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Towards plant wires

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ABSTRACT

In experimental laboratory studies we evaluate a possibility of making electrical wires from living plants. In scoping experiments we use lettuce seedlings as a prototype model of a plant wire. We approximate an electrical potential transfer function by applying direct current voltage to the lettuce seedlings and recording output voltage. We analyse oscillation frequencies of the output potential and assess noise immunity of the plant wires. Our findings will be used in future designs of self-growing wetware circuits and devices, and integration of plant-based electronic components into future and emergent bio-hybrid systems.

1. Introduction

Since its inception in 1980s the field of unconventional computation (Calude et al., 1998) became dominated by theoretical research, including quantum computation, membrane computing and dynamical-systems computing. Just a few experimental laboratory prototypes are designed so far (Adamatzky and Teuscher, 2006), (Teuscher and Adamatzky, 2005), e.g. chemical reaction–diffusion processors (Adamatzky et al., 2005), extended analogue computers (Mills, 2008), micro-fluidic circuits (Fuerstman et al., 2003), gas-discharge systems (Reyes et al., 2002), chemo-tactic droplets (Lagzi et al., 2010), enzyme-based logical circuits (Katz and Privman, 2010; Privman et al., 2009), crystallisation computers (Adamatzky, 2009), geometrically constrained chemical computers (Sielewiesiuk and Gorecki, 2001; Motoike and Yoshikawa, 2003; Gorecki et al., 2009; Yoshikawa et al., 2009; Górecki and Górecka, 2006), molecular logical gates and circuits (Stojanovic et al., 2002; Macdonald et al., 2006). In contrast, there are hundreds if not thousands of papers published on quantum computation, membrane computing and artificial immune systems. Such a weak representation of laboratory experiments in the field of unconventional computation may be due to technical difficulties and costs of prototyping.

In last few years we have developed a concept, architectures and experimental laboratory prototypes of living and hybrid computers made of slime mould *Physarum polycephalum* (Adamatzky, 2010). In course of our studies of the slime mould's computational properties and designs of Physarum chips we found that the slime mould based sensors and processor are very fragile, highly dependent on environmental conditions and somewhat difficult to control and constrain. Thus we have started to look for living substrates that could complement, or even become an alternative to, computing devices made of Physarum's protoplasmic tubes. Plant roots got our attention because they are mobile, growing, adaptive intelligent units (Brenner et al., 2006; Baluška et al., 2009, 2010; Ciszak et al., 2012; Burbach et al., 2012), similar in their behaviour to active growing zones of *P. polycephalum*. Plants are, in general, more robust and resilient, less dependent on environmental conditions and can survive in a hostile environment of bio-hybrid electronic devices longer than slime moulds do. A prospective computing device made from living plant would perform computation by means of electrical charge propagation, by travelling waves of mechanical deformation of immobile structures, and by physical propagation of structures. Conductive pathways would be a key component of any plant-based electrical circuit. Thus to achieve a realistic assessment of the potential of the living plants based hybrid processing technology we must evaluate the feasibility of living plant wires in a proof-of-concept device. Previous findings on of organic wires and using living substrates to grow conductive pathways: self-assembling molecular wires (Wang et al., 2006; Paul and Lapinte, 1998), DNA wires (Beratan et al., 1997), electron transfer pathways in biological systems (Willner and Katz, 2006), live bacteria templates for conductive pathways (Berry and Saraf, 2005), bio-wires with cardiac tissues (Cingolani et al., 2012), golden wires with templates of fungi (Sabah et al., 2012). We are not aware of any published results related to evaluation of living plants, or

