Electronic Food: enabling edible electronic systems for biomedical and food monitoring applications

Rendicontazione

Informazioni relative al progetto

ELFO

ID dell'accordo di sovvenzione: 864299

Sito web del progetto

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Periodic Reporting for period 2 - ELFO (Electronic Food: enabling edible electronic systems for biomedical and food monitoring applications)

Periodo di rendicontazione: 2022-03-01 al 2023-08-31

Sintesi del contesto e degli obiettivi generali del progetto

ELFO will provide the foundations of a new enabling technology for disruptive edible electronic systems, with applications in advanced biomedical devices for continuous monitoring of the health

status within the gastro-intestinal (GI) tract, as well as in electronic tags for food monitoring, serving public health and providing at the same time a very powerful tool against counterfeiting.

These systems will be unperceivable and mass produced mainly with mask-less, printing and direct-writing methods. Besides being completely safe for ingestion, such devices will also be perceived as food, favouring public acceptance. Such an ambitious plan will be implemented by: i) creating knowledge on electronic properties of food and food derivatives and complementing them with edible solution-processable, mainly carbon-based semiconductors, thus developing an extended library of edible electronic materials; ii) developing large-area, solution-based, printing and direct-writing scalable processes with high lateral resolution for the precise patterning of edible functional materials; iii) developing edible electronic components required in systems, from logic to power and sensors; iv) validating the progress with two proof-of-concept systems, an edible smart pill, answering the need for compliance and drug delivery monitoring devices, and actuators within the gut, and an edible food monitoring tag, answering the need for certification and anti-counterfeiting devices directly onto or into food products. ELFO will give solid engineering grounds to the visionary perspectives of edible electronics, introducing imperceptible intelligence in any edible item, thus accessing more information on what we eat, how it is assimilated and enabling biomedical devices for mass health screening.

Lavoro eseguito dall'inizio del progetto fino alla fine del periodo coperto dalla relazione e principali risultati finora ottenuti

A PERSPECTIVE FOR EDIBLE ELECTRONICS

The emerging field of edible electronics is still in its infancy, yet is creating great scientific resonance by envisioning a technology which is safe for ingestion, environmentally friendly, cost-effective, and degraded within the body after performing its function, either digested or even metabolized. Despite the interest, we noticed that the field was still characterized by a few isolated attempts in different laboratories. In order to help shape the field more consistently, the main ideas and perspectives that have been proposed in the recent past were critically curated, underlining what edible electronics is and might be in the future according to our vision. Long-term opportunities (Figure 1) in terms of environmentally friendly smart technologies, remote healthcare monitoring, and the formidable challenges ahead were discussed, covering major issues with respect to safety, materials approval, processing, power supply, communication, and human body interaction.

EDIBLE FUNCTIONAL MATERIALS

In the first half of the project, we focused on developing edible conducting composites to satisfy the needs of the first edible devices. In particular, we formulated an electrically conductive oleogel paste made with materials with a high tolerable upper intake limit (≥mg kg^−1 body weight per day), such as natural waxes, oils, and activated carbon conductive fillers. Such pastes (Figure 2) are hydrophobic and can withstand operation in aqueous media. They have antibacterial and hydrophobic properties so that they can be used in contact with food preventing contamination and preserving its organoleptic properties. To answer the need for lower resistivity electrodes to be used in electrochemical energy devices, we also demonstrated edible cellulose-based conductive composites made of ethylcellulose and activated carbon. With such composites we realized edible free-standing, phase-separated bi-layered films, insulating at the top and with low electrical resistivity (~10 Ω•cm) at the bottom.

EDIBLE ELECTRONIC SYSTEMS AND COMPONENTS
In the first half of the project a strong progress was made in the development of electronic components of future edible systems. Some of the results achieved represent milestones towards the concrete realization of edible electronics.
- Transistors and Circuits
Honey-Gated Complementary Organic Transistors and Circuits: we demonstrated that a cost-effective and edible substance, honey, can used as a gating medium in low-voltage organic transistors (Figure 3).
- Power Supply
We have been evaluating and testing different strategies to provide power. In one case, we demonstrated the successful operation of edible cellulose-based conductive composites as electropositive elements in organic triboelectric nanogenerators and as electrodes in fully edible supercapacitors. We have also unlocked for the first time edible rechargeable batteries, a real breakthrough towards future edible systems. Drawing inspiration from living organisms, which use redox cofactors to power biochemical machines, we demontrated a rechargeable edible battery formed from materials eaten in everyday life (Figure 4).
- Sensors
We proposed a self-powered edible defrosting sensor (Figure 5), a device that can detect defrosting events by coupling a temperature activated galvanic cell with an ionochromic cell, whose color is irreversibly altered by the release of ions during current flow. The temperature at which the sensor reacts can be tuned between 0 and –50 °C.
- Communication
Among different options, we explored Intra-Body Communication (IBC), based on the ionic conductivity of our body, exploiting the same principle that allows us to record an electrocardiogram. In particular, we adopted IBC to monitor passive drug release. In this framework, we proposed an edible pill, realized starting from food additives and food-grade materials, exploiting a passive IBC activation.The proof-of-concept is designed for a targeted release and monitoring of Metformin in the intestine. This work led to a patent application ("Dispositivo degradabile per il rilascio passivo e tracciabile di una sostanza").

