EIT System with Skip Pattern Application: Enhanced Target Image Reconstruction Methodology

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***Abstract* - This paper presents a method for implementing skip patterns in Electrical Impedance Tomography (EIT) systems, which improves upon the limitations of the conventional adjacent method in image reconstruction. By applying skip patterns, we achieve a more uniform current distribution, thereby enhancing the ability to reconstruct target images. This approach provides a flexible and efficient framework suitable for various EIT applications across multiple industries, including medical imaging and industrial process monitoring.**

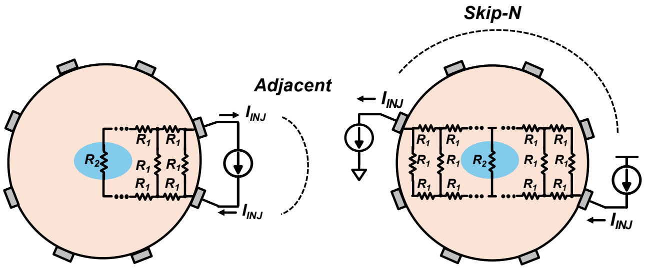
***Keywords*—Electrical Impedance Tomography (EIT), EIDORS, Current stimulator, Biomedical Sensor**

I. INTRODUCTION

Electrical Impedance Tomography (EIT) has been recognized as a promising technology in various fields, including medical imaging and industrial process monitoring and the challenges related to image quality and resolution have persisted.

When EIT readout is implemented using ICs, the conventional adjacent current pattern-based method uses adjacent electrode pairs, which simplifies hardware implementation and allows clear signals due to the close physical distance between adjacent electrodes. This not only improves the SNR of measurements but also facilitates data collection [1]. However, the adjacent method concentrates current on the electrode surface of the measurement target, making it more effective in detecting impedance changes near the surface but relatively less effective for the interior of the measurement target. While there are theories and papers on the benefits of applying skip N patterns, the hardware implementation remains challenging [2].

This paper aims to investigate a method for designing a reconfigurable readout module for detecting relative impedance changes, focusing on the implementation of a skip-N pattern approach in EIT. The research seeks to confirm that applying skip patterns enhances image reconstruction capabilities compared to the conventional adjacent method.



(a) (b)

Fig. 1. Current injection methods for EIT: (a) Adjacent current pattern, (b) Skip-N current pattern.

The study will present an ideal model of an EIT readout capable of performing the skip-N pattern and develop an algorithm to implement this using EIDORS. By analyzing the results, this research serves as a foundation for improving EIT image quality without significant hardware investment, potentially opening new avenues for enhancing EIT technology.

II. DESIGN METHODOLOGY

A. Comparison of Adjacent and Skip-N Methods

The current injection method used in most IC-based existing EIT systems is the adjacent pattern, as shown in Fig. 1(a). Such a pattern method injects current through two neighboring electrodes and measures voltage at the remaining electrodes. When the adjacent current pattern is used, a voltage measurement is typically integrated into a single chip by connecting well-known biopotential amplifiers used for biopotential measurement [3]. Current injection is performed using a differential current generator in a single channel, also integrated into the same chip [4]. This method is most sensitive to impedance changes near the boundary. However, a disadvantage of the adjacent pattern method is that current flows mainly near the phantom boundary, preventing effective current flow to the center. This makes it difficult to accurately capture information about the center of the target. In contrast, the Skip-N method, as shown in Fig. 1(b), injects current and measures voltage through two non-adjacent electrodes. The advantage of this method is that the current is distributed relatively uniformly across the entire target, and it is less sensitive to impedance

