Flying Hand

Aerial Manipulator for Non Destructive Testing

TEAM C



Advisors

Dimitrios Apostolopoulos
John Dolan

Sponsors

Sebastian Scherer

Guanya Shi

Team Members



Shubham Saboo



Weerachai Sangiumpaisankij



Shubha Tanaya



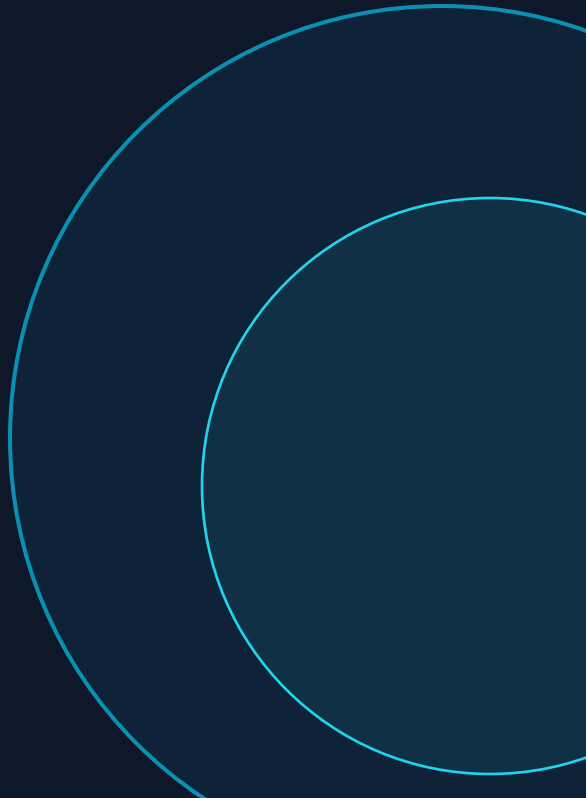
Chenyang Mao



Shunxuan Wang

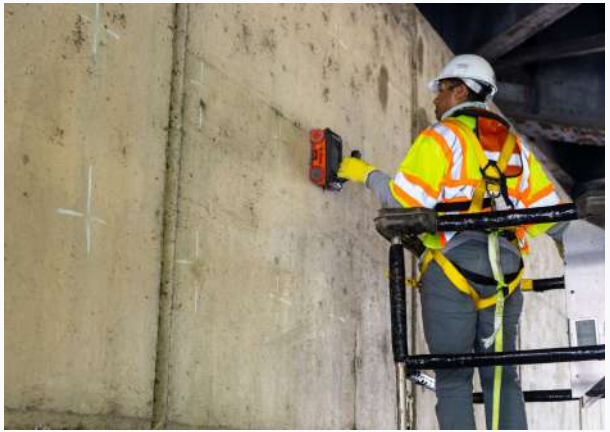
01

Project Description



Background







Non-Destructive Testing (NDT) is critical for preventive maintenance, yet conventional inspections face costly downtime, accessibility challenges, and safety risks.

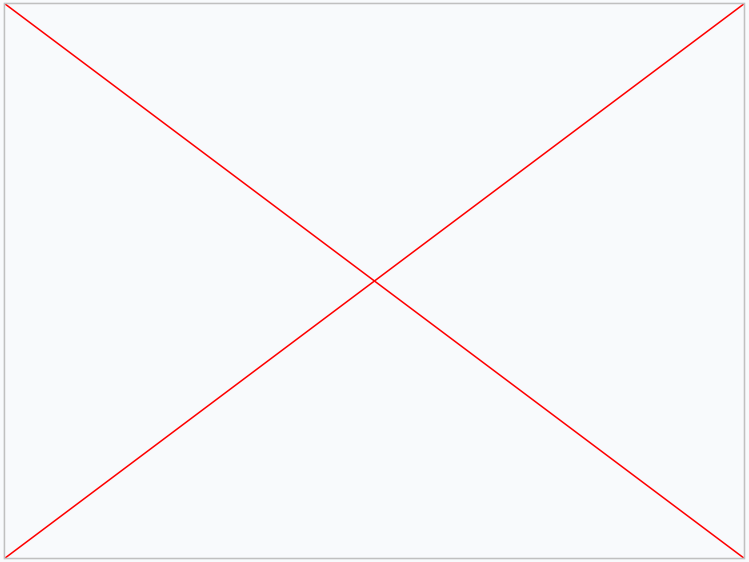
***Flying Hand** addresses these challenges through an aerial manipulator designed for safe, precise, and efficient contact-based NDT inspections of hard-to-reach infrastructure.*

