07/6301 MACHINE/ANIMAL HYBRID CONTROLLERS FOR SPACE APPLICATIONS

Type of activity: Medium Study (4 months, 25 KEUR)

Background and Motivation

Limitation of conventional control architectures

Space operations in general face difficulties when direct control is involved. Both time delay and limited bandwidth narrow the possibilities of real-time remote control from earth. Hence autonomous behaviour is a key element towards an advanced operational scope during space missions. Conventional robots are highly elaborated but primarily developed to function in predetermined or at least well defined environment. Outside the factory/laboratory however, we find that most of the tasks required for autonomous behaviour cannot be met by conventional control architectures. On the other hand even the simplest mobile organisms perform well when a certain goal is to be reached in order to ensure survival. In an unstructured environment such as natural habitats it is impossible to genetically equip an animal with a sufficient library of predefined situations, including given behavioural solutions that the animal could download and make use of. One of many natural examples of an autonomous agent is the desert ant *Cataglyphis fortis* which has a brain of 0.1mg mass but nevertheless finds food sources more than 20.000 times its own body length away from the nest and successfully navigates its way back [1]. During their foraging trips, obstacles [2] and predators have to be avoided and the path of the return trip has to be reduced to the minimal length (e.g. [3]), both amplifying the success rate for individual survival.

Sensory-motor mechanisms of insect behaviour

The long standing fields of neurophysiology, neuroanatomy, and neuroethology have characterized many aspects of insect behaviour. At first electronic demonstrators working with the animals' neuronal principles and employing insects' behaviours were built to prove the working principles of the neuronal circuit. The current activities at the interface between engineering and biology show working demonstrators that allow to understand and reproduce a range of isolated components of complex behaviours such as flight stabilisation, obstacle avoidance, altitude control, directional control, landmark recognition, etc (e.g. [4], [5], [6]). In general, the mentioned behaviours deal with sensorial cues that are present to the animal at the very moment when an appropriate reaction towards these cues is expected. Although the above mentioned behavioural mechanisms are rather complex in their architecture, they are dealing with single components and hence there is a higher level of hierarchy to be expected that actually generates the animals' behaviour by deciding on which cue to follow. Navigation in a foraging animal for example involves planned, directed locomotion towards a goal (i.e. food source, nest) while at the same time negotiating various obstacles and calculating the trade offs between a successful foraging run (i.e. reaching the desired goal), the time of the run (i.e. the energy budget), possible predators (i.e. fatal threats). What seems natural for an animal is difficult to understand and even more so to reproduce in a technical device: Multidimensional parameter spaces challenge state of the art control architectures. They either cost too much computational time in order to perform real time operations or the computation has severe difficulties on focussing on the relevant parameters.

Using insect intelligence

The difference of performance between a living organism and a conventional robot becomes most apparent in unstructured environments with unknown and potentially hazardous situations occurring in a non-predictable manner. However, unmanned exploratory missions to e.g. mars or moon are in general preferred to missions with human presence as due to several reasons these missions allow to cross boundaries far beyond that where humans can be brought at an acceptable risk. However, facing the challenges of autonomous exploration, the range of future automated mission vehicles strongly correlates with capability of control architecture to successfully integrate a whole range of decision parameters. In this context we investigate the potential of integrating "animal intelligence" into the control architecture of exploratory vehicles. Our aim is to reproduce both low level mechanisms and higher level decision taking behaviours that are necessary for an insect. The integration of insect intelligence - or the employed mechanisms that lead to emergent intelligence - shall be realized according to their complexity in different manners:

- Elements of short range orientation, such as obstacle avoidance reaction, wall following behaviour, altitude control, etc. were already successfully realized in artificial electronic demonstrators. But the complex decision structures involved in weighing the different inputs from the analogue electronics is still subject to speculation.
- Additionally parameters such as maintaining the energy budget, navigation towards a distant goal, route learning, etc. require a control architecture that obtains of certain flexibility and the ability to autonomously take decisions and revise them: a level of complexity that current control architectures are still far to be successfully managed.

