ASSISI: Charged hot bees shakin' in the spotlight

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***Abstract*—In this article we describe the concept of generating a mixed society of honeybees and artificial (robotic) agents in the project ASSISI$|_{bf}$. We discuss the motivation of generating a mixed society as novel bio-hybrid system that can achieve self-awareness, self-regulation and environmental awareness through self-organization and collective information processing. In our approach the artificial agents communicate with the natural agents through 4 physical channels, which are emphasized in this article: temperature, vibration, electromagnetic fields and light. We also discuss our methodology of automated model-generation and model-adaptation through evolutionary robotics principles.**

I. Introduction

Mixing autonomous agents (avatars) with natural agents (e.g., animals) offers significantly new ways of understanding natural self-adaptive systems: Artificial agents can react to animal behavior autonomously by emitting stimuli or by showing behaviors that affect the animal. This way, these combined systems "close the loop" between the natural system and the artificial one. Integrating artificial agents onto organisms is basically producing a cyborg [1]. If this is done in a non-invasive way, for example by introducing agents into an animal society, a social variant of a cyborg emerges that allows monitoring the animal society. In addition to that – by introducing provoking stimulus patterns – the artificial component can modulate the animal society according to control directives that are set from outside, for example from a human operator. The higher the social integration of the target animal species is, the more "hooks" are offered to integrate the artificial agent into that society and, often, the more complex collective behaviors can be provoked by the avatar. If the integration has become intensive the whole artificial part merges with the natural part into one single controllable entity: The social cyborg (e.g., [2]).

As the natural society of animals is collectively harvesting, sharing, storing and processing information, it generates a collective awareness about various factors: The current and past state of the environment as well as the current and past status of the society itself. The collective information processing of social animals often leads to efficient and beneficial decision making concerning collective choices of shelters, food sources or routing paths. Thus, the collective awareness of these naturally distributed systems ultimately leads to collective behaviors which can be interpreted as being goal-oriented and situation-aware. However, this interpretation holds not inevitably for individual actions of society members, but for the collective behavior of these groups.

Besides the scientific endeavor of exploring the interaction patterns of such natural animal societies through avatars, there are also significant engineering discoveries to be made: On the one hand, animals possess impressive sensor capabilities combined with evolutionary tuned sensor fusion and neural processing. In addition to that, an animal society is often fusing, filtering, distributing and storing environmental information in a distributed and parallel process. An avatar that is well embedded in the animal society can use the whole society of animals as one highly sophisticated sensor. On the other hand, animals show impressive efficiency concerning actuation. As the animal society's collective behaviors can be modulated by the avatar, the whole animal society can become a very sophisticated actuator network for the avatar. This way, novel design paradigms can be tackled for establishing systems of bio-hybrid and modular robots. However, little knowledge is currently existing on such systems, thus it is important to generate general knowledge on such bio-hybrid systems.

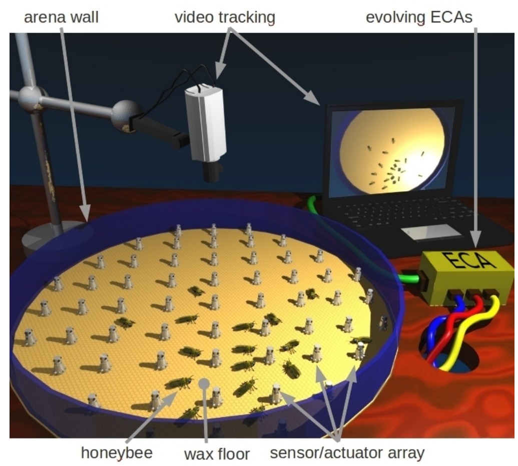

Fig. 1. Computer artwork demonstrating the planned experimental setup with honeybees and autonomous devices (CASUs) in ASSISI$|_{bf}$.

In our EU-funded project ASSISI$|_{bf}$ [3] we generate such mixed societies of autonomous robots and honeybees (and also mixed societies of robots and fish). We describe in the following how we intent to integrate autonomous artificial devices into honeybee societies to modulate their collective behaviors: For instance, we plan to influence the collective decision making process of honeybees at our will to highlight the following issues: (A) how such an intervention can be done. (B) How the information processing in the natural system operates. (C) Which pieces of information an embedded avatar can autonomously "read" from the collective information processing of the bees.

II. CASU Matrix, Autonomous Model Building and Evolutionary Adaptation

Due to the small size of a honeybee artificial devices (autonomous robots) that can interact with bees should be compact, robust and tiny. Miniaturization of an artificial agent is in opposition with energy demands required by a set of temperature, vibration, light and electric field sensors and actuators that such agents should be equipped with. Thus, instead of building a miniature movable autonomous robot, whose scale is defined mostly by an energy source, we plan to design an array of static devices, also called a "matrix of Collective Actuator Sensor Units" (CASU-matrix), placed uniformly on the floor of the experimental arena (Fig. 1). The benefit of such an approach is twofold: i) one is allowed to simultaneously use all sensors and actuators during experimentation without taking care of energy consumption, and ii) duration of the experiment is not limited by the capacity of an energy source.

