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AN INFORMAL ANALYSIS OF FLIGHT CONTROL TASKS

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An important theme of this workshop has been to bring together experts from several different domains to discuss issues important in rotorcraft flight control. The experts have come from several different domains including psychophysics, control theory, human factors, and engineering. One goal of this workshop was to use interactions among the experts in these different domains as a way to understand problems in flight control. While the majority of these interactions, in my opinion, have been successful I believe that the workshop as a whole focussed to much on the specifics and may have missed the big picture of how these different areas are relevant to flight control. In this paper I will suggest a perceptual description of what I believe to be the major issues in flight control. Although this opinion will be from the viewpoint of a psychophysicist I hope that it captures the importance of some the issues from other research domains represented by others who attended the workshop.

When one considers the task of a pilot controlling a helicopter in flight, we can decompose the task in several subtasks. These subtasks include (1) the control of altitude, (2) the control of speed, (3) the control of heading, (4) the control of orientation, (5) the control of flight over obstacles, and (6) the control of flight to specified positions in the world. The first four subtasks can be considered to be primary control tasks as they are not dependent on any other subtask. However, the latter two subtasks can be considered hierarchical tasks as they are dependent on other subtasks. For example, we can decompose the task of flight control over obstacles as a task requiring the control of speed, altitude, and heading. Thus, incorrect control of altitude should result in poor control of flight over an obstacle.

The following sections will discuss each of these task separately. Within this context the importance of possible perceptual information will be discussed.

1. The control of altitude.

Of all the tasks outlined above the control of altitude is one which has received the greatest empirical investigation as a flight control task. Warren has proposed that splay rate (the change in the angle formed by meridian lines converging at the horizon) is a useful source of information whereas Owen has proposed that edge rate (the number of texture elements that pass a specific location in the visual field) is a useful source of information. It is important to note that the effectiveness of these sources of information are dependent on specific constraints present in the world. Specifically, splay rate is only useful if the meridian lines are parallel in the world. Edge rate requires that texture elements be stochastically distributed evenly in the world. While the effectiveness of these sources of information have been investigated in several studies, it is important to realize that they also require that the world be flat and rigid. It is likely that for flight control over varying terrain

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other sources of information, such as the slant of surfaces, the speed of translation, or the absolute distances between the aircraft and points in the world be recovered.

2. The control of speed.

The control of speed is another task that has been studied extensively. The sources of information that have been investigated for this task are edge rate and global optic flow rate. Again, it is important to note that the use of these sources will only be effective if the simulated world is flat and rigid. For flight control over varying terrain it may be necessary to recover information for determining altitude, slant of surfaces, and absolute distances to points in the world.

3. The control of heading.

There are two sources of information that have been proposed to be useful for the control of heading--the focus of expansion (or the point of maximum divergence) and differential motion parallax. Gibson was the first to suggest the usefulness of the focus of expansion and this has resulted in many computational analyses (Lee, Perrone, Koenderink) which use this source to extract out other characteristics of the environment (e.g. relative depth and time to contact). Differential motion parallax (the different rates of velocity of points moving above and below a point of fixation) was proposed by Cutting. A considerable body of research has been conducted to determine what information is used by human observers. Johnston, White and Cummings found that subjects could not determine the focus of expansion for displays simulating motion towards a frontal parallel surface. Warren, found that subjects were accurate in determining heading for displays simulating motion to a ground plane where the direction of looking was decoupled from the direction of motion. Regan and Beverely, found that subjects could not determine the focus of expansion for displays simulating motion towards a frontal parallel surface when a simulated eye fixation was included in the transformation.

However, Reiger and Toet found that subjects could determine direction of heading for displays simulating motion towards frontal parallel surfaces. In their research subjects were quite accurate when the display simulated motion towards two overlapping transparent frontal parallel surfaces that were separated in depth. However subjects were inaccurate when the display contained only a single frontal parallel surface. Finally, work by cutting found that subjects could determine the direction of heading for displays simulating motion through an array of poles that were positioned at varying simulated depths from the observer. Although an initial inspection of the literature would suggest that the results from several studies are contradictory, a closer inspection of these studies suggests an interesting pattern—those studies that failed to find good accuracy involved displays that did not have variations in depth whereas those studies that found good accuracy did involve variations in depth. This suggests that differential motion parallax, which is only effective if the display contains variations in depth, may be the source of information used by human observers.

It is important to note that differential motion parallax and the focus of expansion can only be extracted for rigid worlds. Constraints such as altitude, speed, or absolute distance are not required to use either source of information.

4. Control of orientation.

The control of orientation has traditionally been decomposed into the control of roll (rotation about the line of sight), pitch (rotation about the horizontal axis), and yaw (rotation about the vertical axis). In order to accurately control roll and pitch there are two sources of information that could be used---a change in the direction of the gravitoinertial vector, and a change in the horizon. The direction of the gravitoinertial vector can only be estimated by nonvisual sensory systems such as the vestibular and kinesthetic systems. However, changes in the horizon can be determined by the visual system. In order to control yaw information from the vestibular and visual systems can be used if the rotation involves an acceleration of deceleration.

Another issue of importance for determining changes in orientation is the need to use a frame of reference. A frame of reference (such as the frame in the rod and frame effect) can be viewed as providing information regarding a false horizon.

An alternative way to consider the control of orientation is to describe orientation change as a change in the position of the viewer with respect to the environment. This definition allows us to consider orientation as an issue regarding locomotion in the world as opposed to rotation in the world. I believe this definition is useful as it incorporates navigational issues (such as where am I located on this map) which are extremely important for nap of the earth and low level flight. Inconsistencies between where you think you are when you look out of a cockpit and where you think you are when viewing a map may lead to disorientation.

5. Control of flight over obstacles.

The control of flight over obstacles is an issue that has not received much attention. This is probably a result of the fact that accurate control of flight over obstacles requires the integration of several sources of information. At a minimum it requires information regarding altitude, speed of motion, and heading. In addition, it may require other information such as time to contact, absolute distance to surfaces in the environment, the slant and elevation of the obstacle to be flown over, and the location of the horizon. In many respects these sources of information may be interrelated. For example, a misperception of where the horizon is located may result in a misperception of slant. This could result in a misperception of elevation of the obstacle to be flown over which may have drastic effects on the ability of a pilot to successfully fly a nap of the earth mission.

6. Control of flight to targets.

The control of flight to targets is another type of flight control task that has not received much attention in the literature. There are two versions of this type of flight control that should be considered. One version involves the control of flight to a target that is visible from the outside scene. The second version involves the control of flight to a specific target when the pilot can not see the target in her field of view but has a map which indicates that location of the target in the world.

For the control of flight to a target visible from the outside scene there are several sources of information that the pilot must use. The pilot must determine the difference between the current heading of the helicopter and the desired heading to the target. In addition the pilot must determine the current speed of travel in order to produce an appropriate control adjustment for approach to the target.

For the control of flight to a target not visible in the scene the pilot must navigate such that her current position changes in accordance with a desired location in the world. This task not only requires that the pilot's perceived location in space (from information in the visual world) match the perceived location of the pilot's position on a map but also requires that the pilot correctly determine the relative position of landmarks in the visual scene. Incorrectly perceiving the layout of these landmarks most probably result in poor flight control through these landmarks.

One interesting issue regarding this flight control to a target is whether the pilot must recover the spatial layout of the world in order to successfully perform this task. It may be that all that is necessary to correctly perform this type of task is to recover the spatial layout of the landmarks rather than the spatial layout of the world with the relative position of the landmarks nested in the layout of the world.