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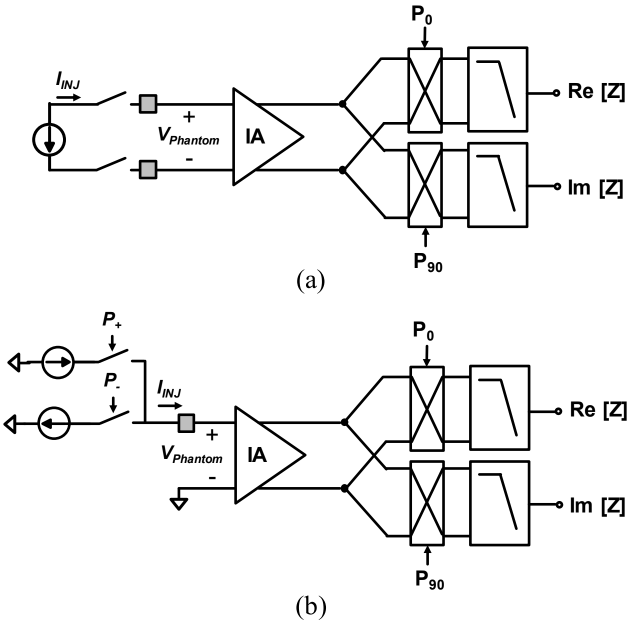

Fig. 2. (a) conventional EIT readout channel and (b) proposed Skip-N reconfigurable EIT readout channel.

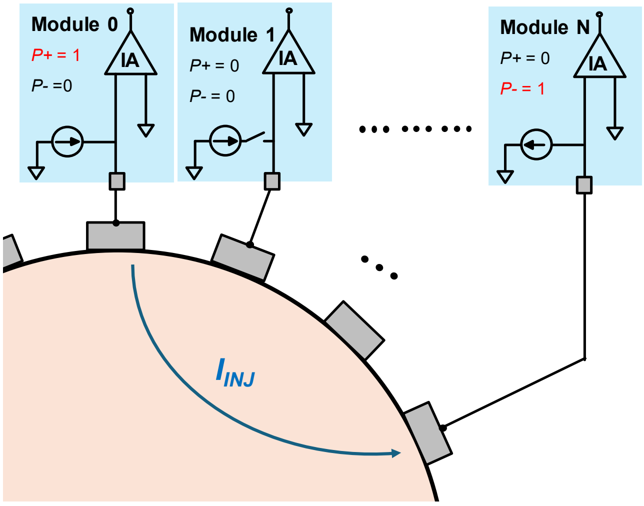

Fig. 3. EIT system configuration using Skip-N EIT readout.

changes at the boundary compared to the adjacent method. Therefore, the skip-N pattern is expected to allow a more accurate reflection of the overall structure of the target and improve the image quality [2], [6].

B. Readout and Phantom Configuration

Fig. 2(a) shows the block diagram of the readout module used for a conventional EIT to detect impedance changes. This design utilizes all components from Cadence, specifically employing ideal current sources, voltage-controlled voltage sources, and resistors, as explicitly stated. The module consists of a current generator and a readout IC [4], responsible for input and output, respectively. The study utilizes 16 electrodes arranged in a circular pattern around the phantom. The current generated from the current source flows through the impedance phantom via the electrodes, creating a voltage across the resistive components of the mesh. The resulting voltage becomes the output of the readout IC section and is used as data for image reconstruction.

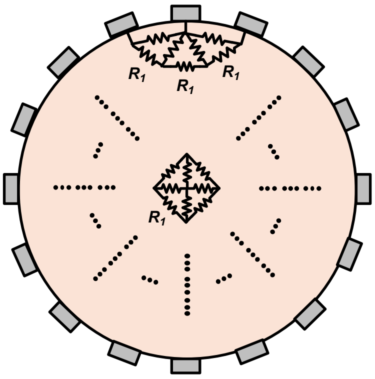

Fig. 4. Impedance phantom for EIT readout.

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imdl= mk_common_model('h2c2' ,16);

imdl.fwd_model.stimulation =
mk_stim_patterns(16,1,[0,Skip],[0,Skip],{'meas_current'},1);
imdl.fwd_model = rmfield( imdl.fwd_model, 'meas_select');

for idx= 1:3
  if    idx==1
    imdl.hyperparameter.value= .01;
  elseif idx==2
    imdl.hyperparameter.value= .03;
  elseif idx==3
    imdl.hyperparameter.value= .1;
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Fig. 5. Forward modeling definition for image reconstruction using EIDORS with skip-N EIT system.