Use Case

An industrial maintenance team deploys **Flying Hand** to inspect elevated or hard-to-reach infrastructure without disrupting operations.

The aerial platform approaches the target surface, while its onboard robotic manipulator positions an NDT probe for contact-based inspection.

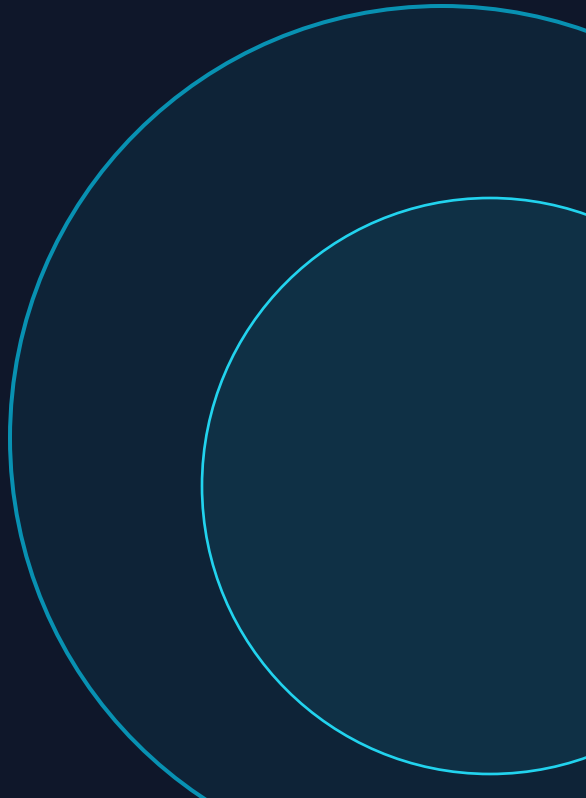
Inspection data is relayed to the operator, enabling early defect detection and timely maintenance decisions.



Our Solution



02
Requirements Modification



Functional Requirements

The Flying Hand SHALL

- Sense the environment
- Localize itself
- Localize POI (Point of Interest)
- Plan the drone's path
- Fly to the AOI (Area of Interest)
- Hover stably
- Detect POI precisely

- Plan the arm's motion
- Manipulate the end-effector
- Contact asset surface ~~Perform NDT~~
- ~~Store/Relay sensor information~~
- Provide real-time visual feedback to the operator
- Execute a fail-safe response upon loss of communication

Performance Requirements

The Flying Hand WILL

- **Sense** the environment in the range of **0.5-4 m** away from itself
- **Localize** itself within **10 cm** of true position
- **Navigate** the environment at the maximum speed of **1 m/s**
- **Detect** POI from the distance of at least **2.5m**
- **Communicate** with maximum latency in **100ms**
- **Sample** NDT data at **5** waypoints in a single flight
- **Maintain** end-effector positioning accuracy of **±0.15 m** during optimal operation
- **Maintain** position hold under **wind speeds up to 3 m/s**
- **Execute** fail safe response within **1 s** of communication loss
- **Maintain** consistent surface contact for **3 s**

