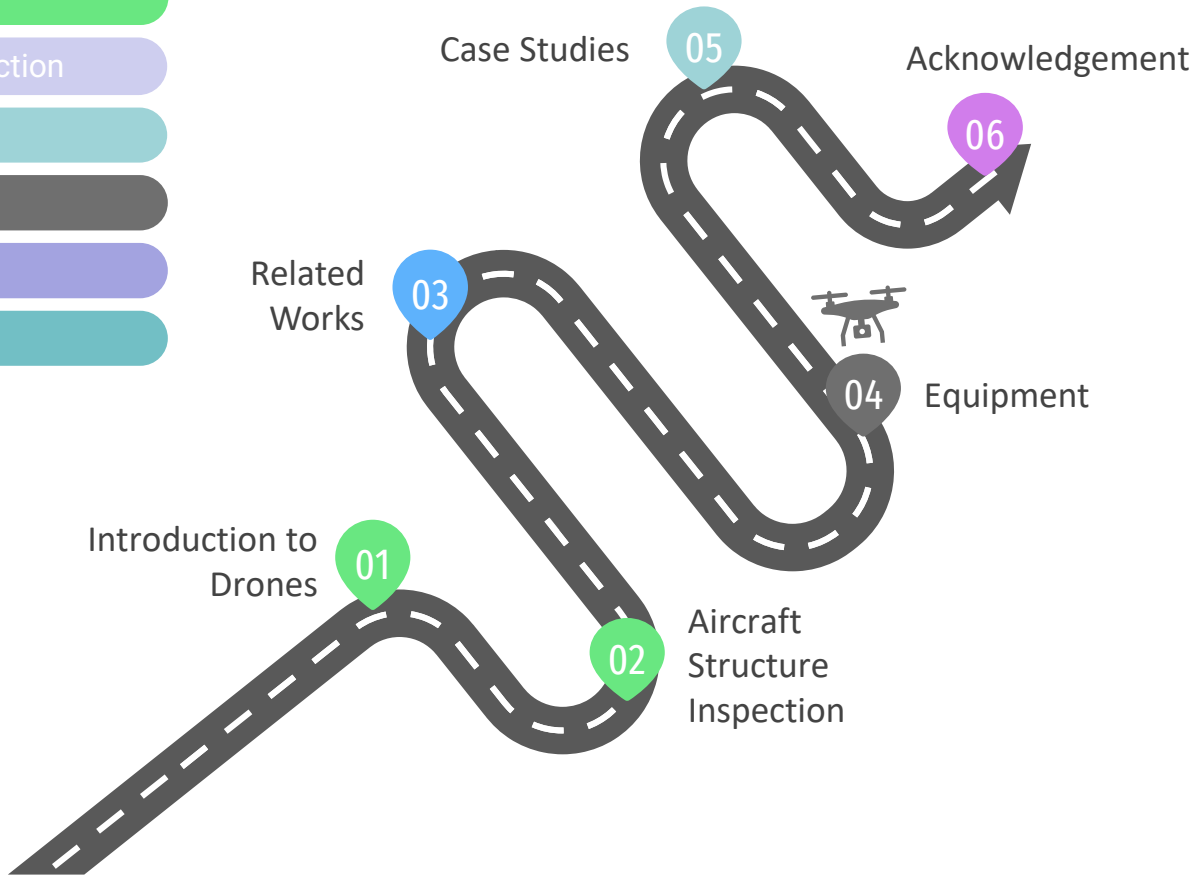


NAVIGATION CONTROL

FLIGHT CONTROLLER

Flight controller is a electrical device responsible for **control and manage RPM** of the motors based on received inputs.

AUTOPILOT

Autopilot is a system used to **control the trajectory** of a drone.

REAL-TIME KINEMATIC (RTK)

RTK is a satellite-based **positioning enhancement** technique.

ELECTRONIC SPEED CONTROL (ESC)

ESC is a module that controls and regulates the **speed** of an **electronic motor**.

COMMUNICATION

DATA LINK (DATA TRANSMITTER)

Data Link is a system (or combination of two systems) to provide a **semi-** or **duplex** communication link.

- Some of the available systems **integrated data and video** links.
- In some scenarios, an **auxiliary communication** line is employed to separate command and data transmission.

VIDEO TRANSMITTER

Video Transmitter is a system to transmit **single** or **multiple video stream(s)** from drone to ground control station.

EMBEDDED SYSTEM

- Embedded systems are commonly used in drones to process data on-demand.
- Common embedded boards which has been used in drones are follows,

SAFETY IS THE MOST IMPORTANT PART OF WORK!

SAFETY & OBSTACLE AVOIDANCE

A possibility of an incident is very high due to **maneuver limitation** considering the **drone** and **environment** scales.

PROTECTIVE STRUCTURES (GUARDS)

Protective structures built to prevent or reduce **destructions** and **injuries**.