For these high-level tasks we want to examine the potential solution of integrating pre-developed living intelligence, i.e. neuronal circuits taken from the brain of a developed animal.

Research and Study Objective

The goal of this study is to develop the concept of a novel control architecture incorporating animal intelligence integrating both electronic analogues of low level behavioural mechanisms and alive, pre-developed animal living tissue, to perform high level integration and decisions. This control architecture should preferably be valid for both aerial and ground based autonomous exploratory vehicles (e.g. [7]).

1. Perform an overview of potential insect models (social and asocial ones) and the peculiarities of their behaviour ranging from “hard wired” behavioural mechanisms to multi-factorial decision taking and finally adapting behavioural strategies, i.e. learning.
2. A characterisation of the most relevant behavioural patterns that are/could be suitable for control purposes in terms of:
    1. the required stimuli (visual, wind, odor, ...)(e.g. [8], [9])
    2. the resulting measurable outputs related to those stimuli
    3. the compensating reactions towards unexpected (internal and/or external) disturbances while fulfilling the main task
3. An overview of existing technical transfers of biological mechanisms guiding stable locomotion and navigation.
4. Identify possible organism machine interfaces (e.g. [10], [11])
5. Propose a hybrid control architecture that incorporates both biological and bio-inspired components and evaluate the technological feasibility of the sub-modules

6. Identify technological state-of-the-art autonomous agents and compare them with the proposed pendant in terms of adaptability, failure tolerance, robustness, and the reaction towards external disturbances.

The study is expected to be conducted in tight conjunction with the Advanced Concepts Team of ESA. Hence, space knowledge is not required and will be provided by the ACT. **This study is addressed to the communities of neurobiology, neurophysiology and cybernetics but experts from other fields are encouraged to apply.**

References

[1] Wehner R (2003). Desert ant navigation: how miniature brains solve complex tasks. J Comp Physiol A 189:579–588.

[2] Seidl T, Wittlinger M, Wehner R (2006). Vertical object avoidance reaction in desert ants *Cataglyphis fortis*. Comp Biochem Physiol B 143:92.

[3] Wehner R, Wehner S (1990). Insect navigation: use of maps or Ariadne’s thread. Ethol Ecol Evol 2:27–48.

[4] Lambrinos D, Moeller R, Labhart T, Pfeiffer R, Wehner R (2000) A mobile robot employing insect strategies for navigation. Robotics and autonomous systems 30:39-40.

[5] Ruffier F, Franceschini N (2003). OCTAVE, a bioinspired visuo-motor control system for the guidance of Micro-Air-Vehicles. Proceedings of Bioengineered and Bioinspired Systems Conference, Maspalomas, Spain, SPIE 5119:1-12.

[6] Serres J, Ruffier F, Franceschini N (2005). Biomimetic visual navigation in a corridor: to centre or not to centre? International Mediterranean Modeling Multiconference.

[7] Seidl T, Girimonte D (2007). A planetary landing device inspired by gliding cockroaches. In: Floreano D (ed.) Symposium on Flying Insects and Robotics, 12.-17.8.2007, Monte Verita, Ascona, Switzerland, p. 105-106.

[8] Ganihar D, Libersat F, Wendler G, Camhi JM (1994). Wind-evoked evasive responses in flying cockroaches. J Comp Physiol A 175:49-65.

[9]Wolf H, Wehner R (2000). Pinpointing food sources: olfactory and anemotactic orientation in desert ants, *Cataglyphis fortis*. J Exp Biol 203:4223-4230.

[10] Bozkurt A, Paul A, Pulla S, Ramkumar A, Blossey B, Ewer J, Gilmour R, Lal A (2007). Microprobe microsystem platform inserted during early metamorphosis to actuate insect flight muscle. 20th IEEE International Conference on Micro Electro Mechanical Systems. January 21-25, 2007, Kobe, Japan.

[11] Gugliotta (2001). The Robot With the Mind of an Eel. Washington Post, April 17, Page A01.