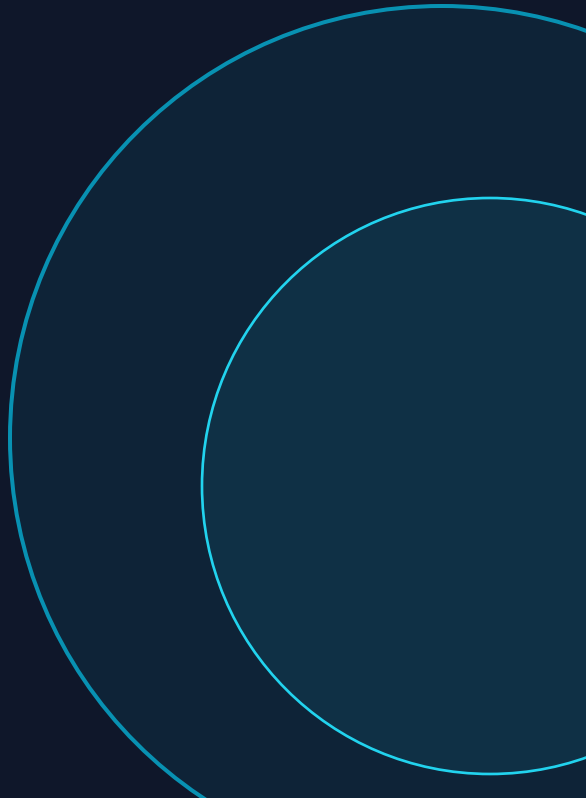
Non-functional Requirements

The Flying Hand WILL

- **Be modular** (Quick probe replacement or end-effector module exchange)
- **Be lightweight** (Total take-off mass will no more than 15 kg)
- **Be easy to use** (Trained operator can plan the mission quickly)
- ~~**Convey actionable information** (Store NDT data in standard formats)~~
- **Be compact** (The system's size will be small for transportation)
- **Be adaptable to environment** (Operate in temperature from −5°C to +40°C & humidity upto 95%)

03

Current System Status



Overall System



Tilted Rotors

CubeOrange
(Flight Controller)

Jetson Orin Nano
(Onboard Computer)

RealSense (VIO)

RealSense (IBVS)

6DoF Arm

NDT Sensor

Hardware (UAV & Manipulator)

Development

- Design & Fabrication 6DOF arm mount and battery mount
- SO-101 6 DOF robot arm (Leader + Follower) Assembly
- Solving rotor failures:
  - Replacement of 2 motor+ESC pair
  - New PWM wire harness
  - Misc. hardware repair (due to crash)