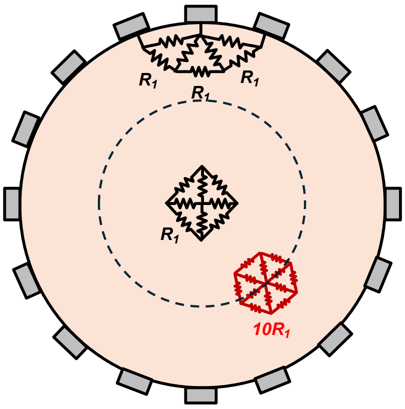
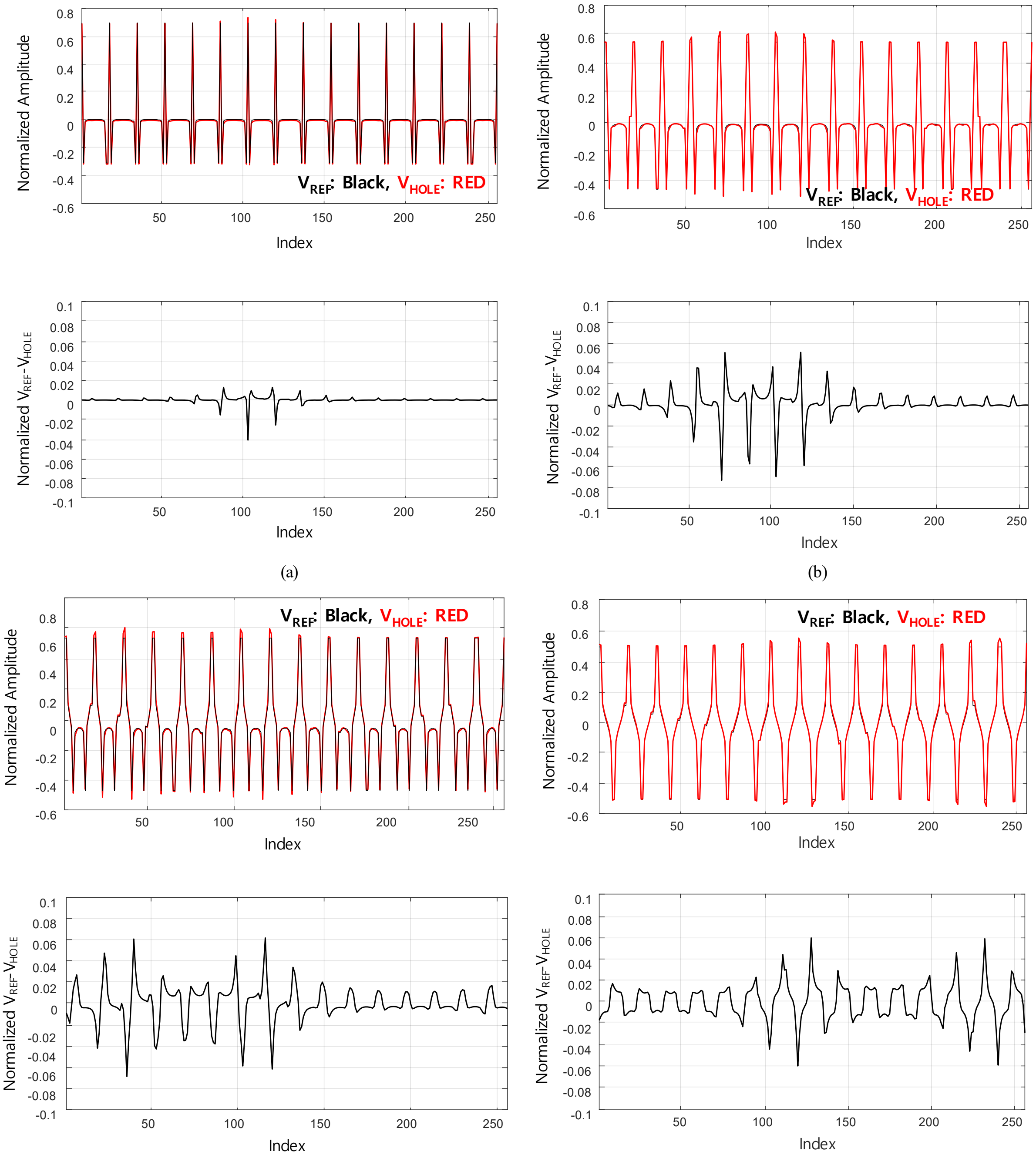


Fig. 6. Deformation of the phantom.

