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GEMS: A MEMS-based Way for the Innervation of Materials

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Abstract. We propose a concept for a novel 'innervated' material that is assembled by addition of a multitude of MEMS to a conventional material. This approach shall enable the material to show specific reactions to external inputs, and make the reaction accessible to external observers. By implementing such innervated material into buildings, clothing or even food, it would be possible to create a virtual neural system in objects. This work introduces the concept, gives an outlook on the potential of such an approach in art, science and technology and the possible impact on the life of future generations.

Introduction

One of the basic properties of higher multicellular organisms is their nervous system [1]. Nerves transport electrical signals to central and/or decentralized processing stations in organisms. Inspired by speckled computing [2], sensors in biology as well as in engineering (MEMS sensors) [3,4] and driven by the vision of engineers to construct materials, structures and processes that give feedback about their respective status, the current work develops a concept for a novel material that informs the observer about its status.

The proposed innervated material could for example be used in various engineering applications (beams, buildings, scaffolds, etc.) as well as in the arts, opening new ways for artistic expression.

The material introduced here is currently in the concept stage.

MEMS-based Innervated Material: Concept Development

GEMS. Group Electro-Mechanical Systems (GEMS) are a specific form of MEMS that are simpler than conventional MEMS and that contribute as parts of a group to a joint signal. In this way, information can be obtained about properties of two- or three-dimensional entities. GEMS (Fig. 1 left) are the basic ingredients of the proposed innervated material. The single MEMS are spheres of elastic material that contain electrically conductive filaments of a specific length (same length in all MEMS sensors). The length of the filaments is smaller than the diameter of the spheres. The spherical shape ensures a random position of the filament in the matrix, independent of the flow during the casting process. Good mechanical attachment of the filaments to the sphere material is provided by surface modifications on the end of the filaments, e.g. by roughening the respective surfaces to increase bonding. The single MEMS can be compressed or elongated, with the filament being longer or shorter compared to the neutral case (Fig. 1 right). The setup of the GEMS is the simplest possible given the requested features, to allow for mass production and failsafe function (access problems in the final innervated material – no repair/replacement possible).

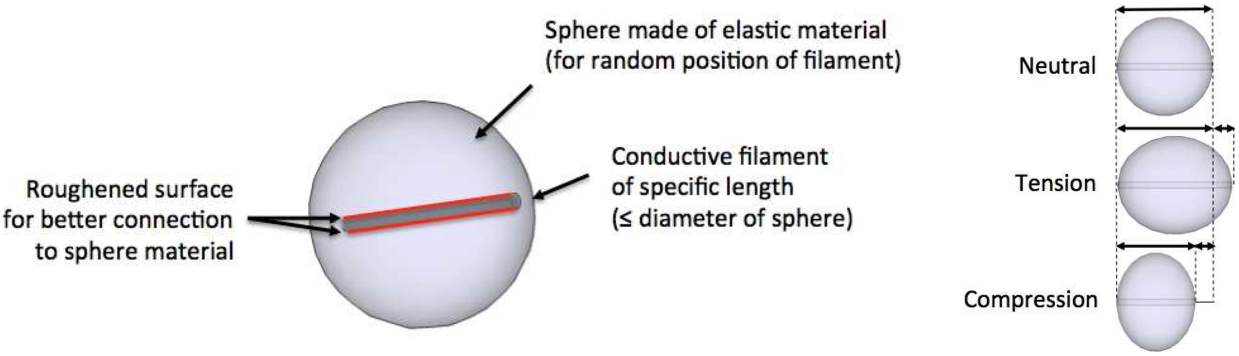

Figure 1. Left: GEMS for the innervation of materials. Right: Effect of mechanical stress and strain on the GEMS.

Frequency sweeping (Fig. 2 left top) of the final, unstressed material with the embedded GEMS would yield a certain, characteristic response in the induction signal, depending on materials characteristics and length of the filaments (Fig. 2 right middle). In this case, all filaments have the same length, contributing to the spike-like peak that can be seen in Fig. 3 middle. In the stressed condition, when many filaments are deformed, the frequency dependent induction signal changes its characteristic shape from peak-like to more broad (Fig. 2 left bottom). This method is similar to the electrical theft protection systems in shopping malls.