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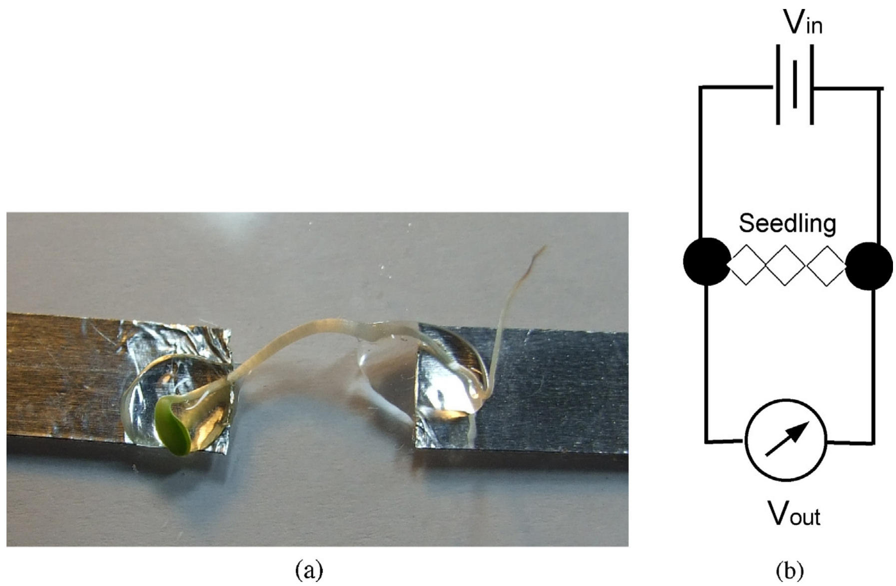

Fig. 1. Experimental setup. (a) A photo of lettuce seedling resting on aluminium electrodes in drops of distilled water. (b) A scheme of the experimental measurement of potential transfer function.

their parts, as electrical wires. There are substantial experimental findings on electrical impedance of plants however mostly related to evaluation of the plants physiological state via their impedance characteristics, see e.g. (Zhang and Willison, 1993; Inaba et al., 1995; Mancuso, 1999, 2000).

The paper is structured as follows. We describe experimental techniques in Section 2. Section 3 presents results on resistance of lettuce seedlings, approximation of direct current potential transfer function and immunity of plant wires to noise. Outcomes of the research and future directions of study are discussed in Section 4.

2. Methods

We experimented with lettuce (*Lactuca sativa*) seedlings 3–4 days after germination. Electrodes were made of a conductive aluminium foil, 0.07 mm thick, 8 mm wide, 50 mm (inclusive part

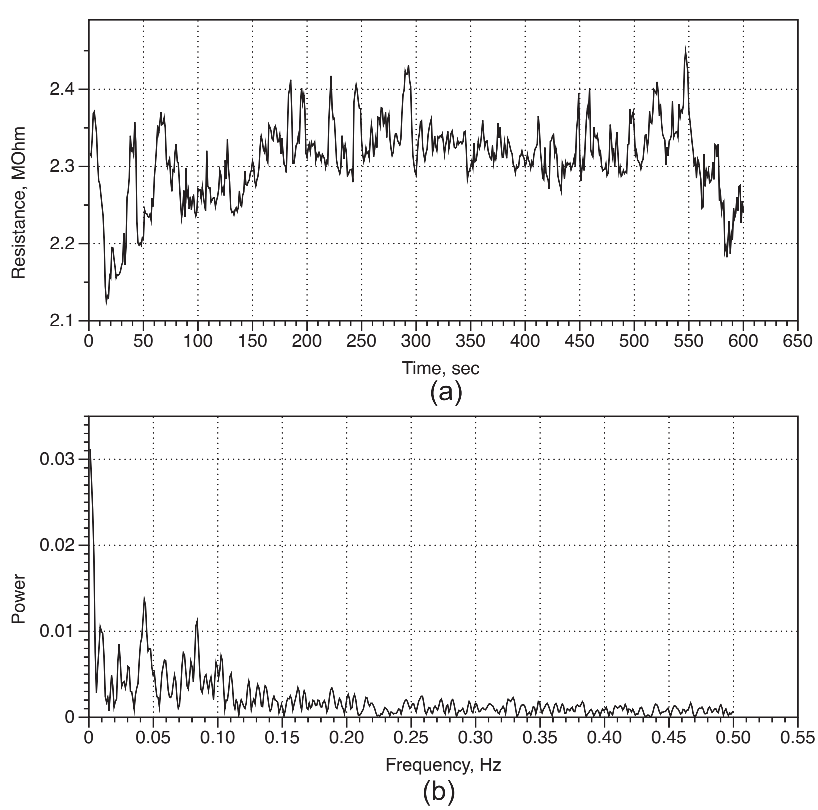

Fig. 2. Lettuce resistance. (a) Exemplar dynamics of resistance. (b) Power frequency spectrum.