- Motor Guards
- Hand and Finger Guards

SAFETY NET

Safety nets are very useful for **indoor missions** specially during development phase.

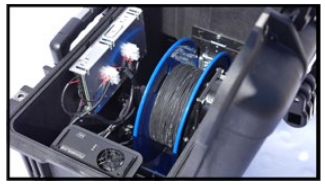
OBSTACLE AVOIDANCE SYSTEM

Install proximity sensors integrated with flight controller like DJI A3.

TETHERED POWER SUPPLY

TETHERED POWER SUPPLY

- Blue Vigil Tether System
- Elistair SAFE-T
- Powerline Tethered
- UNMND Tethered System



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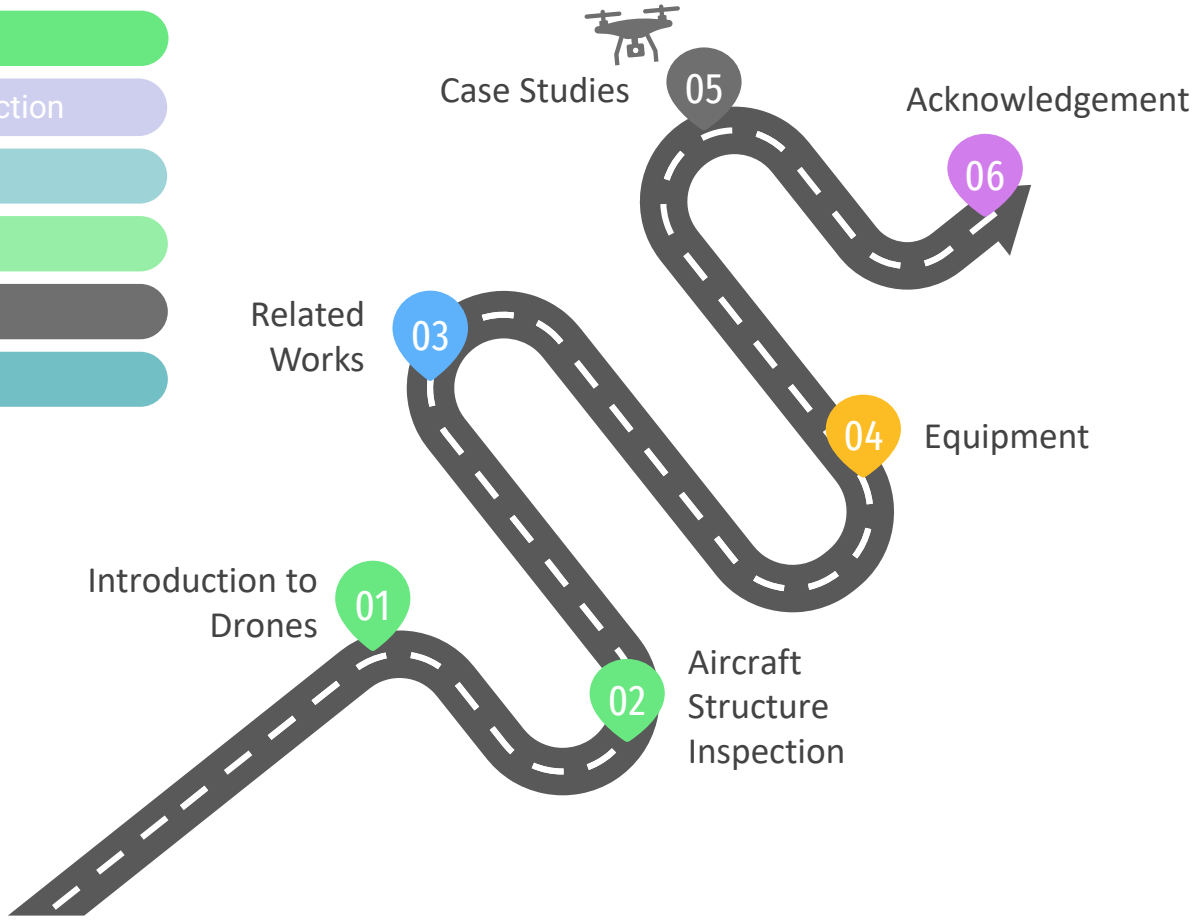


AERIAL THERMOGRAPHIC IMAGE STITCHING

DEFINITION

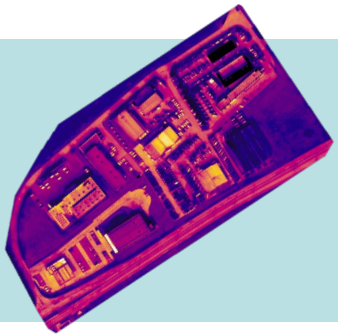
Image stitching is the process of joining overlapping images together to form a larger image to cover all the targeted environment.

