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Modeling of the visual approach to landing using neural networks and fuzzy supervisory control [☆]

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ABSTRACT

During the visual approach to landing of a fixed wing aircraft, a human pilot bases control and timing of subsequent maneuvers mainly on the out-the-window view, as there is not sufficient time to read all instruments. The skill of making smooth and soft landings is acquired mainly through experience. Research has been done to identify the most important features in the visual scene (cues) for two phases of the visual approach to landing: glide slope tracking and the flare maneuver. Using simulator and real flight data, neural networks have been trained for both phases to mimic the pilot's control based on the visual cues available. By using the γ operator in neuron transfer functions, a transparent model is obtained. Fuzzy supervisory control is proposed to couple the networks and thus provide insight in the pilot's decision making process with respect to timing the flare initiation.

1. Introduction

The visual approach to landing is generally considered one of the most demanding phases in human pilot control [2]. The combination of high workload, having to interpret the visual scene, timing the initiation of subsequent maneuvers and executing those maneuvers, all with the risks inherent to low-altitude flight, makes this process difficult to learn for new pilots. Real and/or simulated experience is indispensable to obtain and maintain landing skills, and performance feedback is thought to greatly improve learning efficiency [2,23]. However, most pilots cannot explain what they look at or how they make their decisions and even training methods are not consistent.

The research presented in this paper focuses on finding the visual cues a pilot uses, through analysis of scene and flight control data. A method is presented to construct a model of a human pilot which takes visual cues and generates longitudinal control actions during the visual approach to landing. This model is based on numerical data from real or simulated landings by human pilots. The model itself however is merely used to verify correspondence between the real pilot and the model. Of main interest are the structure and parameters of the resulting model, i.e., the driving inputs, internal relations and thresholds, as these give insight in the pilot's (subconscious) behavior.

The knowledge gained from this "reconstruction of the pilot's mind" would be useful in training or evaluation of pilots: if we know how experienced pilots use the available visual cues to make smooth and soft landings, these insights can be taught to trainees. Comparison of behavior between pilots could be helpful to give specific feedback to improve one's performance. It can also help finding out why and when optical illusions arise and how pilots can be trained to recognize or avoid them. Direct application of this knowledge to automatic landing systems may not be meaningful, since accurate state information is abundant within the flight computer, and image processing may not be sufficiently robust to meet safety requirements. Such automatic landing systems could however prove useful for small unmanned aerial vehicles (UAVs) [4] — which have limited positional and state information due to payload restrictions — provided the availability of a camera and microprocessor (which might be on board for specific mission goals anyway). Apart from pilot training and UAV landing systems, there is a wide application for the knowledge of which visual cues pilots use, ranging from cockpit display design and human–machine interaction studies, to enhancing the realism of the important cues in flight simulators.

2. Visual perception during landing

Some of the earliest studies on the visual perception for vehicular guidance[1] are those on ego-motion and motion perspective (optical flow) by Gibson et al. [7] and Gordon [8] in the 1950s and

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[☆] This work has previously been presented at the ICAS 2008 Conference (http://www.icas.org/).

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[1] The problem discussed in this paper is closely related to that of car driving, a skill which is also learned through experience.

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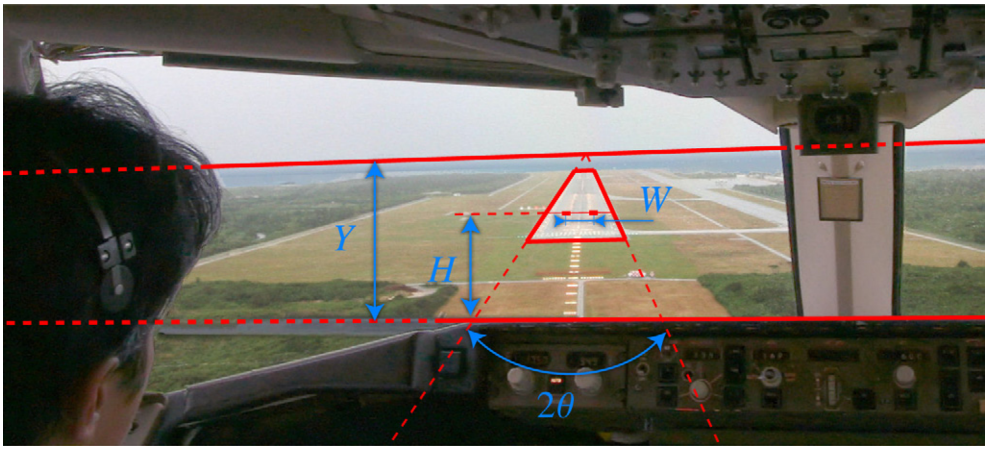

Fig. 1. Definition of visual cue variables. Y and H are the vertical positions of the horizon and the touch down zone markings (TDZM) relative to a fixed location in the aircraft. The implicit horizon is therefore defined by $Y - H$. W is the apparent distance between the TDZM, and thus a cue for distance. θ is the apparent inclination of the runway edge, an altitude cue. τ_θ will be defined as $\theta/\dot{\theta}$, with $\dot{\theta}$ the time derivative of θ.

