Wearable Microwave Imaging System for Brain Stroke Imaging

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***Abstract*—This paper presents the experimental validation of the detection capabilities of a low complexity wearable system designed for the imaging-based detection of brain stroke. The system approaches the electromagnetic inverse problem via a 3-D imaging algorithm based on the Born approximation and the Truncated Singular Value Decomposition (TSVD). For testing, flexible antennas with custom-made coupling-medium are prototyped and assessed in mimicked hemorrhagic and ischemic stroke conditions. The experiment emulates the clinical scenario using a single-tissue anthropomorphic head phantom and strokes with both 20 cm^3 and 60 cm^3 ellipsoid targets. The imaging kernel is computed via full-wave simulation of a virtual twin model. The results demonstrate the capabilities for detecting and estimating the stroke-affected area.**

I. Introduction

Stroke is a severe medical condition that disrupts the normal oxygen-rich blood-feeding of the brain, triggering the death of millions of neurons per minute and provoking temporal and permanent disabilities, or even the dead in many cases. There are two typologies of stroke, ischemic and hemorrhagic. In the first case, a clot diminishes the blood irrigation, starving the surrounding areas gradually by the ischemia. In the second type, the burst of a vessel leads to internal bleedings. Whatever the typology, a prompt diagnosis and intervention directly impact the patient's recovery [1].

Clinicians support stroke emergency care with imaging-based diagnosis techniques such as magnetic resonance imaging (MRI) and computerized X-ray tomography (CT), which contribute with valuable information for the prognosis. Though, current standard technologies present limitations in terms of cost, portability, time-consume, and harmfulness (in the CT case). Thus, in recent years, microwave imaging (MWI) technologies have arisen as complementary solutions [2]–[6]. MWI relies on the contrast of the electrical properties (permittivity and conductivity) between the stroke-affected area and the healthy brain tissues at microwave frequencies.

In this paper, we assess experimentally the detection and imaging capabilities of a new wearable version of the system for 3-D stroke imaging presented in [5], [6], considering both stroke typologies.

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II. Methods

A. Imaging Algorithm

The detection imaging-based algorithm used here aims to retrieve a qualitative mapping of the variation of the electric contrast due to a stroke onset or a status variation, e.g. the growing or shrinking of the affected brain area. The algorithm takes as input a differential scattering matrix (ΔS), referred to the time interval (t_0, t_1), and a pre-computed electric field $\mathbf{E}$ of a reference nominal condition, which is obtained via a full-wave simulation of a realistic virtual twin [7]. In this case, the reference condition is a healthy scenario using a single-tissue head, i.e. a homogeneously filled head without the stroke. Then, considering the expected weak and concentrated field perturbations, the imaging kernel is built using the fields and the Born approximation [5].

The algorithm allows to map the unknown electric contrast $\Delta\chi = (\epsilon(t_1) - \epsilon(t_0))/\epsilon_b$, where $\epsilon(t_0)$ and $\epsilon(t_1)$ are the complex permittivities, and b stands for the background, inverting the following relation,

$$\Delta S(t_0, t_1) = -\frac{j\,\omega\,\epsilon_b}{2\,a_p\,a_q} \int_D \mathbf{E}_p(t_0) \cdot \mathbf{E}_q(t_0)\,\Delta\chi\,d\mathbf{r}, \quad (1)$$

through the truncated singular value decomposition (TSVD) scheme [8], where the symbol "$\cdot$" denotes the dot product between vectors, D the imaging domain, j is the imaginary unit, $\omega = 2\pi f$ is the angular frequency, and a_p and a_q are the known incoming root-power waves at the p and q antenna ports, respectively [9]. Thus, the truncation index, here set to -30 dB, acts as a regularizer. Finally, the variation description is given by the normalized modulus of the retrieved differential contrast.

B. Antenna Module and MWI System

To gather the needed S-parameters for the imaging reconstruction, we employ a low complexity MWI prototype that consist of a 2-port vector network analyzer (VNA) [10], set with 0 dBm and 50 Hz intermediate filter (IF), an 2-to-24 electro-mechanical switching matrix and a 24-element array of antenna-coupling pairs (see Fig. 1(a)), following the rigorous design procedures described in [11]. For details on the switching matrix refer to [5], [6].