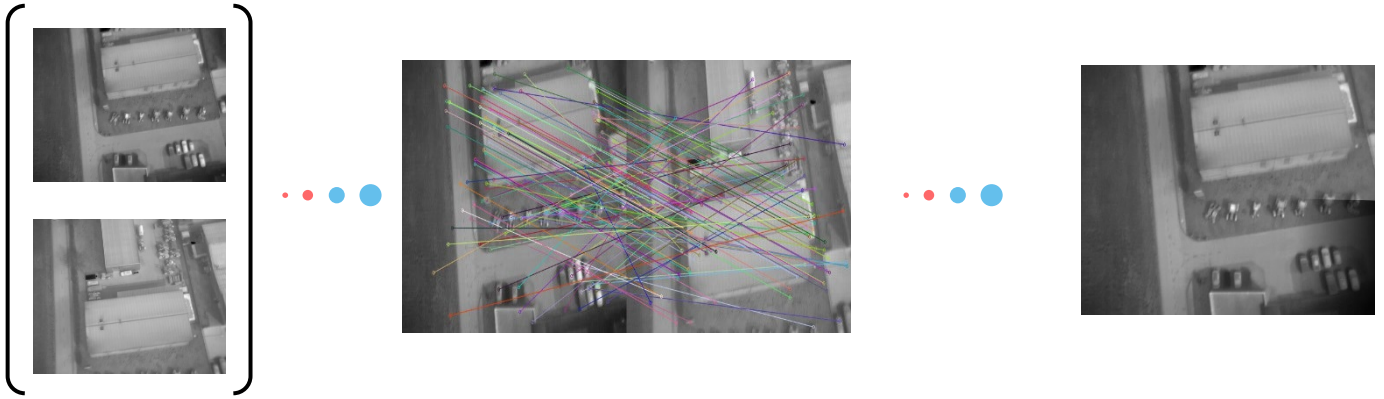
TARGET

- Form larger image to cover the whole area
- Assist inspectors to locate defects more efficiently.
- Reduce the operation cost by using cameras with less FOV.

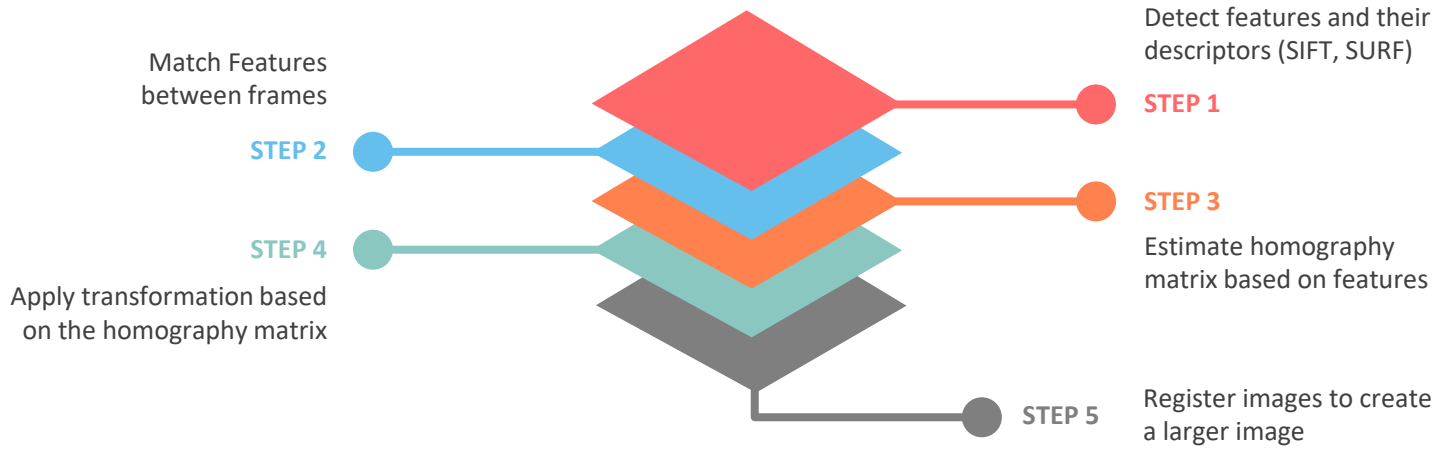
DATASET

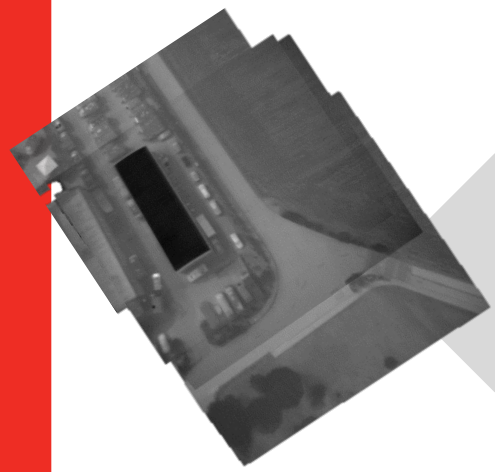
- SenseFly Industrial Estate
- RGB + Thermal data
- Flight height: 84 m
- Ground resolution: for thermal 11 cm/px





