# Comparing Visual Cues Necessary for Inner- and Outer-Loop Control

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(Topic Area: Perceptual issues in remote control of UAVs)

The remote control of unmanned aerial vehicles encompasses a wide variety of control levels, from completely manual "stick-and-rudder" (or, more likely, joystick and finger lever) to supervisory control of automated UAVs flying in formation. Our presentation will focus on the first situation; specifically, where the operator is manually controlling the UAV primarily based on a video image that substitutes for a pilot's out-the-window (OTW) view.

A video image (which may consist of visible light, IR, amplified light, or fused imagery) differs from the OTW scene in many respects. Even the most "natural" of video analog (i.e., daylight clear-weather video imagery) differs from direct vision in terms of field-of-view (FOV), field-of-regard (FOR), dynamic range, and spatial/temporal resolution. If the video image is to serve as an integral part of the UAV operator's instrument suite, designers must ensure that the image contains the information necessary to perform the control task.

Most flight vehicle control tasks can be characterized as multiloop. That is, the human operator closes successive loops of reducing bandwidths. For example, altitude control of a fixed-winged aircraft in cruise can be described as consisting of three successive loop closures: 1) the pilot controls the pitch attitude through the stick or control column, 2) the pitch change causes an increase or decrease in vertical velocity, and 3) a change in altitude (vertical position) occurs. Within this characterization, it is useful to distinguish between inner-loop and outer-loop control. For most flight vehicle systems, inner-loop generally describes the pilot's control of vehicle attitude and attitude rate; outer-loop refers to the pilot's control of position and velocity. In the airplane example, pitch rate and pitch attitude constitute the inner-loop states, and vertical velocity and altitude constitute the outer-loop states.

Often, the image characteristics necessary for inner- and outer-loop control create conflicting design requirements for the UAV operator's display. For example, outer-loop control requires a relatively large FOV and FOR. However, given the transmission bandwidth limitations common to UAV operations, filling a large FOV display compromises the spatial and/or temporal resolution of that display. This, in turn, degrades the image characteristics critical for inner-loop control.

We will provide examples from simulation studies that examined FOV, collimation, scene texture, resolution, and update rate on pilot performance (specifically, characteristics that support inner-loop and outer-loop control). Our methods guide the selection of image characteristics appropriate to the flight task. A design can then be chosen (or a display can be designed to dynamically adapt) to the task-specific requirements. Further, we will discuss the roles of two additional design options: the display of additional instrumentation sources (which can serve to provide information inherently lost in the OTW to video-image transition); and augmentation of vehicle dynamics (which can alter the nature of the control task to one compatible with the image characteristics).