Matrix material and production of innervated MEMS material. Concrete or some other homogeneous material that can easily be mixed with the GEMS and then be cured/hardened/stabilized etc. serve as matrix material for the GEMS. In the production of the innervated materials, great care is taken to choose a substance that bonds to the spheres, ensuring stress and strain transfer to the GEMS spheres. An example for the production of an innervated concrete beam is given in Fig. 2 right.

Response Characteristics of MEMS-based Innervated Material

The mechanical stress in the MEMS-based innervated material induces different shapes of the induction response characteristics when a frequency sweep is applied to the material (Fig. 2 left, Fig. 3).

Material Stress Factor Analysis with MEMS-based Innervated Material

The MEMS-based innervated material now allows for stress factor analysis deep inside bulk materials, inaccessible structures and the like. For example, stress in beams can easily be measured by frequency sweeps and acquisition of the resulting induction *vs*. time curves (Fig. 4).

Summary and Outlook

This work introduces the concept of a novel innervated material that allows external observers to determine its stress or strain status. Adding GEMS to a matrix material produces such material. The GEMS consist of elastic spheres in which metal rods of same length are embedded. Tension or compression of the spheres results in shortening or elongation of the metal rods. When a frequency sweep is applied to the innervated material, the induction vs. time curve gives information on the status of the innervated material, and therefore allows for stress factor analysis.

Further development of such innervated materials include various other GEMS being embedded into the matrix, widening the response parameters to more than just one signal type, similar to the senses in organisms, where hearing, touch and vibration sensing are possible via deflection sensing, smelling and taste via chemical detection, and finally, seeing, temperature sensing, magnetic sense and electroreception via detection of electromagnetic waves [5].

The GEMS introduced in this manuscript are the simplest possible ones, they are passive and do not actively communicate with each other. Active GEMS would open up a whole new area of possible applications, but are not treated here because of space constraints. The impact of material innervated with active and passive GEMS on the future of engineering would be enormous.

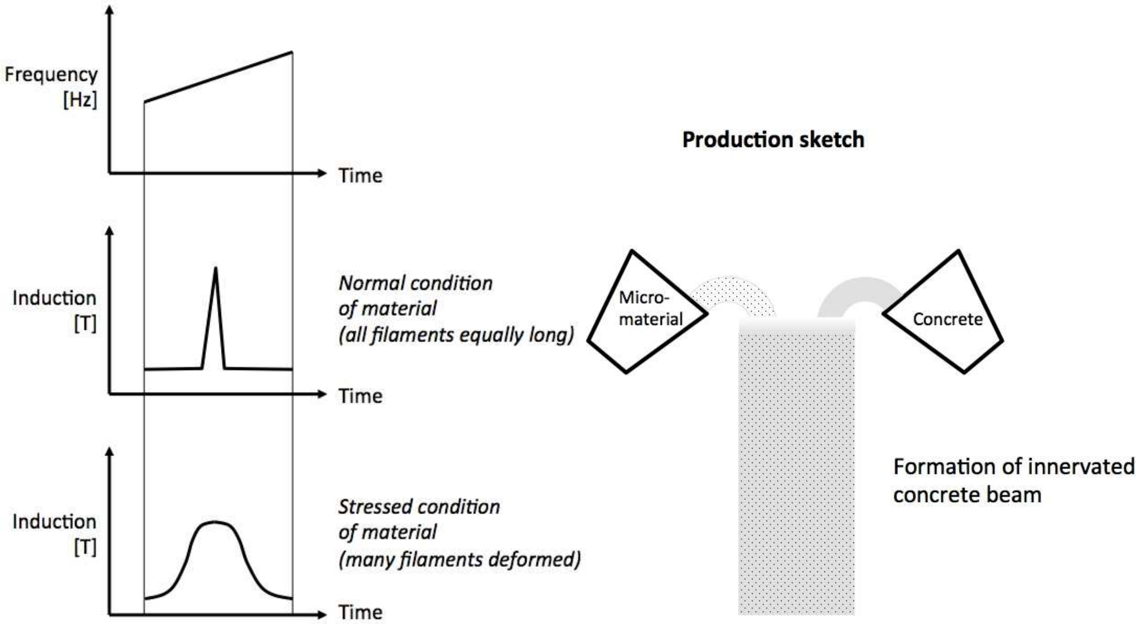

Figure 2. Left: A frequency sweep allows discriminating between the normal condition, where all filaments have the same length, and the stressed condition, where a substantial amount of the filaments is deformed. Right: Production of a concrete beam made from innervated material: GEMS are mixed with concrete, shaped as beam, and allowed to harden.