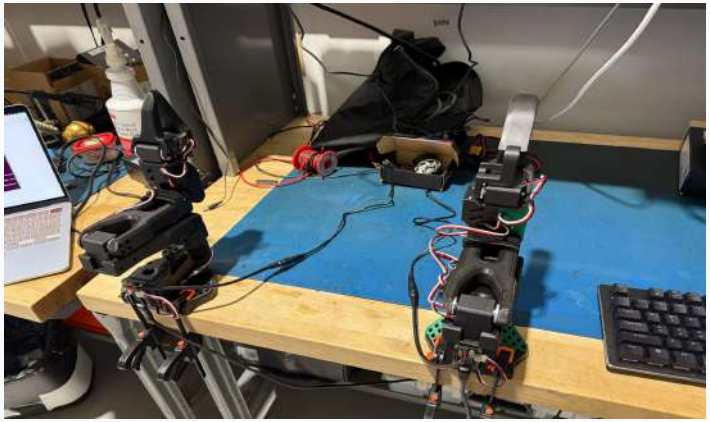


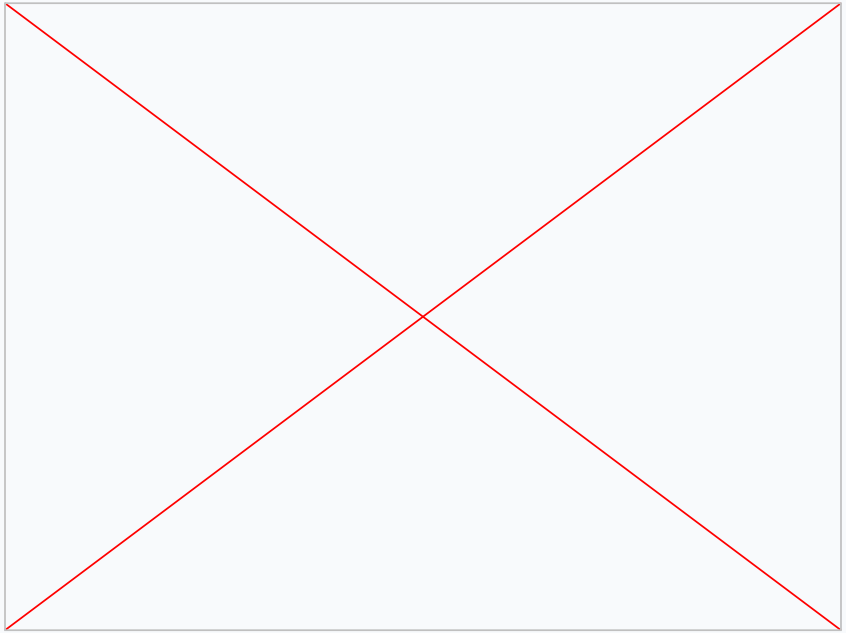


Hardware (UAV & Manipulator)

Current Functionality

- Airworthy UAV platform
- 6 DOF arm ready for IBVS and surface contact





Hardware (UAV & Manipulator)

FVD Functionality

- Fully-actuated UAV
- Stable hover during manipulation:
  - 6 DOF arm mounted on the drone and balanced COG
  - Well tuned position controller for dynamic movement of the arm

Challenge

- Structural rigidity of the mount and vibrations
- Safely test flight stability during dynamic motions of the arm (Hang & Fly?)

Localization: VIO

FVD Functionality

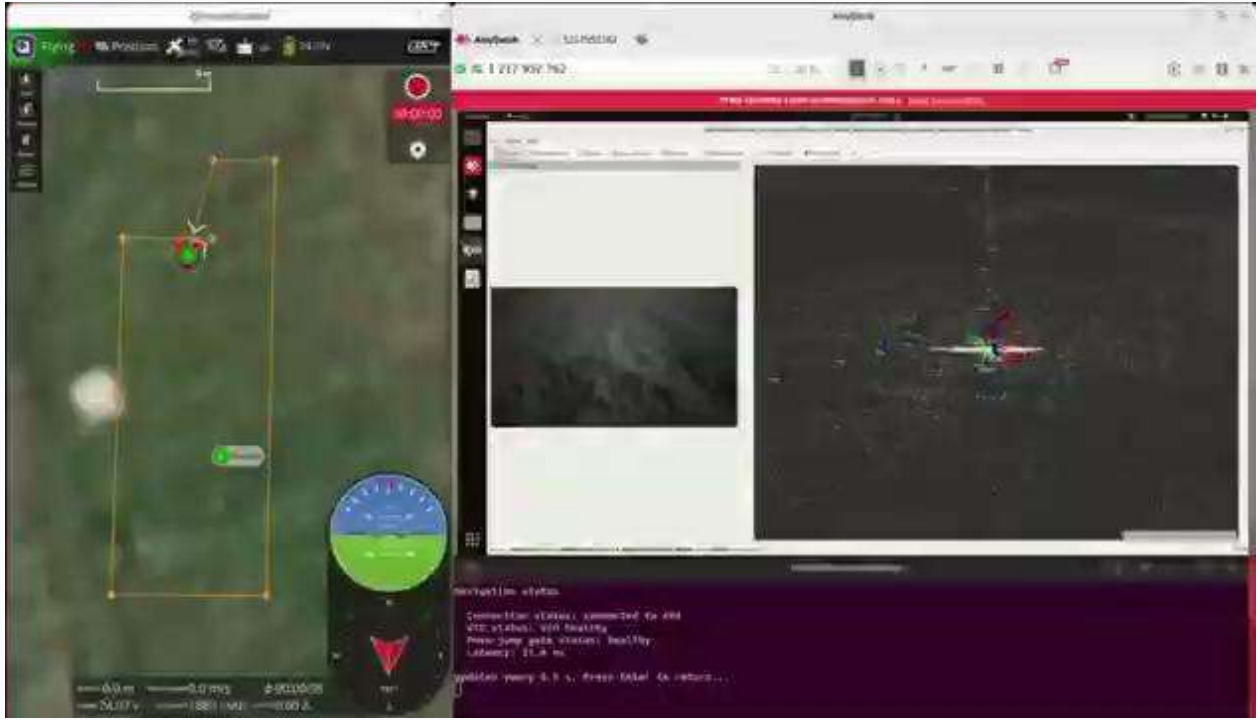
- Determine the drone's position (Globally)
- Enable flight path planning.
- Enable the drone to navigate to the Area of Interest (AOI).
- Enable the drone to maintain a stable hover.

