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

Insect-based Vision for Autonomous Vehicles: A Feasibility Study

Principal Investigator: Mandyam V. Srinivasan
Centre for Visual Science
Research School of Biological Sciences
Australian National University, Canberra

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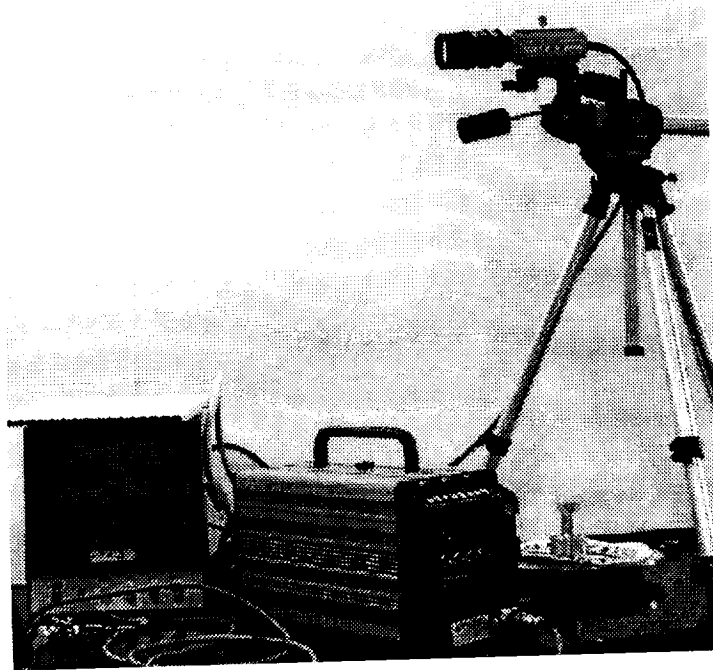
The equipment was ordered on 6 May 1999 and it arrived on 16 June 1999. A view of the instrument is shown in Figure 1.

JUL 0 6 1999

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

Figure 1: View of the Motioncorder showing camera head, control unit and a viewing monitor

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.

Title:
discimage.eps
Creator:
MATLAB, The Mathworks, Inc.
Preview:
This EPS picture was not saved
with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers

Figure 2: *Sectored disc used to test performance of Motioncorder system*

Title:
flow1.eps
Creator:
MATLAB, The Mathworks, Inc
Preview:
This EPS picture was not saved
with a preview included in it
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers

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

Title
flow2.eps
Creator
MATLAB, The Mathworks, Inc
Preview
This EPS picture was not saved
with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers

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
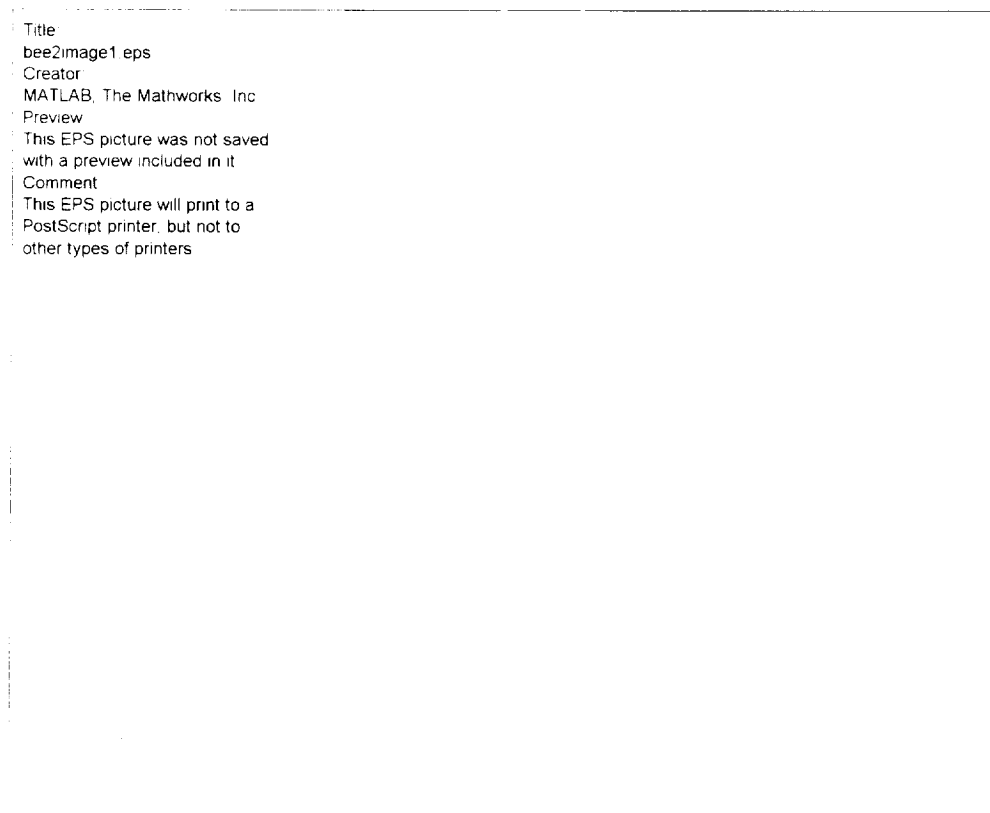
she approaches, a manoeuvre typical of bees approaching a novel feeding site during the first few visits.

