SUBJECT: FINAL CLOSE-OUT OF NASA-AMES AWARD NO. NAG 2-1252

Insect-based Vision for Autonomous Vehicles: A Feasibility Study

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Project Report

Project aims

The aims of the project were to use a high-speed digital video camera to pursue two questions:

i) To explore the influence of temporal imaging constraints on the performance of vision systems for autonomous mobile robots;

ii) To study the fine structure of insect flight trajectories with in order to better understand the characteristics of flight control, orientation and navigation.

Funding

The funding for the camera was awarded by NASA contract NAG 2-1252 (Neurotechnology Program; Director: Dr. S. Zornetzer). The amount of the award was USD 21502.00

Progress

The award was offered by NASA on 15 August 1998. However, there was a considerable delay in commencing the project because the Australian National University had to wait for NASA to respond to certain questions regarding Intellectual Property before accepting the funding. These questions were resolved on 6 February 1999.

After comparing performance specs and prices of various brands of high-speed digital video cameras, we chose to purchase a Kodak Motion Corder Analyser (Model SR-500C). This instrument is capable of recording digital images at frame rates of 60, 125, 250 and 500/sec with a spatial resolution of 520 x 240 pixels at the highest frame rate and 520 x 480 pixels at the lower rates. Accessories included a zoom lens ((12.5-75mm f 1.8), a 2x lens extender, and a close up lens set (49 mm).

The total cost of the equipment was AUD 32,193.00 (USD 21,569.31, assuming an exchange rate of 1 AUD = 0.67 USD). The difference between the NASA award and the actual cost of the equipment (USD - 67.31) was borne by my research budget. An copy of the invoice for the equipment is included in the last page of this report.

The equipment was ordered on 6 May 1999 and it arrived on 16 June 1999. A view of the instrument is shown in Figure 1.

We have had the equipment for ca. two weeks now.
Results

Preliminary investigations have been undertaken with respect to Aims 1 and 2.

Aim 1

We have examined the ability of the Motioncorder to register the true motion of rapidly moving images without aliasing. The camera head was positioned above a specially designed sectored disc which was spun rapidly, in the counterclockwise direction, by hand (Figure 2). Frames were acquired at a rate of 250/sec and optic flow was computed using an image matching algorithm developed in our laboratory. The optic flow computed between successive frames (i.e. at an interframe interval of 4 msec) is shown in Figure 3. It is evident that motion near the centre of the disc is computed accurately as being in the counterclockwise direction. In this region, image velocities are relatively small and spatial frequencies in the direction of local motion are relatively large. However, as one proceeds outward towards the periphery, motion is erroneously computed to be in the clockwise direction. In this region, image velocities are higher and spatial frequencies are lower, so that the frame rate is not high enough to prevent temporal aliasing. Increasing the frame rate to 500 / sec eliminates this temporal aliasing (data not shown). We have also examined the effect of decreasing frame rate by computing optic flow between frames separated by 3 interframe intervals, as shown in Figure 4. The interframe interval is now 12 msec, corresponding to a frame rate of 83 / sec. In this case the computation of image motion is false even near the centre of the disc. Evidently, the frame rate is too low to register motion accurately in any region of the disc.
Figure 2: Sectored disc used to test performance of Motioncorder system

Figure 3: Optic flow computed from images of rotating disc at a frame rate of 250/sec.
Figure 4: Optic flow computed from images of rotating disc at a frame rate of 83 sec.

Aim 2

Honeybees were trained to fly through a tunnel, 2.3 m long, 20 cm wide and 22 cm high, to receive a reward of sugar solution from a feeder placed at the far end. The high-speed camera was used to film (a) flights of bees in the tunnel en route to the reward (cruising flights) and (b) flights of bees approaching and landing on the feeder. Frames were captured at the highest rate (500/sec).

A frame capturing a bee in a typical cruising flight is shown in Figure 5. The cursor represents the output of a Matlab software program, created in our laboratory, to track the instantaneous position of the bee. Profiles of X and Y position and X and Y velocity (Velx and Vely, in relative units) as a function of frame number are shown in Figure 6. The flight velocity along the tunnel axis (Vely) is remarkably constant. An interesting preliminary observation is that the control of lateral velocity (Velx) appears to be rather independent of the control of forward velocity (Vely).

Figure 7 shows a frame capturing a bee that is about to fly over and beyond the feeder without landing on it. The corresponding position and velocity profiles are shown in Figure 8. Here again, the flight velocity along the tunnel axis (Vely) is rather constant. As the bee approaches the feeder, she starts to swing from side to side, presumably using the resulting motion parallax cues to glean information on the feeder's range. Again, the control of lateral velocity appears to be rather independent of the control of forward velocity. We cannot say whether the bee increased altitude to avoid the feeder, since the filmed trajectory does not include information on motion in the vertical (z) direction.

Figure 9 shows a frame capturing a bee approaching to land on the feeder. The corresponding position and velocity profiles are shown in Figure 10. Here the bee swings from side to side as
she approaches, a manoeuvre typical of bees approaching a novel feeding site during the first few visits.

Figure 5: Frame showing a bee during a cruising flight through the tunnel

Figure 6: Profiles of X and Y positions and velocities (Velx and Vely) during cruising flight of Figure 5
Figure 7: Frame showing a bee during a flight in which she cruises past a feeder.

Figure 8: Profiles of X and Y positions and velocities (Velx and Vely) during cruising flight of Figure 7.
Figure 9: Frame showing a bee during a flight in which it approaches and lands on a feeder

Figure 10: Profiles of X and Y positions and velocities (Velx and Vely) during landing flight of Figure 9
FUTURE WORK

Aim 1
The camera head will be mounted on a computer-controlled gantry, available in our laboratory, and moved (rotated/translated) at various speeds in natural outdoor environments. The results will help determine whether vision systems carried by future autonomous flying vehicles can perform sufficiently well using conventional video cameras (with conventional frame rates of 30 /sec), or whether one would need to use systems that have a higher frame rate or even analog vision systems. These studies will also be used to design suitable early-vision algorithms for incorporation on a flying vehicle.

Aim 2
We will film and analyse the fine structure of flights of (i) wasps performing orientation flights near their nests, (ii) bees landing on stationary and moving targets (iii) flies avoiding obstacles and moving projectiles, to better understand the principles of flight control and navigation in flying insects. Filming methods will be modified to capture and analyse trajectories in three dimensions.

Mandyam V. Srinivasan, Ph.D.
3 July 1999
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