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BIO-INSPIRED SMART SENSORS FOR A HEXAPOD ROBOT

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Abstract: *EMICAB (Embodied Motion Intelligence for Cognitive, Autonomous Robots) is an EU founded project where a consortium of 4 Universities is working together to integrate smart body mechanics and sensors with intelligent planning and motor behavior in order to make a holistic approach to artificial cognitive systems. This contribution provides information and the first experimental results about smart material sensors done at the Mads Clausen Institute at the University of Southern Denmark, where the aim is to make a distributed smart sensor network with a redundancy of sensors mimicking that found on limbs of for instance stick insects.*

Key words : *Smart sensor material, distributed sensor network, bio-mechatronics, DEAP*

1. INTRODUCTION

Inspired by the agility, versatility and adaptability of walking insects, autonomous legged robots based on biological principles have seen a considerable interest in the last years (Delcomyn & Nelson 2000). One of the key interest points in successful biological systems is their ability to move across rough terrain outperforming even the most agile robot. This lacking in performance of the robot can partly be contributed to a main focus on generating a predefined stable gait for the robot with a minimal influence from sensory feedback. On the other hand biological systems usually rely heavily on a redundancy of sensors which provides the insect with sensory feedback for adaptive locomotion. The aim of the EMICAB project is bridging this gab by taking a holistic approach to implementing bio-inspired artificial cognitive systems onto a legged hexapod robot seen in Fig 1. The Mads Clausen Institute part of the EMICAB project is the design and implementation of a sensory network where a redundancy of smart material sensors will mimic functions of sensor organs found on insect legs. This combined with planning and motor behavior will generate an intelligent platform for agile movements where the hexapod robot interacts with and learns from the surroundings through sensory feedback.

Fig 1: Full scale plastic model of the EMICAB hexapod robot. The final hexapod will be made in carbon fiber and is about 60 cm long and weighs around 11 kg fully equipped

2. LIMB SENSOR ORGANS FOR LOCOMOTION

Before describing the technical aspects of the project a brief review of sensor types mimicked in the project will be given. On an insect limb two main categories of sense organs can be found; mechanoreceptors and chemoreceptors, where only the former type are thought to have influence on agile locomotion (Delcomyn, F. et al. 1996). Mechanoreceptors can again be divided into overlapping subcategories; proprioceptors (position and motion of body parts in respect to each other), tactile receptors (contact with and to another object) and stress receptors (stress in the exoskeleton and also contact to another object). The final version of the developed sensors and sensor network in the project should perform the tasks of the above mentioned sensor receptors types.

3. DEAP AS SMART MATERIAL FOR SENSORS

The material chosen for all three sensor types are a subcategory of so-called EAP (Electro Activated polymer) materials namely DEAP (Dielectric -EAP). Since the beginning of the 1990s EAP materials have seen a growing interest as active material in both actuators and sensors (Bar-Cohen, Y. 2004; Kornbluh, R. et al. 2004). We have chosen DEAP as the sensor material because of its large strain capabilities, environmental tolerance and low cost. The specific DEAP material used for sensors in this project is produced by the Danish company PolyPower A/S***.

3.1 General functionality of DEAP

Basically a dielectric elastomer device functions as a plate capacitor where an incompressible and highly deformable material is sandwiched between two electrodes as seen on the left in Fig 2. If an electric field in the order of kilo volts is placed across the electrodes the so-called Maxwell stress causes the electrodes to move closer squeezing the material between them thereby causing actuation (Samatham, R et al. 2010). If used as a sensor an outside pressure, P seen on the left in Fig 2, deforms the DEAP device by moving the plates closer together inducing a capacitance change which is correlated to magnitude of P. In the general case the deformation will be uniform in the plane perpendicular to the force and therefore non-directional. If instead both the plates and the dielectric material between them are structured in order to make, an anisotropic compliant to the force a platform for smart sensor are created. The DEAP material used in the project is corrugated in one direction making the sheet nearly unidirectional compliant which means that the thickness strain s_t is approximately equal to the negative of the compliant strain s_{comp} (Sommer-Larsen, P. & Benslimane, M. 2008):

$$S_{comp} \approx \frac{P}{Y} \quad (1)$$

Here Y is the Young's modulus (≈ 1MPa) and P the pressure. The capacity change of the deformed device is given by:

$$C = C_0\,(1 + s_t)^{1.8} \qquad (2)$$

Here C is the measured capacitance and C_0 is the start capacitance (≈ 40 pF/cm^2 unstressed). The outside influence is of course not only limited to pressure deformation but also strain deformations can be measured by the DEAP material.