AERIAL THERMOGRAPHIC IMAGE STITCHING





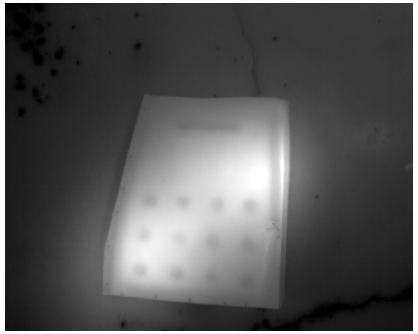
Case studies: DRONE-BASED ACTIVE THERMOGRAPHY OF AIRCRAFT STRUCTURES

EXPERIMENT

This is designed to investigate the feasibility of performing drone-based active thermography for inspection of aerospace structures.

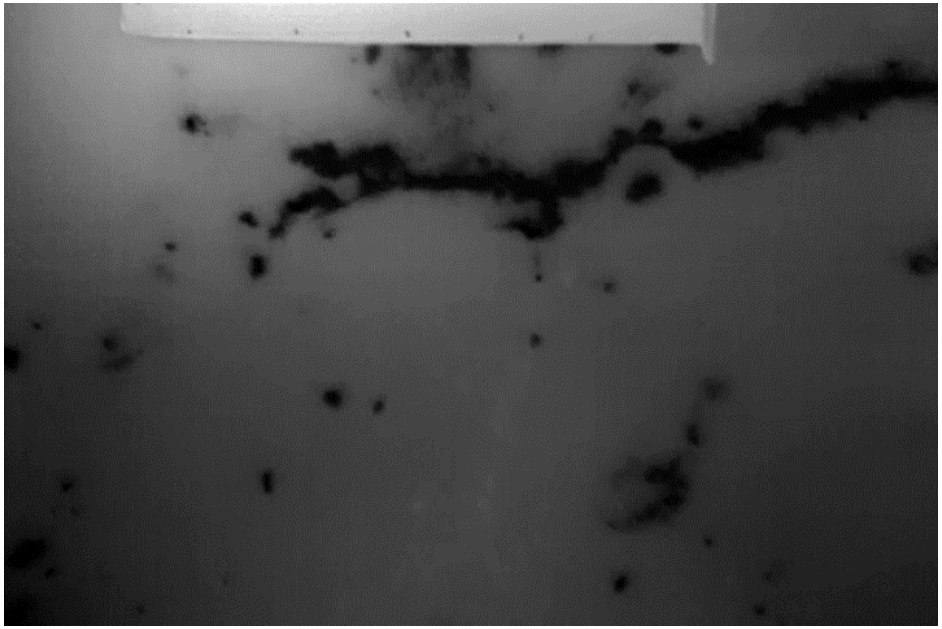
The data collected by a thermal camera installed on the drone while the drone is hovering around the object and stimulation units are exciting the specimen.

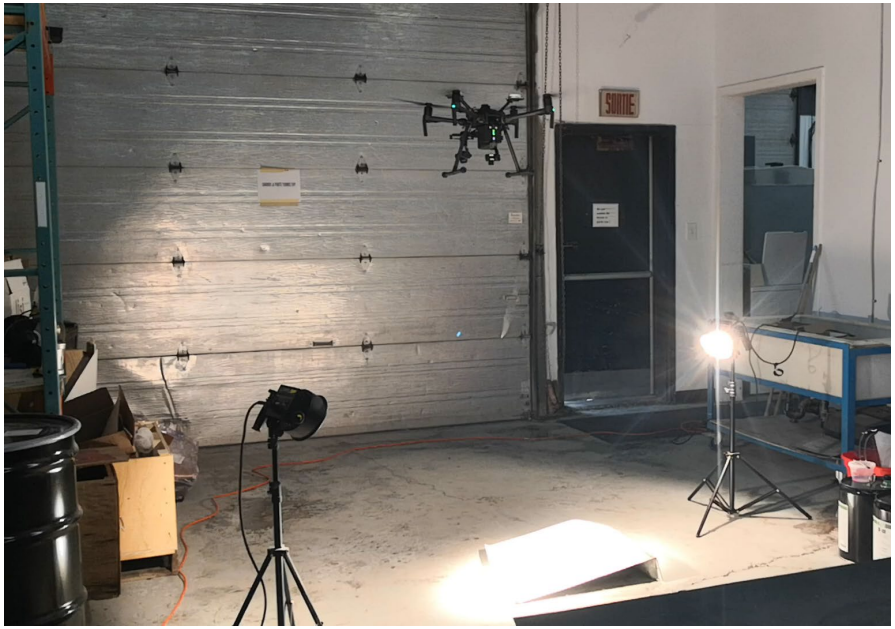
Equipment	Specification
Aerial Platform	DJI Matrice 210 RTK
Drone's Thermal Camera	Zenmuse XT