Unlike the adjacent method, the Skip-N approach requires a reconfigurable design to determine where the current enters and exits. Consequently, the EIT readout is designed as shown in Fig. 2(b). In this configuration, P+ and P- switches determine the electrodes for current input and output, comprising a current injector for current injection and an Instrumentation Amplifier (IA) for reading the phantom's voltage.

When applying this Skip-N EIT readout to an actual phantom, its structure resembles that shown in Fig. 3. N

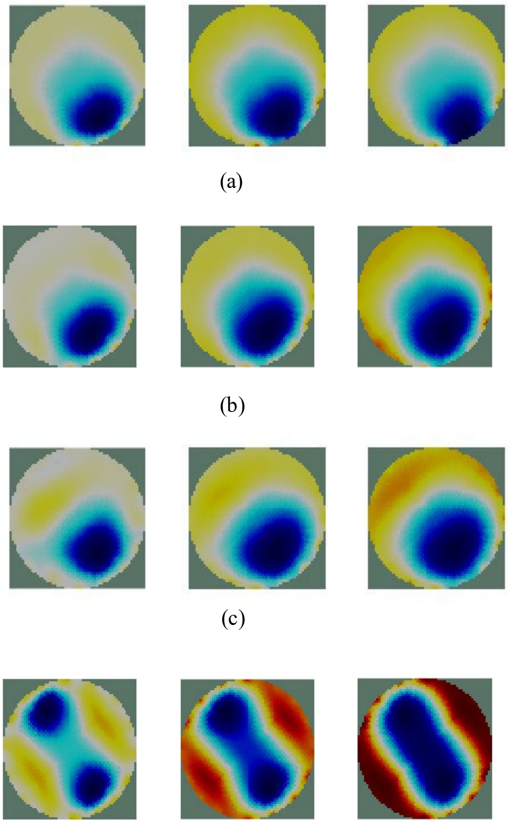


(a) (b)

(c) (d)

Fig. 7. Raw data for differential EIT and normalized V_{REF}-V_{HOLE} for (a) Skip-1 (adjacent), (b) Skip-2, (c) Skip-4 and (d) Skip-8.

modules are arranged around the phantom, and by appropriately inputting 1 or 0 to P+ and P-, the system can generate the current pattern required for Skip-N and read the voltage. The key components of this Skip-N EIT readout design include: 1) A switching technique that allows current sinking from a specific channel and current sourcing to another channel among N modules. 2) Current injector for precise current application. 3) IA for accurate voltage measurement 4) N modules surrounding the phantom for comprehensive coverage. Notably, key component number 1) is a technique we added in our research to implement skip-N EIT. This design allows for the implementation of various Skip-N patterns by simply adjusting the switch configurations, enabling EIT measurements with better image quality compared to the traditional adjacent method. Note that when implementing the Skip-N pattern with an EIT system dedicated to an adjacent pattern in [3], the physical distance between electrodes increases during injection using the current generator, making the wiring more complex and thus making it very difficult to achieve optimal signal quality. Fig. 4 represents a model of the impedance phantom. Each triangular resistive mesh uses a unit load of $1k\Omega$ to divide



(a)

(b)

(c)

(d)

Fig. 8. Image reconstruction result for (a) Skip-1 (adjacent), (b) Skip-2, (c) Skip-4 and (d) Skip-8.

the mesh into a hierarchical structure in a regular pattern. The configuration is symmetric, with electrodes positioned diametrically opposite each other on the circular phantom.

