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Integrated Flight and Payload Control for Directional Payloads on UAVs

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1 Notation

B	Earth to body axes transformation matrix
$\mathbf{F}$	body axes force vector
$\mathbf{g}$	gravity vector
$\mathbf{H}_P$	engine/propeller angular momentum
J	inertia matrix
m	aircraft mass
$\mathbf{p}$	Earth axes position vector
$\mathbf{T}$	body axes torque vector
$\mathbf{v}$	body axes velocity vector
$\mathbf{\Phi}$	Euler angle vector
Ω	angular rate cross product matrix
ω	body axes angular rate vector
$\mathcal{E}(\mathbf{\Phi})$	Euler angle update matrix
$\dot{x}$	derivative of x with respect to time
J^{-1}	the inverse of the matrix J

2 Introduction

Research into autonomous Unmanned Aerial Vehicles (UAVs) has been underway for many years. The availability of reliable and low-cost global satellite navigation and communications has brought the arrival of these vehicles one step closer. It is anticipated that by removing the pilot from the aircraft a significant reduction in operating costs can be achieved. Autonomous UAVs are expected to replace manned aircraft used for long endurance or hazardous missions. Maritime search and coastal surveillance are examples of long endurance missions which are particularly relevant to Australia.(1) In these applications the UAV would be searching for an object such as a ship in a large area of ocean.

The UAV payload for these search missions could consist of a radar and a camera. The radar enables searches of large areas of ocean to be made. The results of radar searches would be monitored by the mission management software which provides high level planning and decision-making for the UAV. (2),(3) The mission management software would initiate further investigation of radar contacts in the search for the mission objective. This investigation would involve the use of the UAV's camera.

In order for the UAV to perform it's mission, communication between the mission management software and the payload sensor systems is necessary. The UAV trajectory must allow the payload sensors to effectively perform their task. The use of directional payloads such as cameras requires that the UAV manoeuvre to keep the object in the sensor's field of view. A similar problem has been considered for a camera with only a single degree of rotational freedom.(4)

This paper introduces an Integrated Payload and Flight Control System (IPFCS) which is intended to coordinate the UAV flight and sensors to enable an autonomous UAV to perform it's mission.

The purpose and functionality of the IPFCS will be discussed. The method to be used in the development of the system will be explained, and a description of the simulation will be given.

In the following sections the object of the mission will be referred to as the target of the payload sensor.

3 Integrated Flight and Payload Control

3.1 Purpose

The purpose of the IPFCS is to provide the capability for the aircraft and the payload gimbal system to be driven in a coordinated way such that the target remains in the field of view of the sensor.

Similar integrated systems have previously been considered in. (5)–(8)

3.2 Context

In an autonomous UAV, the top level processing and decisions concerning the conduct of the mission are made by the Mission Management software. At the lowest level of the control system are the closed loop systems which drive the control actuators and gimbals to their demanded positions. The control system can be viewed as a hierarchical structure with a different computational method suitable for each level. (9) Figure 1 shows how the IPFCS interfaces to other UAV

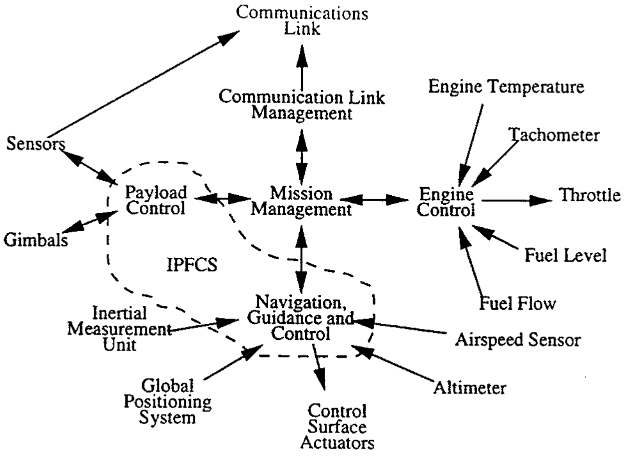

Figure 1: Context Diagram

systems.

Payload control has guidance and control components. In this paper guidance will be taken to mean the process of determining the path to be followed to move between two points. Control of motors and actuators (as opposed to the control of a system) will mean the generation of drive signals to cause a particular path to be followed. The guidance component of the IPFCS generates position demands for each gimbal. The control component converts the guidance demands into drive signals for the gimbal motors.