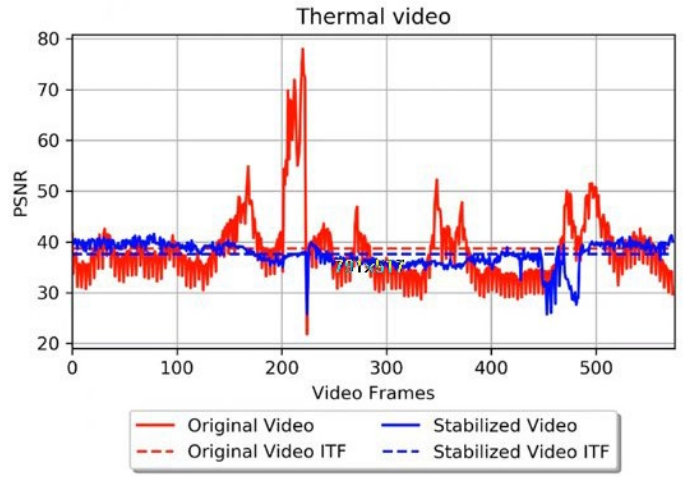
Zenmuse XT

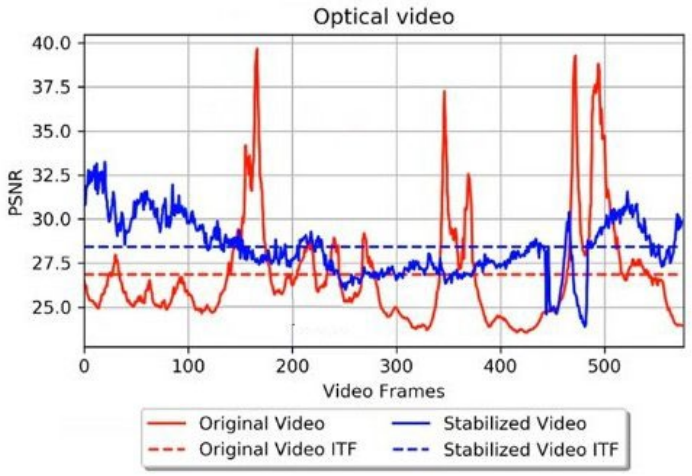
DRONE-BASED ACTIVE THERMOGRAPHY OF AEROSPACE STRUCTURES





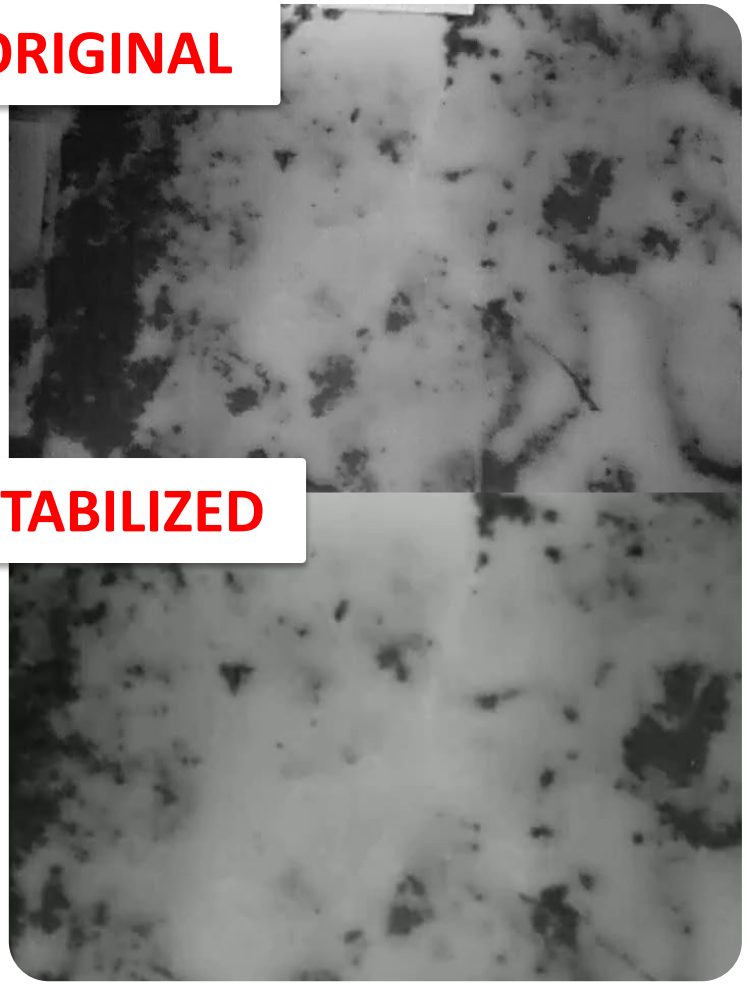
THERMAL IMAGE STREAM STABILIZATION





ORIGINAL

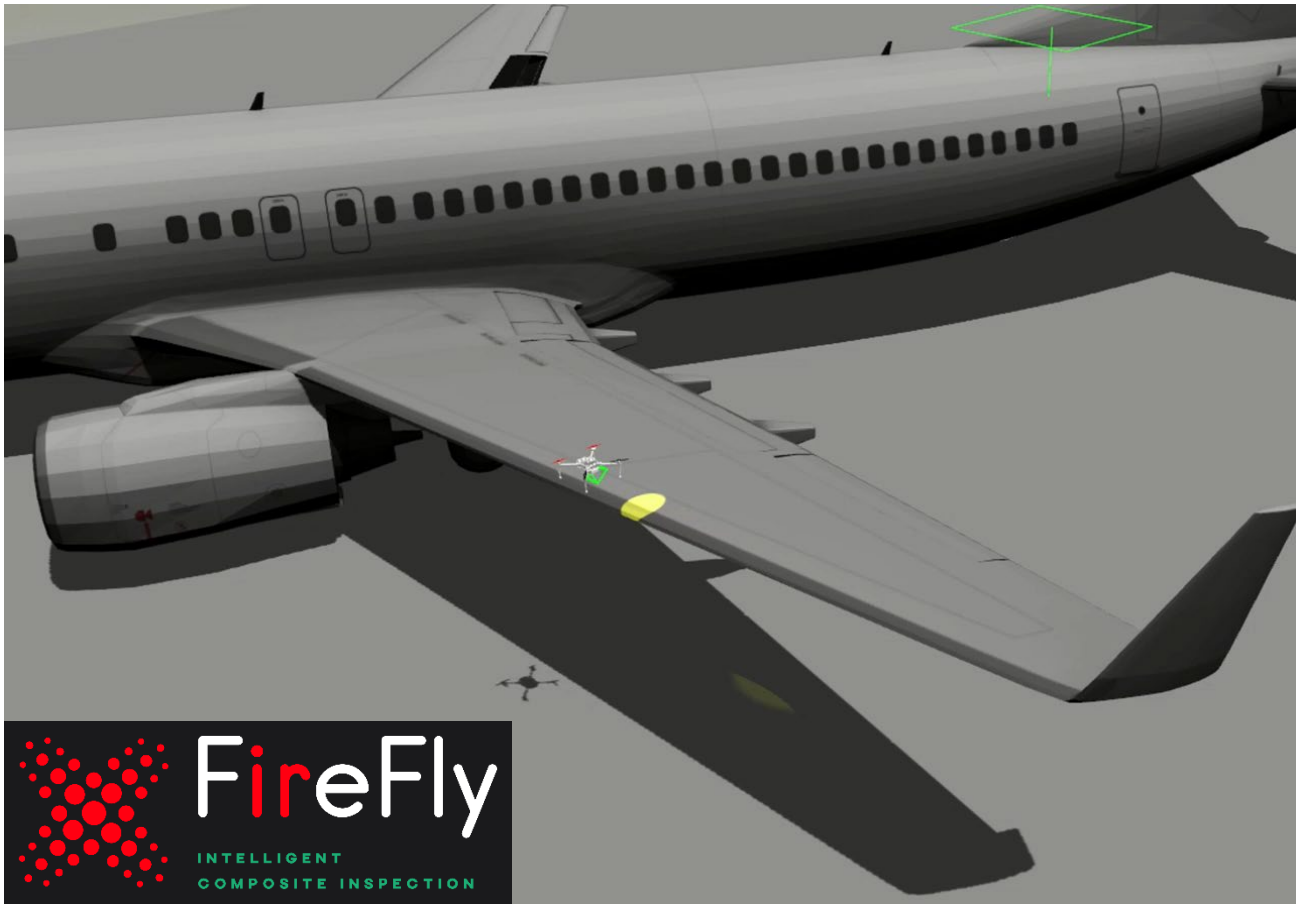
STABILIZED



DRONE-BASED ACTIVE THERMOGRAPHY OF AEROSPACE STRUCTURES: cable approach

Sample back side

CONCEPT OF AIRPLANE INSPECTION

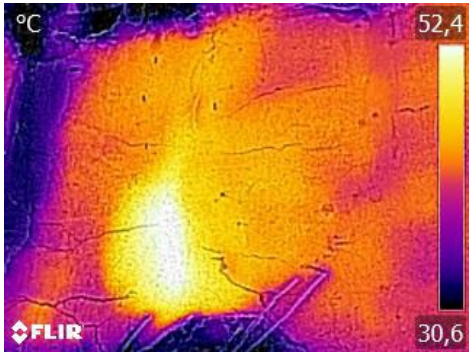


CONCEPT OF AIRPLANE INSPECTION

ARGUS 107

INSPECTION of Other structures: concrete bridge (visible, IR - passive)