Title
bee4image1 eps
Creator
MATLAB. The Mathworks, Inc
Preview
This EPS picture was not saved
with a preview included in it.
Comment
This EPS picture will print to a
PostScript printer, but not to
other types of printers

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

Title
bee4plot eps
Creator
MATLAB. The Mathworks, Inc
Preview
This EPS picture was not saved
with a preview included in it.
Comment
This EPS picture will print to a
PostScript printer, but not to
other types of printers

Figure 6: Profiles of X and Y positions and velocities (Velx and Vely) during cruising flight of Figure 5

Title
bee2image1 eps
Creator
MATLAB, The Mathworks Inc
Preview
This EPS picture was not saved
with a preview included in it
Comment
This EPS picture will print to a
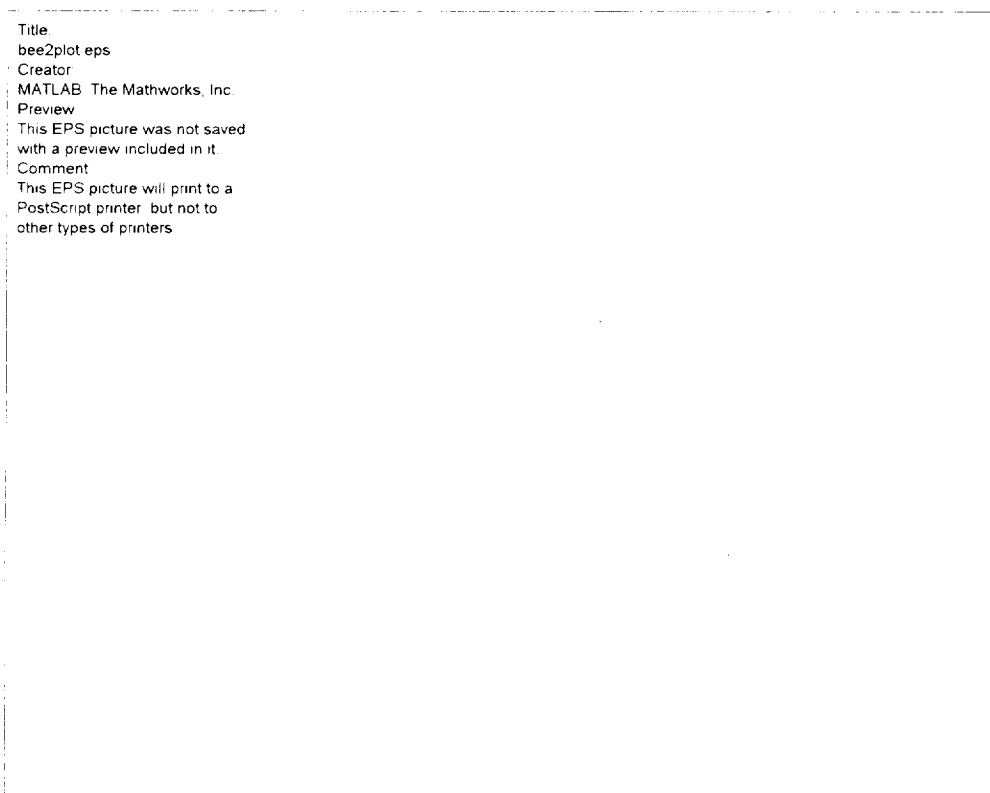PostScript printer, but not to
other types of printers