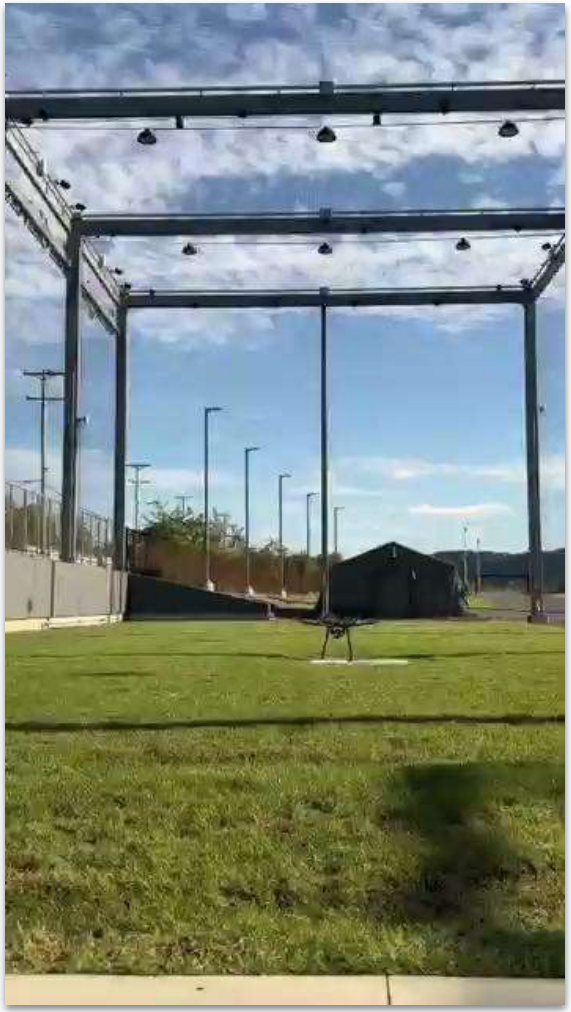
Current Functionality

- Able to determine the drone's position (Globally)
- Able to enable flight path planning.
- Able to enable the drone to navigate to the Area of Interest (AOI).
- Able to enable the drone to maintain a stable hover.

Localization: VIO

Current Functionality





Localization: VIO

Development

Model : HIL-GPS interface on PX4

Local position data from cuVSLAM is converted into GPS-compatible data through the GPS bridge and transmitted to PX4 via Hardware-in-the-Loop (HIL) GPS interface.. This interface automatically establish a global reference frame which enable autonomous mode like Guided, Mission, RTL and allow us to utilize built-in GPS failsafe functionality

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Localization: VIO

Challenge

- Heading drift due to Magnetic Interference (Solved)
- Localization hand-off policy during the pose jump period (In Review)
- Mounting camera backward due to space constraint (In Progress)
- Performing accuracy test against RTK measurement
    - Find solution to reduce interference within Drone Cage @RIC
    - Obtain Part 107 to conduct a flight at other locations.

IBVS-based Manipulation

Development

- Assembled and calibrated the SO-101 robotic arm.
- Developed leader-follower teleoperation & integrated vision-based target detection.
- Implemented visual servoing, collision avoidance, and safe shutdown.