Here we present the design of the CASU-matrix, comprising: i) temperature stimulus devices based on Peltier effect, which will provide a relatively fast change in required temperature and, furthermore, implementation of various temperature gradients within the experimental arena, ii) vibration stimulus produced by miniature motors, placed below the arena floor, iii) electromagnetic fields and iv) light stimulus with different frequencies of light generated by RGB diodes. In order to mimic movement of an artificial agent, we propose the development of prototype patterns executed by the CASU-matrix. Immobile agents will be programmed in a way to propagate signal(s) (vibration, temperature, light) by implementing prototype patterns: circular motion, rectangular motion, aggregation, split of a group, etc. By combining those prototype patterns we demonstrate that also agents that exist in a virtual habitat can, because of their projection into the real world of the bees through the CASU-matrix, influence the bees and the other CASUs in our mixed society.

The temperature stimulus utilizes thermodynamically reversible Peltier effect, i.e. direct conversion of electric voltage to temperature difference of two united conductors. By controlling the electric voltage of a H-bridge through a PWM signal one is able to define the required temperature in a range of 10 - 40 °C, which is the range that is most appropriate for experiments with honeybees. The required temperature setpoint is controlled by using the feedback from a temperature sensor placed in close proximity to the heat device. The vibration stimulus device (DC motor) is controlled in the same way and it is able to generate vibration (0 - 400 Hz, 0 to 2g) in two planes (x-y and y-z). As sensors we use 3DOF accelerometers. The light stimulus (465 nm to 625 nm, 800 mcd to 4000 mcd) is generated by a RGB diode. The control is utilized in open loop (no feedback sensor) by a simple change of the voltage level on the corresponding diode pin.

Electromagnetic radiation (spectral light, electric and magnetic fields) is biologically active in terms of interaction with cellular metabolism, e.g., [4]. On a higher level, the electromagnetic radiation represents an environmental stressor linked also to the development of organisms. Important is not only the presence and intensity of the corresponding fields but also their modulation by specific frequencies [5]. In ASSISI$|_{bf}$ the CASU's strategy includes local impact by electric and magnetic fields, and modulated light. The development of electric and magnetic field emitters represents some challenge due to a size constraint and the requirement on a strong local field. In the current prototypes we follow the strategy of flat emitters, about 0.5 mm thickness, which can be installed on the arena' ground. Tests demonstrated a local intensity of up to 2kV/m and 100 μT of electric and magnetic components with low frequency modulation between 10 Hz and 100 Hz. Since the field decays inverse proportionally to a square distance, about 80% of field intensity is concentrated within 5-7 cm area around emitters - a few body lengths of a bee - for achieving a local impacting strategy.

We will use evolutionary algorithms inside of individual CASUs to adapt the behavioral models acting in our CASU array. This way we will allow each unit to change its behavior, thus change its stimulus-response pattern. Over time the CASUs will respond diversely to stimuli that they receive from other society members. This will, in consequence, alter those behavioral feedback loops that merge the natural and the artificial society, in turn changing the collective behavior of the bio-hybrid system. The group behavior of bees is inherently self-organizing, thus we expect that evolutionary adaptation will explore the potential of these group behaviors and identify novel emergent properties within this "behavior space". We plan to use the observed collective behaviors of our bees as a fitness function that is governing the evolutionary computation of the CASU programming to modulate the behavior of the CASU-matrix until the bees perform the desired target behavior. This way, it will be the bees that will in fact program our CASU array and not us. This will be a scientific novelty. By looking at these evolved programs afterwards, we expect to find novel principles of collective information processing and group-level self-awareness.

III. Impact on Society

The developments within the project will provide new tools for researching animal behavior, and will lead to the generation of new algorithms for autonomous robotics as well as sensors and actuators for micro-robots. This way ASSISI$|_{bf}$ will have an influence in the field of ethology, on the agricultural industry (e.g., by helping to avoid animal pests), as well as the robotic industry.

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References

[1] S. K. Talwar, S. Xu, E. S. Hawley, S. A. Weiss, K. A. Moxon, and J. K. Chapin, "Behavioural neuroscience: Rat navigation guided by remote control," *Nature*, vol. 417, no. 6884, pp. 37–38, 2002.

[2] T. Landgraf, H. Moballegh, and R. Rojas, "Design and development of a robotic bee for the analysis of honeybee dance communication," *Applied Bionics and Biomechanics*, vol. 5, no. 3, pp. 157–164, 2008.

[3] (2013) ASSISI$|_{bf}$ project. [Online]. Available: http://assisi-project.eu/

[4] P. A.A. and M. M.S., "Bioeffects of weak electromagnetic fields," *Rev Environ Health.*, vol. 10, no. 3-4, pp. 155–169, 1994.

[5] R.-C. Jao and W. Fang, "Effects of frequency and duty ratio on the growth of potato plantlets in vitro using light-emitting diodes," *HortScience*, vol. 39, no. 2, pp. 375–379, 2004.