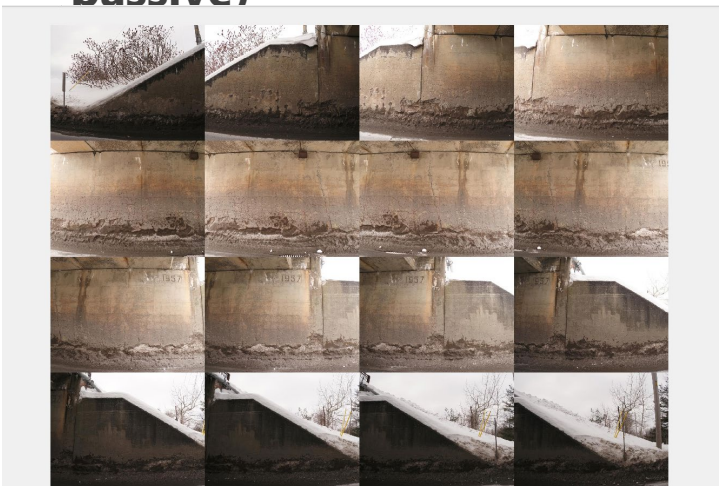
visible



infrared

Concrete bridge

INSPECTION of Other structures: concrete bridge (visible, IR - passive)



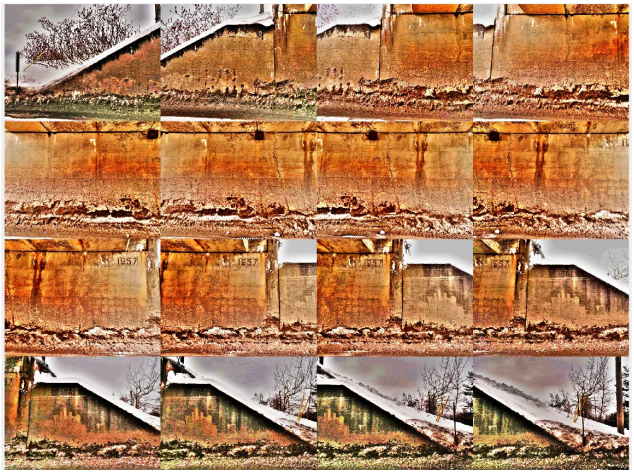
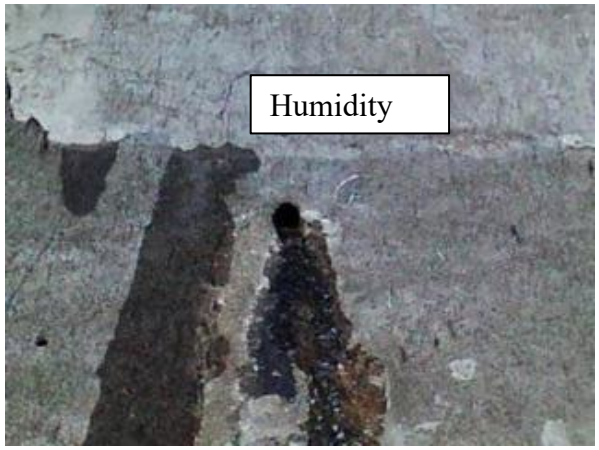


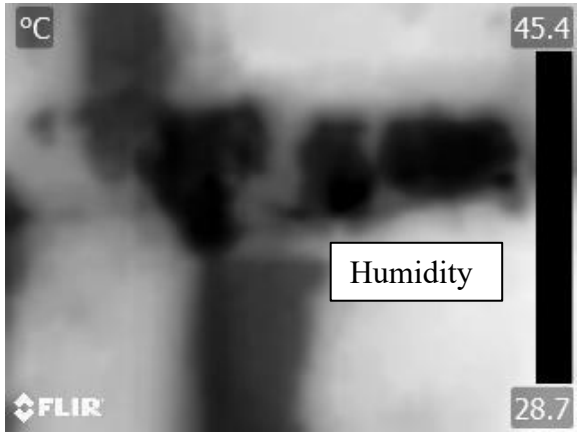
Image stitching & registrating

INSPECTION of Other structures: concrete bridge (visible, IR - passive)



Visible images

Other possible defects: cracks, spalling, etc.