The antenna in this case, is an optimized version of the one in [12], that reduces the size and weight of the device while keeps the benefit of using a discrete and solid matching medium. It is designed to work in vicinity of the human head

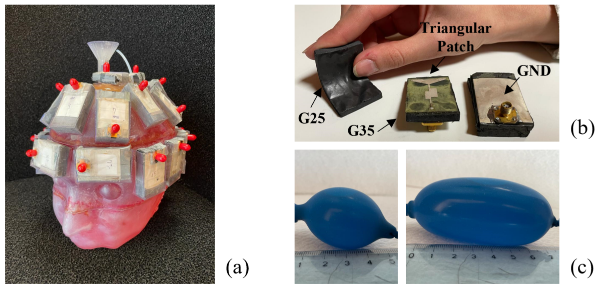

Fig. 1. Experimental system components. (a) Homogeneous head phantom filled with brain-mimicking liquid and surrounded by the 24 antenna-coupling elements. (b) Sectioned antenna. (c) Balloon filled of hemorrhagic or ischemic-like liquid, mimicking the stroke cases.

TABLE I
MATERIALS COMPOSITION AND PERMITTIVITY

	Isopropyl Alcohol[%]	Demineralized Water[%]	Salt [%]	ϵ_r (1 GHz)	σ [S/m]
Brain	32.5	67.2	0.3	42.6	0.78
HEM	18.5	80.7	0.8	67.1	1.30
ISC	55.3	45.7	1.0	30.5	0.72

in a band around 1 GHz, hence reaching a good trade-off between wave penetration and spatial resolution [2], [11]. In the specific, we use flexible custom-made materials based on a mix of graphite powder and rubber as either matching medium and the substrate between the monopole antenna and the ground plane as shown in Fig. 1(b). For the matching (referred as G25), the percentual weight proportion is 25% graphite – 75% rubber, obtaining a relative permittivity and conductivity at 1 GHz of 13 and 0.18 S/m, respectively. Instead, the substrate (G35) is a 35%–65% mixture, with a relative permittivity and conductivity of 18 and 0.3 S/m.

Finally, to perform the experiment we consider a 3-D printed anthropomorphic head [13], filled with alcohol-water-salt liquid mimicking the electric properties of an average brain at 1 GHz. The stroke is realized using a balloon, representing a 60 cm^3 hemorrhage (HEM) and a 20 cm^3 ischemia (ISC). Table I summarizes materials composition and their electric properties.

III. RESULTS

The normalized reconstructed dielectric contrast of both mimicked hemorrhagic and ischemic conditions are summarized in Fig. 2, illustrating the detection, localization, and the 3-D recovered shape.

IV. CONCLUSION AND PERSPECTIVES

This paper explores experimentally the detection capabilities of a wearable low complexity system to detect mimicked hemorrhagic and ischemic affected brain areas applying a differential imaging algorithm based on a distorted Born approximation. The system retrieves truthful 3-D shape and location estimation of the stroke contrast, significant medical information, in a simplified clinical condition. Future work approaches the open issue of the stroke classification and the applicability of the system on more complex and realistic scenarios.

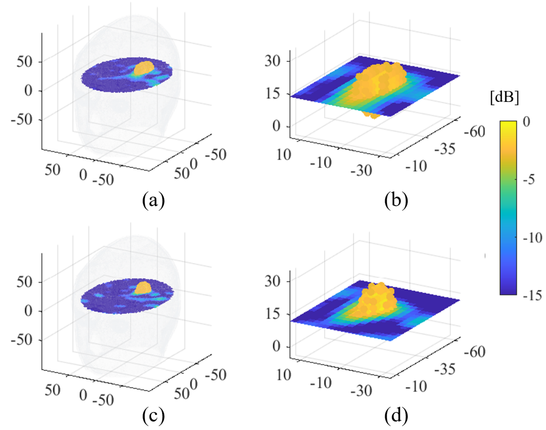

Fig. 2. Normalized reconstructed dielectric contrast transverse sliced in the middle of the stroke region, zooming up in the right column the values above -3 dB. (a, b) 60 cm^3 HEM; (c, d) 20 cm^3 ISC. Dimensions in [mm].

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