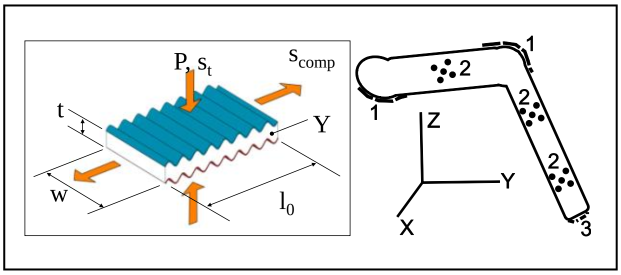

Fig. 2: Left: Schematic drawing of the structure of DEAP material and important parameters, see text for in-depth explanation (Courtesy of PolyPower A/S, Denmark). Right: A schematic drawing of one of the hexapod limbs with position of sensors; 1) DEAP material joint-position sensors (propriocetor), 2) External contact and limb stress sensors (tactile and stress receptors) and 3) Pressure sensor for limb contact to the ground and weight distribution measurements.

4. SMART SENSOR DESING AND PLACEMENT ON LIMB OF THE EMICAB HEAXPOD

The idea in the EMICAB project is that the sensors should only mimic the function of receptors found on the insect limb and not be a direct replica. A schematic view of our sensor idea and placement are seen on the right in Fig 2. Either strips or, to increase the active area of the sensor rolled-up strips of DEAP material are placed on moving joints on the limb, mimicking functions of the chordotonal organ and muscle, strand and stretch receptors (1 on the right in Fig 2). This will give the hexapod sensory feedback about position, speed and acceleration of the different segments of the limb in respect to each other. Arrays of DEAP pressure and strain sensors correctly placed for maximum efficiency mimicking functions of sensory hair and the campaniform sensillum organ will act as tactile sensors giving feedback of contact with objects (2 on the right in Fig 1). A pressure sensor working as the contact surface will give feedback about actual ground contact and weight distribution of the hexapod (3 on the right in Fig 1). All sensory input will be transferred to and processed by a decentralized pattern generator for each limb. The individual limb patterns are then coupled together to produce a quick and strongly sensory influenced coordinated locomotion for the hexapod robot. This setup with a redundancy of sensors on the robot insures a constant flow of sensory input even at the failure of one or more sensors.

5. CHALLENGES AND FUTURE EXPERIMENTS

One of the biggest challenges in working with the DEAP material is securing a good and flexible contact to the 100 nm thick corrugated silver electrodes of the DEAP material. The electrical contact should stick to the silver electrode without destroying it, be flexible enough to follow the strain of the polymer material without breaking and stay conductive. The first basic test was done with conductive sticky tape which proved feasible and successful but not as a solution for the final sensors because of its tendency to destroy the silver electrodes. Instead we used a mixture of silicone and carbon nanotubes creating a conductive polymer. This material nearly has the same stretching capabilities as the DEAP material while keeping conductive and adhesive to the silver contacts at the same time. Different mixing ratios of silicone and carbon nanotubes is tested for conductivity, adhesiveness and mechanical properties in order to find the best suited one.

The next project steps are:

- Sensor design to optimize performance, robustness and location on the hexapod robot.
- Development of the electronic for each sensor and sensor array together with the decentralized processing of sensory data on each limb.

6. CONCLUSION

The Mads Clausen Institute part of the EMICAB project is the development of smart sensors, mimicking functions of receptors found on insect limbs for a distributed sensory network. The sensors will provide the hexapod robot with additional information besides the basic pattern generators making it possible for the robot to alter its movement behavior. The individual smart sensor will be made from DEAP material and will be specifically designed to meet requirements for sensor placement, robustness and function. Sensory input from each sensor will be processed decentralized by a sensory network found on each limb and coupled together in a central pattern generator to produce a stable gait for the robot.

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