C. Algorithm Setting

The EIT algorithm primarily consists of two main components: the forward problem, which models changes in surface voltage due to impedance variations, and the inverse problem, which estimates impedance changes based on observed surface voltage variations. These two components form the foundation of the EIT algorithm, enabling the reconstruction of internal impedance distributions from external voltage measurements. When the current pattern changes, the voltage variations due to impedance changes also differ, requiring a reconfiguration of the forward problem. EIDORS provides a method to set this up. First, the impedance mesh for the forward problem is set to 'h2c2'. Then, the current stimulation is implemented using the ‘mk.stim.pattern’ function. During this process, a 'skip' variable is introduced, as illustrated in Fig. 5. This allows for the computation of the forward problem for any arbitrary skip-N current pattern. By incorporating this skip variable, the system can adapt to different current injection patterns, enabling a more flexible and comprehensive analysis of the electrical impedance tomography data.

III. SIMULATION RESULTS AND DISCUSSION

Using the above Skip-N EIT system for image reconstruction yields the following results. Skip values of 1, 2, 4, and 8 were used, with Skip 1 being identical to the adjacent pattern. The simulation bench based on the ideal model of Fig. 3 for 16 channels and the phantom shown in Fig. 4. was implemented in Cadence. Additionally, Fig. 6 shows the phantom with a specific layer's impedance value partially set to 10 times its original value in Fig. 4. After setting up, we simulated the voltages resulting from current injection over time, both before and after deformation, and performed differential EIT. First, each upper figures of Fig. 7(a)~7(d) show the raw data of voltage measurements for EIT. The black color represents the reference voltage when no deformation is applied to the phantom, while the red color shows the voltage distribution when a hole is made on one side of the phantom's resistor. In addition, for Skip values of 1 and the others, the voltage distribution changes overall as the current injection site changes, and when a hole is present, a slight change in the pattern occurs compared to the reference. When such differences are observed, As can be seen in the lower figures of Fig. 7(a)~7(d), the skip-2, Skip-4, and Skip-8 cases show much more change than the skip-1 case, occurring throughout the entire sweep process. This suggests that skip-4 has lower noise requirements compared to skip-1.

The results of image reconstruction using this data are shown in Fig. 8. These results confirm the ability to locate the hole's position with hyperparameter settings of 0.1, 0.3, and 0.5 from left to right. skip-1 (a), skip-2 (b), and skip-4 (c) demonstrated the ability to acquire images using the newly proposed EIT acquisition technique. Note that in the case of skip-8, (d)due to the complete symmetry of the current and voltage patterns, the location of the impedance hole cannot be uniquely determined. Instead, two opposing points are both recognized as impedance holes.

IV. CONCLUSION

In this study, we proposed an approach to enhance target image reconstruction in EIT systems by utilizing skip patterns. While the conventional adjacent pattern is widely used, it has limitations in terms of spatial resolution and image accuracy. By introducing skip patterns in the stimulation and measurement configurations, we achieved significant improvements in reconstruction quality and efficiency. Simulation results demonstrated that skip patterns can provide more accurate and detailed information in imaging target areas compared to conventional methods. This approach is expected to reduce the effect of extrinsic or intrinsic noise and allow for better differentiation of impedance changes within the imaging area. Furthermore, the proposed method offers a flexible and efficient framework suitable for various EIT applications, including medical imaging and industrial process monitoring [5].

ACKNOWLEDGMENT

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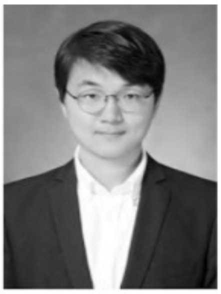
Junho Park is currently pursuing his B.S. degree in electrical engineering from Dankook University, Yong-in, Korea, since 2020. He is currently conducting research on low-power IC design for biomedical devices, especially on EIT systems.



Nahmil Koo (S’19-M’21) received the B.S. degree in electrical engineering from Hanyang University, Seoul, South Korea in 2016, and the M. S. degree and the Ph.D degree in electrical engineering from Korea Advanced Institute of science and technology, Daejeon, South Korea in 2018 and 2021, respectively. From 2021 to 2023, he was a staff researcher at Samsung Advanced Institute of Technology in Suwon, South Korea, where he was involved in multi-modal neural recording SoC. Since 2023, he has been with the Department of Convergence Semiconductor Engineering, Dankook University, where he is currently an assistant professor. His main interests are integrated biomedical sensors and systems, which include ExG sensor, Bio-impedance sensor, electrical impedance tomography (EIT) sensor, and sensor security solutions.