Progressi oltre lo stato dell’arte e potenziale impatto previsto (incluso l’impatto socioeconomico e le implicazioni sociali più ampie del progetto fino ad ora)

The project progressed well beyond the state-of-the-art under many aspects. Here a list of the most significant achievements.
1) The first Honey-Gated Complementary Organic Transistors and Circuits were demonstrated
2) An Electrically Conductive Oleogel Paste for Edible Electronics was demonstrated for the first time
3) We demonstrated the world’s first Edible Rechargeable Battery
4) We devised a methodology to monitor passive drug release through switching of the in IntraBody Communication coupling
5) We reported a self-powered edible defrosting sensor, exploiting a simple principle, the dependence

of the ionic conductivity of water (or of salted water) on its state (liquid or solid, when frozen).

We are currently active in the following activities, which should produce results in the next months.
a) Edible Semiconductors: we are testing and optimizing a series of edible and potentially edible molecules in electrolyte-gated field-effect transistors.
b) Circuits: we are optimizing edible inverting logic gates in order to enable monolithic edible oscillators.
c) Sensors: we are active in the development of edible gas and pH sensors.
d) PoC: we are actively monitoring the progress in all components to device the best strategy for the realization of proof-of-concept smart pills (ELFO-Pill) and edible food tags (ELFO-tag), planned at the end of the project.

Figure 5. Edible Defrosting Sensor

Figure 4. Edible Rechargeable Battery

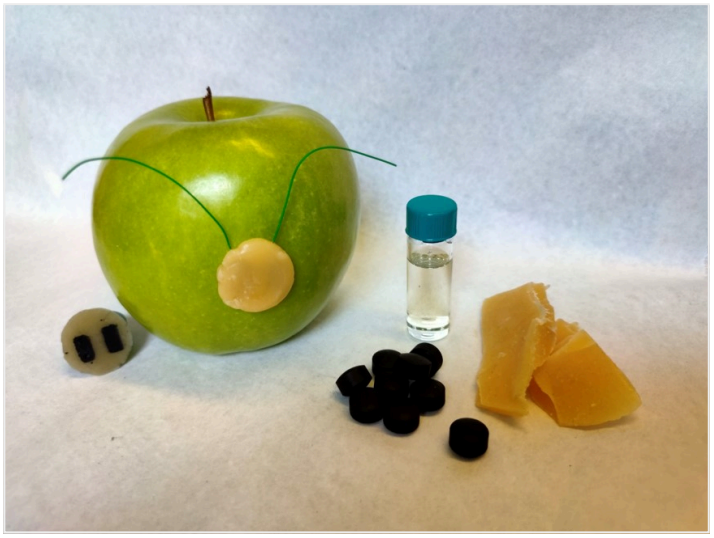

Figure 2. Conductive oleogel paste and its possible use as impedance sensor

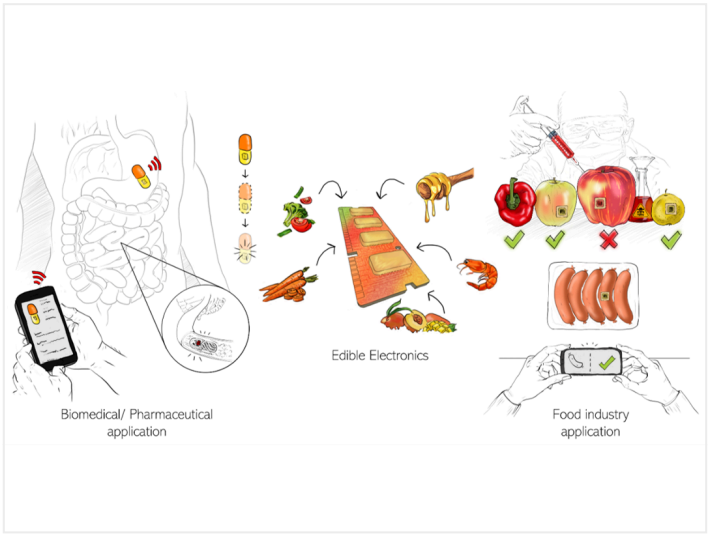

Figure 1. Long-term vision of ELFO project

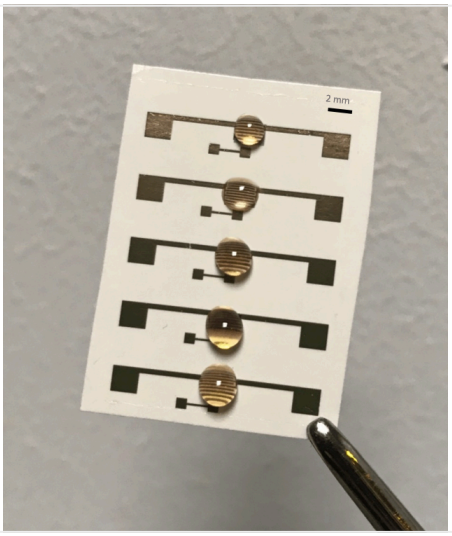

Figure 3. Honey-gated transistors on temporary tattoo paper

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