08/6302 QUANTIFYING THE LANDING REACTION OF COCKROACHES

Type of activity: Medium study (4 months)

Background and motivation

Planetary exploration missions include an entry-descent-landing phase, where the spacecraft descends on a relatively steep trajectory to the surface. In order to minimize the loads during landing, a deceleration system is employed, consisting essentially of some or a combination of parachutes, retrorockets and airbags. Due to the communication round-trip delay time between spacecraft and ground control, external supervision of the descent is limited. As a consequence, a landing device is desired that can autonomously stabilize the descent and guide the spacecraft to a safe landing place.

In the research field of unmanned autonomous vehicles, animal models have become intensively studied models for potential technological transfer. Inspiration is drawn from various aspects such as neuronal control, aerodynamics, material properties, and actuators. Studying the neuronal control (biocybernetics) of insect flight is appealing for a number of reasons. First, in insects neurons can be addressed individually and hence, their function can be well determined. Secondly, flight control is realized in a fly-by-wire manner: Sensory data is acquired and processed in a way that only one individual steering signal for each flight situation is generated and sent downstream to the motor control. From this single signal, the appropriate motor reactions are generated. The present study aims at a 'technological transfer' of the neuronal architecture involved in triggering the landing reaction of steeply descending cockroaches.

Cockroaches obtain flying capacities of robustly designed wings but are rarely observed to fly. From observations of scientists we know that cockroaches use their wings mostly in emergency situations, i.e. when forced to jump off elevated spots. Once air born, the cockroaches quickly deploy their wings and use them to glide to the ground, controlling their trajectory and choosing a landing site. This task requires fast reactions and quick decisional strategies. The cockroaches' flight system is therefore assumed to be tuned specifically towards fast landing and not to e.g. flying or take-off. In consequence, it is assumed that the cockroach model – compared to other potentially flying insects – is simpler in its neuronal architecture and hence faster in its reaction and hence displays a potential model for a biomimetic transfer to an engineered landing system. Proposing universities and research centres are encouraged to include in their proposals relevant additional scientific information or a critical analysis of these assumptions.

Cockroach behaviour

Cockroaches are a popular model animal in the study field of dynamic legged locomotion, mostly because of their self-stabilizing dynamic legged locomotion skills. Up to now the flying behaviour of cockroaches has not received much attention. Apart from neurophysiological studies on the flight onset [3,4], there are only anecdotal remarks on flight behaviour available. Mid sized cockroaches of e.g. *Periplaneta spec.* show gliding behaviour combined with wing movement (Ritzmann, personal communication). If such a cockroach (usually the male types fly) falls off from an elevated point, it can be observed using its rigid and small wings to obtain control over its descent and hence minimize the impact on the ground [1,5]. From all the observations made, it can be assumed that the entire flight system of cockroaches is a rather simple one, both in terms of mechanical design and control architecture. Compared to the fragile and transparent wings of the commonly studied flying insects, cockroaches obtain of rather rigid and robust wings and hence could be a more feasible model in terms of biomimetic transfers. The cockroaches' flight control system, which deals only with landing and obstacle avoidance tasks, is expected to be of a rather robust and simple design. In consequence, the sensory processing could be among the quickest and simplest to be found.

In the present account, we want to study the performance of the cockroaches' sensory-motor loops during landing and develop a control model of the neuronal processes involved in landing [6].

Study description

Two main research themes of approximately equal importance are proposed to assess these hypotheses.

These are, (i) the identification and quantification of the landing parameters of a cockroach model under a number of constraints (e.g. quality of visual data). The results shall then (ii) serve for computer modelling of the cockroach control system. Throughout the entire project only the landing of spacecraft (i.e. approximately the last 500m) will be considered. Other phases of a space mission such as de-orbiting are not within the scope of this project.

1. Quantifying the biological model as a basis for a biomimetic transfer

We aim at mimicking the cockroach's descent behaviour without trying to achieve autonomous free flight or take-off capabilities. The goal of this study is to design a controller using the working principles of the neuronal system of flying insects, when confronted with the situation of a steep descent. Since the cockroach's neuronal system deals with such situations, we aim at getting a deeper insight into the currently not well quantified behaviour of the animal model.

In order to do so, the model animal will be confronted with an experimental situation where it has to control descent and choose a landing site. By manipulating boundary conditions the properties of the behaviour in question will be assessed. In the present case, cockroaches will be released unexpectedly from an elevated platform and, while trying to navigate safely to the ground, they will be recorded with video cameras (approx. 100-200 frames per second) from different perspectives. The trajectory can then be reconstructed as well as the exact moments when stereotypic reactions (unfolding wings, steering reactions, and deceleration) are triggered.

A) The boundary conditions to be manipulated are: height of release, presence of visual cues (lateral, ground), optic contrast of visual cues, field of view (i.e. reducing the visual field by partially obscuring the visual field), airflow direction and speed, mass of the animal. (This is to be considered a preliminary list and proposals with additional or different argued parameters are welcome.)

B) After a first characterisation of the cockroaches' behaviour, the influence of different parameters on the performance of the cockroach is to be assessed: Presenting the cockroach with repellent cues, such as obstacles in the preferred landing area as well as attractive cues, i.e. a dark shelter outside the common landing area, will allow to characterize the potential and the limitations of the cockroaches steering abilities. Attaching weights to the animals' body will accelerate the descent and hence characterize the minimum reaction times.

C) A small work-package deals with observing the animals' steering reactions to non-frontal air flow. In a setup different from the one used for A and B behaviour of the wings of a tethered cockroach is to be analyzed qualitatively when the animals are subjected to wind hitting the body at different yaw and pitch angles, both with free and mechanically blocked antennae. Here, again the reaction properties of the neuronal system will be evaluated but this time focussing on the air-flow sensitive antennae.

From the trajectory of the animal, the instantaneous visual cues can be calculated and parameters found which trigger certain reactions. From this data, we can assess important properties of the insects' visual piloting capabilities, especially in terms of separating translational optic flow and expanding optic flow.

In addition, extrapolation on the requirements for landing in e.g. Titan-conditions and used in spacecraft of different size will be performed in close cooperation with the ACT-researchers.

Finally, the results of the trajectory analysis will be used to quantify the flight apparatus' performance indicators: Maximum deceleration, maximum steering angles, estimations on lift and drag of the wings. It is important to note that this study is <u>not</u> proposing to include an in depth aerodynamics analysis. However, a few basic estimations on aerodynamic performance will be necessary since neuronal control and mechanical performance interact with each other.

2. Creating a functional model of the cockroach behaviour

In a second part of about equal importance, the findings of the quantification of the cockroach-landing behaviour will be used for the design of a universal control scheme realized in a common software environment. With this simulation environment, the results on the biological model have to be verified and an extrapolation to "artificial cockroaches" of varying weight, size, and flight performance will be performed. These results will be discussed in the view of an autonomous lander for application on earth surface.

Collaboration with the Advanced Concepts Team

This study is mainly addressed to research laboratories in the fields of neuroethology, biomechanics, neuroinformatics and biocybernetics. The project will be conducted in tight scientific collaboration with ACT-researchers. Next to the scientific discussions, the ACT-researcher will also provide both knowledge concerning space related issues and behavioural neurobiology. It is proposed that also most of the modelling activities will be performed by the ACT-researchers, with input and in close cooperation with the research laboratory/ies.

References

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