IBVS-based Manipulation

Current Functionality

- Detects and tracks multiple targets with persistent IDs.
- Performs target localization and IK-based visual servoing.
- Supports teleoperation, collision avoidance, and safe shutdown.





IBVS-based Manipulation

FVD Functionality

- Robust multi-target tracking and operator-based selection.
- Accurate visual servoing with perpendicular wall contact.
- Integrated teleoperation, collision avoidance, and safe shutdown.
- Stable aerial manipulation after drone integration.

Challenge

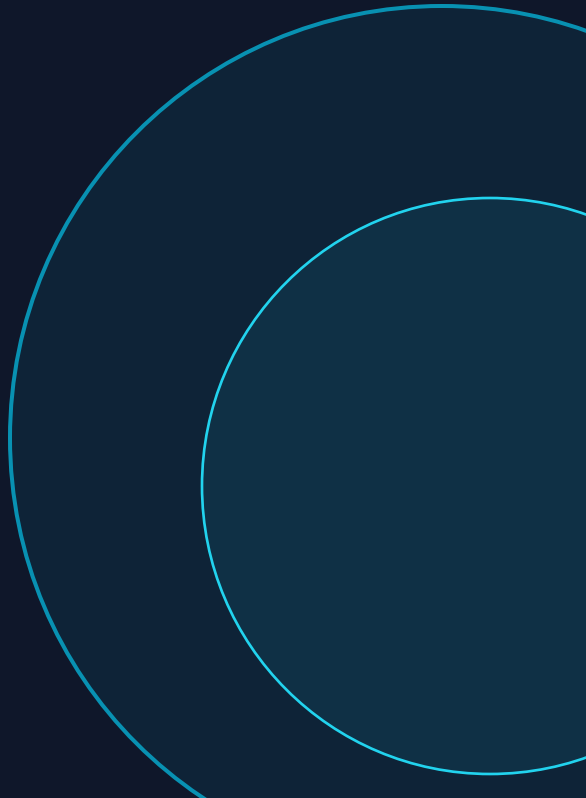
- Contact Accuracy: Design end-effector for perpendicular wall contact.
- Perception: Improve target detection and tracking robustness.
- Integration: Integrate UI, teleoperation, and visual servoing.
- Flight Stability: Maintain stable flight during arm motion and contact.