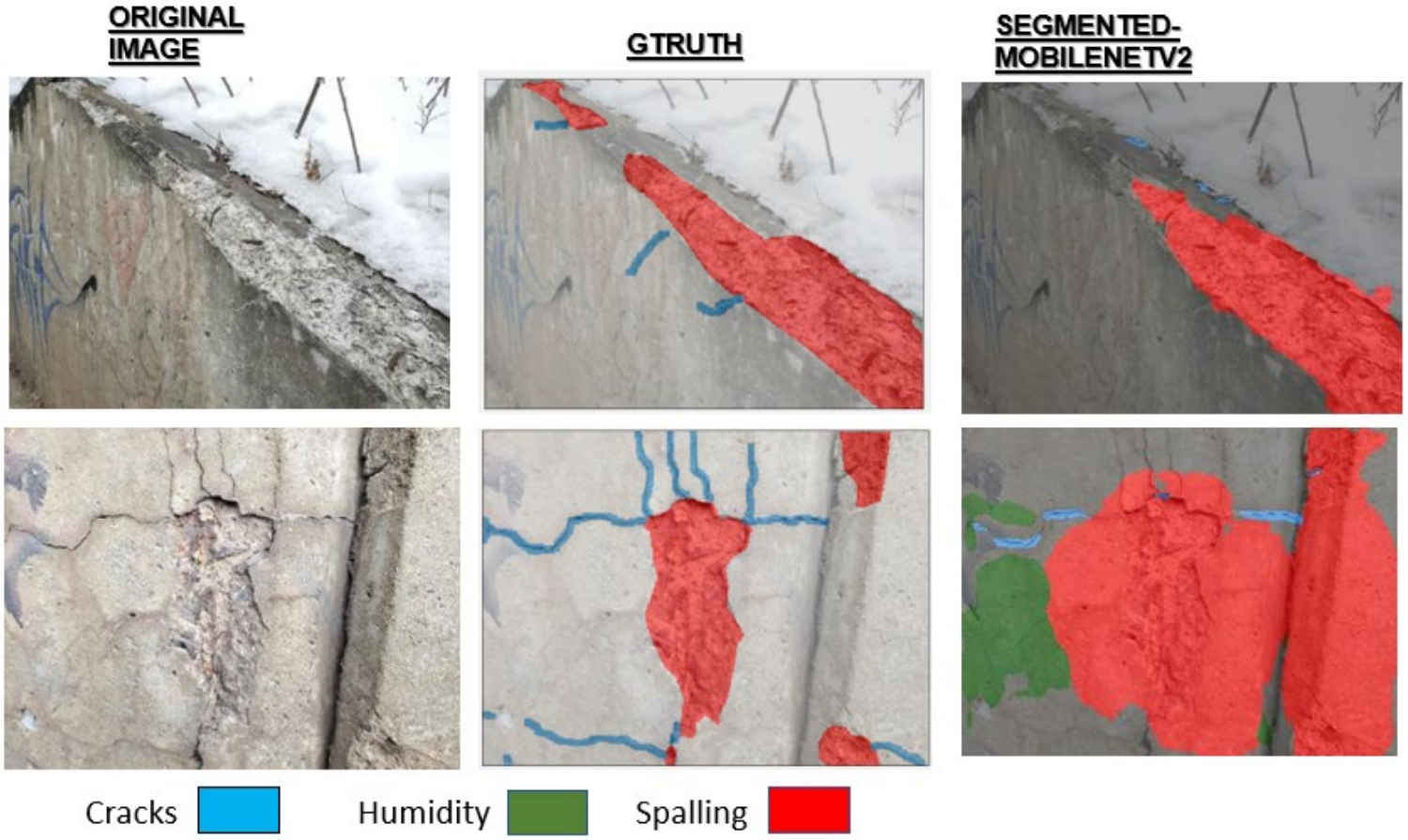


Thermal images

INSPECTION of Other structures: concrete bridge (visible, IR - passive)

QUALITATIVE RESULTS – VISIBLE IMAGES

DEEP LEARNING MODEL – visible only



INSPECTION of Other structures: concrete bridge (visible, IR - passive)

Data fusion: hypothesis better diagnosis possible

Work on progress!

INSPECTION of Other structures: wind turbine blade (visible, IR - passive)

Wind blade

INSPECTION of Other structures: turbine wind blade (visible, IR-active)

Wind blade

Conclusion

- Drone inspection brings many opportunities for inspection of large structures
- Visible, thermal infrared passive & active have been discussed
- There are still many challenges to extract all useful information from available data: AI could be an approach

* * *

ACKNOWLEDGEMENT

THANKS

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NSERC CRSNG

Cranfield University

TORNGATS
Technical Services

map air

NSERC CREATE
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serving industry

BI Expertise

THANK YOU FOR LISTENING!

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