3.3 Functionality

The IPFCS will perform the following functions:

1. UAV navigation, guidance and control,
2. Payload stabilisation,
3. Payload guidance and control,
4. Target tracking and prediction, and
5. UAV trajectory generation.

The UAV navigation and control, and the payload stabilisation will be essentially the same as in current aircraft systems. The UAV guidance function will have a new mode which accepts aircraft position and attitude demands from the trajectory generation module. The payload guidance and control module will have interfaces to the target tracking and prediction, trajectory generation and UAV navigation, guidance and control modules (Figure 2).

In addition to common autopilot stabilisation and control modes, the integrated system will provide the following automatic modes:

1. Wide area search,
2. Linear search,
3. Point observation,

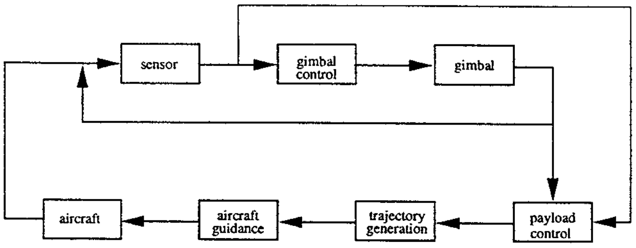

Figure 2: IPFCS Block Diagram

4. Moving ground target observation, and
5. Moving airborne target observation.

The search modes will coordinate the UAV trajectory with the payload gimbal motion to view an area while minimising some criteria such as search time. (10) The observation modes will use the UAV trajectory and gimbal motion to continuously view a target. The target may be either moving or stationary, and airborne or on the Earth's surface.

4 Method of Approach

4.1 General

The IPFCS will be developed using a computer simulation of the aircraft, sensor, gimbals and control system. Various control methodologies and trajectory planning methods will be investigated. Combinations of control systems and trajectory planning algorithms will be tested.

4.2 Payload Control System

Various implementations of the payload control system will be developed. Each implementation will use a different control system methodology. The following methodologies will be considered:

1. Classical,
2. Fuzzy logic, and
3. Robust control.

4.3 Trajectory Planning

Methods which will be considered for trajectory generation include dynamic interpolation and goal programming. (11),(12)

4.4 Performance Measurement

The most effective control system and trajectory planning algorithm pair will be determined by quantifying the performance of each combination. Metrics for performance measurement include:

Figure 3: Ariel UAV

1. The amount of time spent within a certain range of the target
2. The amount of time required to search a specified area
3. The amount of computer time required for the algorithms to execute.

5 Simulation Overview

5.1 Axis Systems

The axis systems to be used are:

1. Inertial Earth axes,
2. UAV body axes,
3. (Outer) Gimbal axes, and
4. Sensor axes.

A flat Earth is assumed in the model.

5.2 UAV Platform

The UAV used in this simulation is the Ariel RPV (Figure 3) developed by the Department of Aeronautical Engineering at the University of Sydney. The Ariel is a high wing, twin tail-boom configuration with a pusher propeller engine. The payload is carried in the nose section of the aircraft.

A nonlinear six degree of freedom simulation model of the vehicle was written.$^{(13)}$ The aircraft is assumed to be rigid. The equations of motion are:

$$\dot{\mathbf{v}} = \frac{1}{m}\mathbf{F} - \Omega\mathbf{v} + B\mathbf{g}$$

$$\dot{\omega} = J^{-1}\mathbf{T} - J^{-1}\dot{\mathbf{H}}_P - J^{-1}\Omega J\omega - J^{-1}\Omega\mathbf{H}_P$$

$$\dot{\mathbf{\Phi}} = \mathcal{E}(\mathbf{\Phi})\omega$$

$$\dot{\mathbf{p}} = B^{-1}\mathbf{v}$$

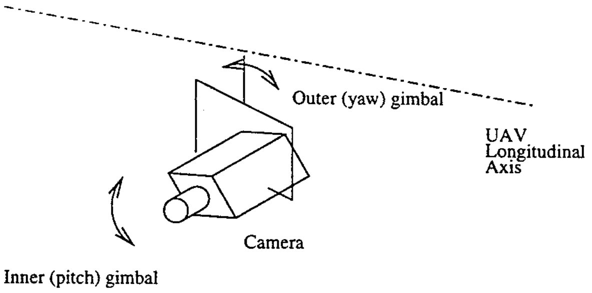

Figure 4: Two Axis Gimbal with Camera

where $\Omega = \begin{bmatrix} 0 & -R & Q \\ R & 0 & -P \\ -Q & P & 0 \end{bmatrix}$

and $\mathcal{E}(\mathbf{\Phi}) = \begin{bmatrix} 1 & \tan\theta\sin\phi & \tan\theta\cos\phi \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix}$