Major Remaining Challenges

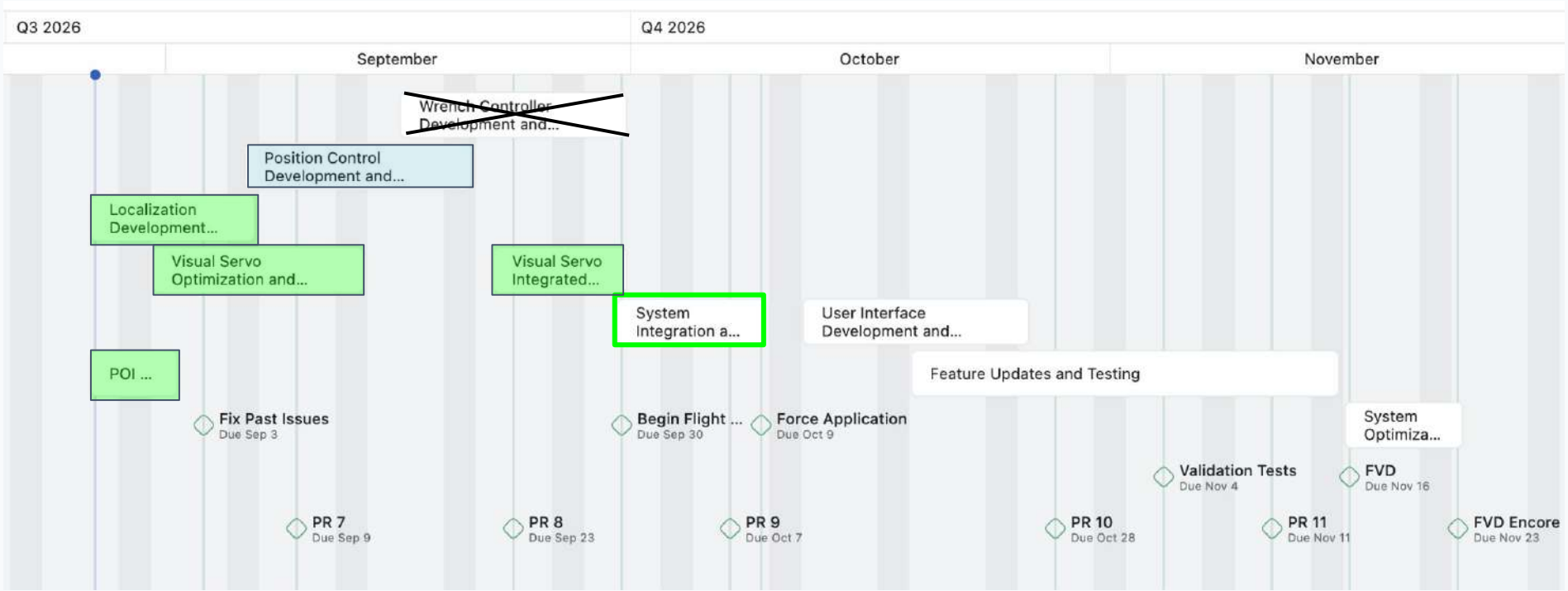
- **Contact-Based Manipulation:** Ensure precise, collision-free wall contact.
- **Robust Visual Servoing in the air:** Improve target tracking and control accuracy.
- **Aerial Integration:** Maintain flight stability and manipulator functionality after mounting the arm on the drone.

04

Project Management



Schedule Status



Fall Test Plan

Test ID	Test Title	Test Description	Finish Before
T19	Singularity & IBVS Robustness Test	Verify that image-based visual servoing (IBVS) control remains stable near kinematic singularities and does not generate excessively large or divergent joint commands.	28-Oct **PR 10**
T21	End-to-End Autonomous Manipulation Test	Verify the full autonomous manipulation pipeline — from visual input through IBVS, kinematics, safety/planning, and actuator commands — to ensure the manipulator can reliably reach and make contact with target points on a real surface.	11-Nov **PR 11**
T22	Fall Validation Demonstration (FVD)	Demonstrate end-to-end readiness of the Flying Hand system: the UAV is manually flown to an Area of Interest, the manipulator autonomously contacts multiple points on a planar target surface, control is then switched to teleoperation via the leader arm to contact additional points, and the UAV is manually flown back to the launch point.	16-Nov **FVD**

Fall Validation Demo

Location	Mill 19 Area / RIC Drone cage
Equipment	Full Flying Hand platform (manipulator, camera, IBVS stack) Leader-arm teleoperation station Ground Control Station / laptop mock industrial asset/panel with multiple marked target points

Procedure

1. Pilot performs pre-flight checks and manually **pilots the UAV to a stable hover position near the target** panel (Area of Interest).
2. With the UAV holding position, the system **autonomously detects and sequentially contacts multiple marked target points** on the panel using the IBVS-guided manipulator pipeline..
3. Operator **switches the manipulator to teleoperation mode** via the leader arm.
4. Operator teleoperates the manipulator to sequentially reach and contact **additional marked target points** on the panel.
5. Once both the autonomous and teleoperated manipulation phases are complete, the pilot manually flies the UAV **back** to the launch point and lands.

Fall Validation Demo

Verification Criteria

1. The manipulator autonomously contacts **at least 3 target points** on the panel, each **within a 4 cm radius**.
2. The mode **switch** from autonomous to teleoperated control is completed smoothly **within 1 second**, without loss of contact-force control or unsafe motion.
3. **No collisions, joint-limit violations, or safety failsafe triggers** occur throughout the demonstration.
4. The UAV is safely flown back to the launch point manually, **landing within 1 meter of the target**, without incident.