Figure 7: *Frame showing a bee during a flight in which she cruises past a feeder*

Title
bee2plot eps
Creator
MATLAB The Mathworks, Inc
Preview
This EPS picture was not saved
with a preview included in it
Comment
This EPS picture will print to a
PostScript printer but not to
other types of printers

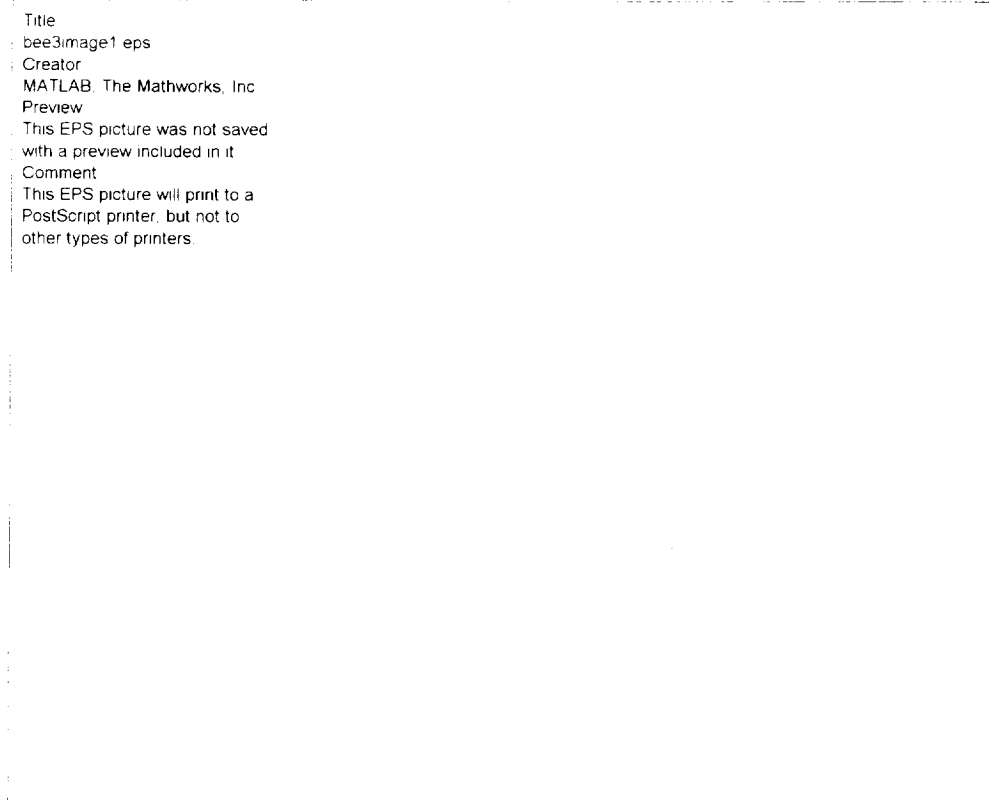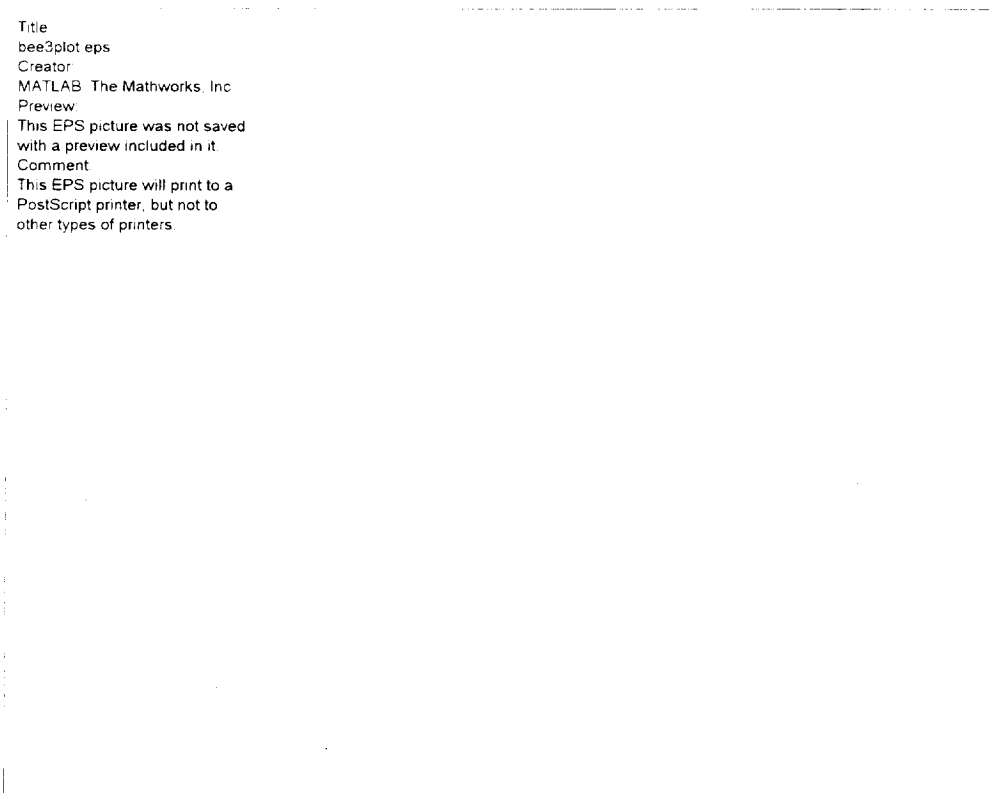**Figure 8**: *Profiles of X and Y positions and velocities (Velx and Vely) during cruising flight of Figure 7*