'60s. Since then several researchers have investigated the way pilots look at the out-the-window scene and a wide variety of visual cues has been suggested for guidance during the final approach to landing.

Apart from general cues such as optical edge- and flow rate and texture [3,5,13], the 'implicit horizon' (distance between the horizon and the aim point, measured in the visual plane; $Y - H$ in Fig. 1) is often mentioned as an important cue [1,6,18,22], especially for keeping the preferred glide slope. The position of the horizon (Y) is known to have a close relation to the pitch of the aircraft. The runway shape in general (also referred to as perspective), or specific cues like the perceived inclination angle of the runway edges (splay; θ) and the apparent length or width of the runway are also mentioned in literature, but there is no consensus about their use [6,10,18,23].

Another controversial cue is τ, the time to contact as defined by Lee [17], which can be derived from the optical flow or from a specific feature such as the apparent runway width. τ has been suggested as a guide for the flare phase (roundout) [15,23], although others [9] could not confirm this and found a dependency on sink rate instead (which is consistent with [11], but sink rate is not a readily available visual cue).

This quick overview of possible cues shows that there are many visual cues available to the pilot and for most of these cues, taking the time derivative of the cue into account could also be meaningful. Fig. 1 shows an overview of the cues considered in this research. It must be kept in mind that the usage of cues varies through the phases of the landing [21], and that some cues are used as a trigger to commence a new phase.

3. The final approach to landing

The final approach to landing can be divided into two phases. In the first phase the pilot should maintain a constant descent which is generally about 3 degrees and keep the airplane aligned with the runway centerline. This phase will be referred to as the 'glide'. The second phase is the 'flare' (also called roundout), where the pilot slowly pulls the column to make the aircraft pitch up in order to decrease the sink rate and land on the main landing gear first before the nose gear (Fig. 2).

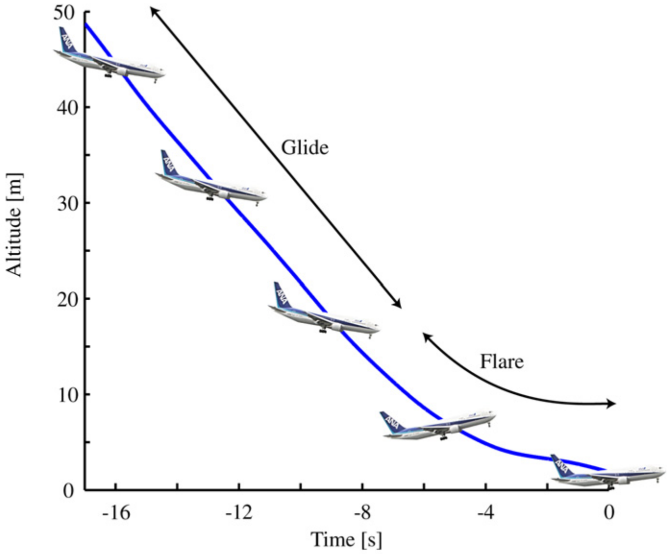

Fig. 2. In the final approach to landing, the pilot pitches up to arrest sink rate and land softly on the main gear. This maneuver is called the flare.

Proper timing and execution of the flare are critical for a soft and safe landing. *The rate at which the roundout is executed depends on the airplane's height above the ground, the rate of descent, and the pitch attitude. A roundout started excessively high must be executed more slowly than one from a lower height to allow the airplane to descend to the ground while the proper landing attitude is being established. The rate of rounding out must also be proportionate to the rate of closure with the ground. When the airplane appears to be descending very slowly, the increase in pitch attitude must be made at a correspondingly slow rate* [1].

4. Data acquisition

To find the cues a pilot is using when landing an airplane, a relation is sought between the available cues and the pilot's control. The current investigation only considers longitudinal motion (i.e., motion in the vertical plane) which limits the pilot control inputs to throttle setting and column deflection. As the throttle setting is normally[2] kept constant and only set to idle at the end of the flare, the control column deflection is the main source of pilot response data.

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[2] It should be mentioned that in simulated landings of a Dornier Do228-202 propeller airplane, some flares appeared to be performed by slowly decreasing the throttle, while column deflections were minimal (see Fig. 5). In the experiments with jet aircraft this behavior has not been observed.