Budget

Core Expenses

No.	Date	Part Name	Quantity	Price
#3	02/23/26	Eolo Carbon Fiber Reinforced Nylon UAV Propellers	6	$107.94
#4	02/23/26	Holybro H-Flow Optical Flow and Distance Sensor Module	1	$145
#5	03/21/26	Calibrated Capacitive Force Sensor	1	$135.95
#29	03/24/26	12000mAh 22.2V 6S 20C Lipo Battery	4	$399.96
#33	04/01/26	RM3100 Compass	1	$79.9
#35	04/08/26	RC Series 10000mAh 22.2V 6S 100C Lipo Battery	2	$305.98
#37	03/09/26	LeRobot Arm SO-101 Servo Motor Kit	1	$277.79

Total Expenses: $2672.5 / $5000









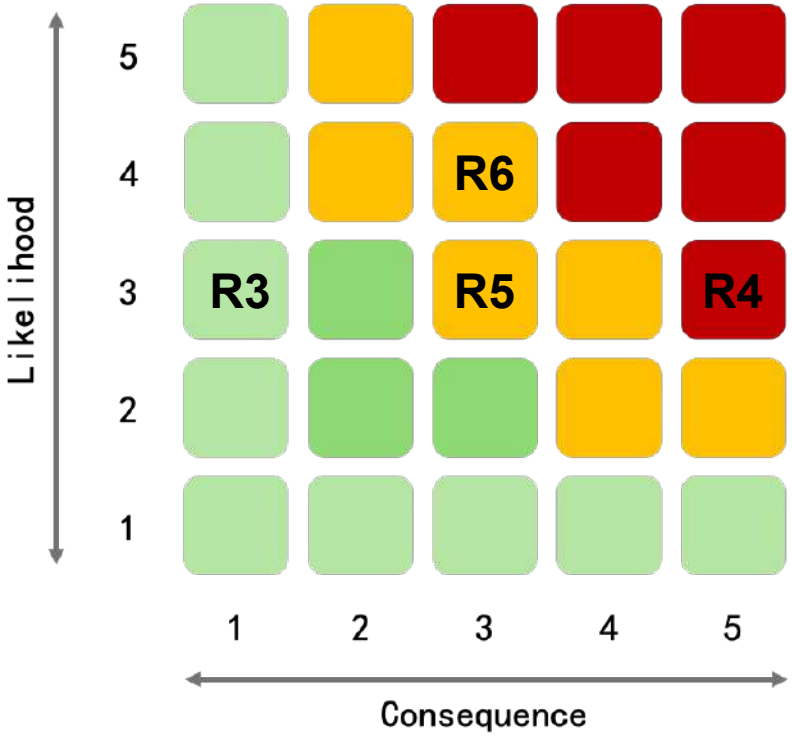
Risk Management

Risk ID	Risk Description	Old Likelihood	Old Impact	Mitigation	Updated Likelihood	Updated Impact
R1	Inability to make PX4 EKF trust the VIO estimates	2	4	Fusion of multi-sensor data, including IMU, achieved robust performance	0	0
R2	F/T sensor is broken	1	5	Test early and have piezoelectric as a backup option	5	0
R3	Insufficient Advisor Guidance	5	2	Establish connections with partner labs & Mohammad	3	1
R4	Drone Crash	3	5	Pre-Check and safety facility	3	5

Risk Management

Risk ID	Risk Description	Old Likelihood	Old Impact	Mitigation	Updated Likelihood	Updated Impact
R5	End-effector Design Decision			Determine the FVD site as early as possible and conduct detailed research and discussions.	3	3
R6	Insufficient platform stability			Optimize the localization algorithm; improve the response speed of the arm's tracking	3	4

Risk Management



- R1- Inability to make PX4 EKF trust the VIO estimates
- R2- F/T sensor is broken
- **R3- Insufficient Advisor Guidance**
- **R5- End-effector Design Decision**
- **R6- Insufficient platform stability**
- **R4- Drone Crash**

Thank You!

TEAM C