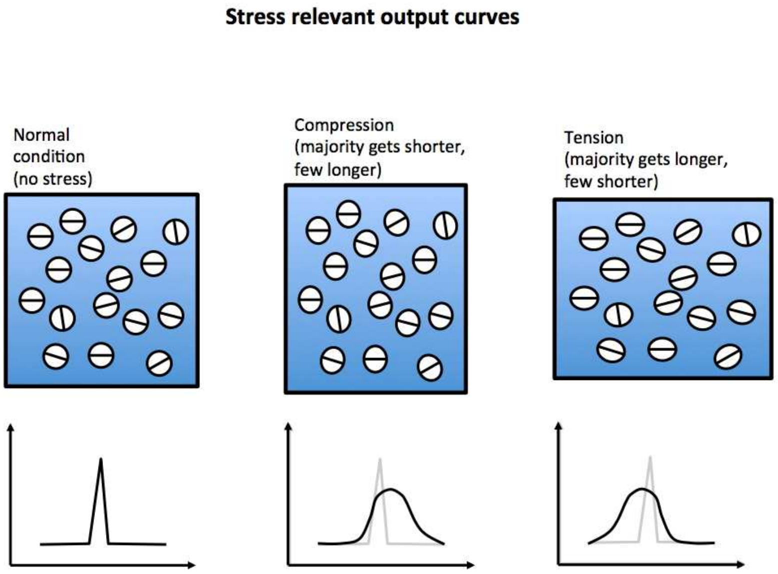

Figure 3. The characteristic responses of the innervated material, exemplified for the normal condition (left), the compression condition (when the majority of the GEMS gets shorter, some stay the same length and only some get longer) and the tension condition (when the majority of the GEMS gets longer, some stay the same length and only some get shorter). The top images give a sketch of the GEMS embedded in the matrix, and the bottom images the characteristic resulting induction *vs*. time curves.

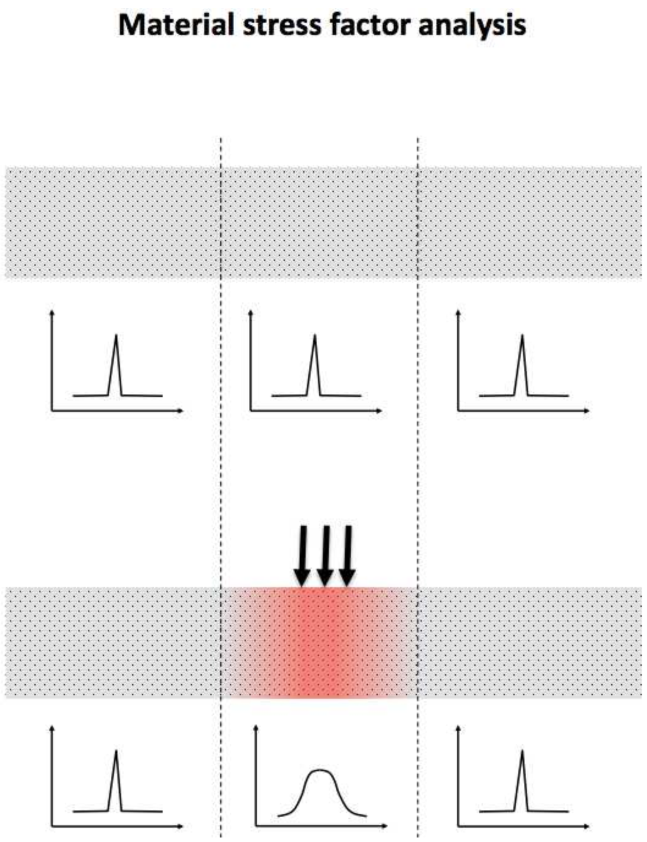

Figure 4. The characteristic responses of the innervated material along a beam. Top: Normal condition, no compression or tension along the beam. The signal is the same along the structure. Bottom: Signal change induced by a compression/tension state in the middle section of the beam (red area).

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NEMS/MEMS Technology and Devices

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