Title
bee3image1 eps
Creator
MATLAB. The Mathworks, Inc
Preview
This EPS picture was not saved
with a preview included in it
Comment
This EPS picture will print to a
PostScript printer, but not to
other types of printers

Figure 9: *Frame showing a bee during a flight in which it approaches and lands on a feeder*

Title
bee3plot eps
Creator
MATLAB The Mathworks, Inc
Preview:
This EPS picture was not saved
with a preview included in it
Comment
This EPS picture will print to a
PostScript printer, but not to
other types of printers

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

HADLAND PHOTONICS PTY. LTD.
A.C.N. 004 714 265
19A HAMPSHIRE ROAD, GLEN WAVERLEY,
VICTORIA, 3150, AUSTRALIA
PHONE (03) 9560 2366 • FAX (03) 9560 8402
INTERNAT PHONE 61 3 9560 2366 • FAX 61 3 9560 8402
E-MAIL: saleinfo@hadlandphoto.com.au

INVOICE
NO.   12250
DATE: 16 June 1999

OUR REF: A/11161F	YOUR ORDER: BB 51343 (COMP)	SALES TAX: EXEMPT (ITEM 109)
INSURANCE: OUR CARE	DELIVERY NOTE NO: 11198	DELIVERED BY: D.F.E. PAID
	DELIVERY DATE: 16 JUNE 1999	CONNOTE: J 1232643

ITEM	QTY	DEL. PREV.	DEL. NOW	BAL DUE	SUP. CODE	CAT. NO.	DESCRIPTION	RATE	AMOUNT
1	1	0	1	0	X	----	CAMERA, MOTION CORDER (S/N 08807120) With zoom lens, lens extender and close-up lens as per fax Quotation QT:7894F. PLEASE NOTE PAYMENT TERMS NETT 30 DAYS		$32,193.00

QUOTATION BASIS:
FIRM   ☒
VARIABLE   ☐   AN ADDITIONAL INVOICE OR CREDIT NOTE WILL BE ISSUED TO COVER EXCHANGE RATE VARIATIONS AS SPECIFIED ON OUR QUOTATION QT:

ACCOUNTS PAYABLE
RESEARCH SCHOOL OF BIOLOGICAL SCIENCES
AUSTRALIAN NATIONAL UNIVERSITY
SULLIVANS CREEK ROAD
CANBERRA ACT 2600

CLIENT CODE:	STAFF REF: VJ

TERMS NETT 30 DAYS
AS PER QUOTATION QT: 7894F.
PLEASE PAY ON INVOICE.
NO STATEMENT WILL BE ISSUED.

Nasareport.doc