5.3 Sensor

The UAV payload will be assumed to be a directional sensor suite consisting of an imaging sensor and a range finder. The directional payload will be used by the UAV for detailed investigation of the target. It could be realised as a video camera and a laser range finder. Control of the camera focal length will be necessary to adjust the field of view. The effects of error sources in the sensor system will be modelled.

5.4 Gimbal System

Gimbal systems are used to support the sensors and provide them with rotational freedom of movement. Rotational motion is usually provided about either two, three or four axes. A two axis gimbal system was selected as a compromise between sensor field of regard and weight and complexity in the UAV. The gimbal response will initially be modelled as a first order system in the simulation.

The integrated control system will be simulated with the gimbals mounted below the fuselage and in the nose of the aircraft. In both cases the rotational axis of the outer gimbal will be parallel to the UAV yaw axis, and the inner gimbal will provide pitch motion. A schematic diagram is shown in Figure 4.

The mechanical and electrical design of a gimbal-system is underway at RMIT. A more detailed model based on this design will be incorporated in the simulation when it is available.

5.5 Sensor Stabilisation

The sensor must be stabilised to ensure that the sensor output is not affected by the motion of the sensor or it's platform. Stabilisation will not be modelled in detail, however some techniques have been investigated.

Possible methods for sensor stabilisation include field of view shifting, gimbal stabilisation, and a moving lens system. (14)

Field of view shifting involves displaying an area around the target image and translating that area to remove the effects of UAV and sensor motion. Gimbal stabilisation measures the disturbances in motion at the sensor and applies drive signals to the gimbal actuators to counter the disturbances. The moving lens system adjusts the attitude of a lens in front of the sensor to compensate for disturbances.

The effect of disturbances on the sensor will be modelled.

5.6 Image Processing

Image processing will be considered to be a black box and will not be modelled in detail. It will be assumed to contain a frame store and an image recognition and processing system. The image processing module will take the camera image as an input, and output the target coordinates in the sensor axis system.

5.7 Target Tracking and Estimation

Target tracking and estimation will be used to provide predictions of the target's position. Initially the target predictions will be simple extrapolations of the observed trajectory. More advanced tracking algorithms such as a Kalman filter may be substituted later in the project. A Kalman filter which models both the target and the error sources within the UAV sensor system could remove the effects of disturbances.

5.8 Payload Control

The payload control block will receive target coordinates from the tracking and estimation module and payload gimbal rates and positions. As the gimbals approach their limits of movement, the payload control block signals the aircraft guidance module that changes to the flight path are necessary. The payload control block as it is shown in Figure 2 includes the image processing and target tracking and estimation blocks.

5.9 Trajectory Planning

The trajectory planning block performs a guidance function for the UAV. It generates trajectory demands which the autopilot converts into control surface actuator demands. It is necessary for the trajectory planning block to know the range of motion of the gimbal system to ensure that the target remains in the field of view of the sensor.

5.10 Autopilot

An autopilot for the Ariel developed by the University of Sydney will be used. The autopilot will be modified to include additional modes as required by the IPFCS. These modes will accept flight demands in the form of position and attitude waypoints $(x, y, z, \phi, \theta, \psi, t)$ from the trajectory planning block.

5.11 Target

The target will be modelled as a point which moves between four-dimensional way-points (x, y, z, t). The target position and time between the way-points will be calculated by linear interpolation. It will be given dimensions to enable the size in the sensor image to be determined.

6 Conclusion

The purpose and functionality of an Integrated Payload and Flight Control System for directional payloads on UAVs has been shown. The IPFCS will be an important component in building an autonomous UAV. The proposed development method has been outlined, and a description of the simulated system has been given.

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