

PAPER • OPEN ACCESS

Image reconstruction for liquid-gas regime identification based on multiple excitation sources in electrical resistance tomography system

To cite this article: Y A Wahab *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **705** 012025

View the [article online](#) for updates and enhancements.

Image reconstruction for liquid-gas regime identification based on multiple excitation sources in electrical resistance tomography system

Y A Wahab*, M F Fuad, N M A Ghani, Z M Zain, M M Noh, M A Zawawi and M S Najib

Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang

*Corresponding author: yasmin@ump.edu.my

Abstract. Electrical resistance tomography (ERT) reconstructs internal resistance images of the field from electrical measurements on the surface. The objective of this paper is to obtain the tomogram of the liquid-gas regime of ERT system by using multiple excitation sources. A linear back projection algorithm was implemented as a basic algorithm. Then, it was modified to suit the implementation of multiple excitation sources. A liquid-gas regime in the steel pipe was used as a tested medium. The analysis and performance of the image reconstructed which applies multiple excitation sources were compared with the single excitation technique. As a common strategy applied a single excitation source and produce problem especially at the center of the pipe, this paper mainly focuses on image reconstruction of multiple excitation sources. As a conclusion, 50% of the excitation source cannot produce the image as expected. Tomograms that produced by using the single excitation source were much better than the images obtained by using 50% of the excitation source.

1. Introduction

ERT is considered a promising process tomography technology due to its advantages such as high speed, low cost, and non-intrusive sensors [1]. The ERT system consists of sensing electrodes, a data collection system, and image reconstruction and visualization unit [2]. The operation mode of ERT applies a current or voltage on an excitation electrode and measure a potential difference or a current at the detection electrodes [3]. A current is excited at a pair of electrodes in the measurement section and the sensing field. In the case of conduction pipes, the electrodes need to be insulated from the conducting wall [4].

ERT system can be categorized as one of the soft-field tomography [5]. The nature of soft-field behavior is that it produces a curve line for each of the projection in the forward problem. It means that, when the image is reconstructed, the possibility to get a quality tomogram of the medium of interest especially at the center of the region of interest also reduced. One of the methods that commonly used to solve the problem is by increasing the number of electrodes applied in the system. However, by increasing the number of electrodes it also increases the cost of the system because the cost of the sensor fabrication become more expensive. Simultaneously, that approach applies a single source excitation. Therefore, multiple excitation sources technique was introduced in [6]. The technique was introduced to avoid the increment number of electrodes in the ERT system and hence



can reduce the sensor fabrication cost. The results showed that by increasing the number of excitation sources up to half of the total electrodes in time will increase the sensor reading performance. Based on this paper, the authors believed that the increment of the sensor reading performance will also increase the quality tomogram obtained in the image reconstruction part.

Thus, based on [6] this paper is focused on the linearization approach of the image reconstruction part for the ERT system. The main objective is to prove either it is true or not that the multiple excitation technique can increase the quality of tomogram obtained especially at the center of the pipe.

2. Image reconstruction of ERT system

2.1. Forward problem solving

The forward problem is identified as the system's sensitivity map [7]. The linearization solution is used by the ERT system when the sensor output is assumed to be a linear approximation [8]. The general mathematical equation for the forward problem of ERT system can be applied by using equation (1) [9].

$$M_{i,j}(x,y) = \int_{A(x,y)} \frac{E_i(x,y)}{I_i} \cdot \frac{E_j(x,y)}{I_j} dx dy \quad (1)$$

Where $M_{i,j}(x,y)$ is the sensitivity map between pair electrode i and j at position (x,y) within area $A(x,y)$, E_i and E_j are the electric fields due to the current or voltage driven owing to electrode i and j . The dot multiplication between E_i and E_j produce a pair for each of i - j electrode.

COMSOL Multiphysics was applied as the software platform to solve the forward problem. The 2-dimensional electric current, ec physic in the COMSOL software was chosen for this purpose. Then, the geometry that mimics a real pipe as well as the material for each domain, were set. Sixteen rectangular electrodes (E1-E16) had been installed and attached along the inner circumference of the steel pipe (see Figure 1). The electrodes were positioned equidistantly to ensure that the system can withdraw as much information as possible. The applied parameters in the simulation are shown in Table 1.

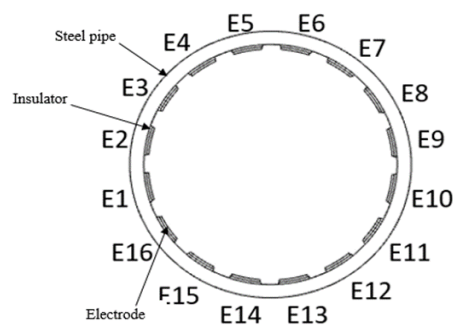


Figure 1. Geometry of ERT system in COMSOL Multiphysics

Table 1. Properties and specific dimension [10]

Item	Value
Inner diameter of steel pipe	54mm
Thickness of wall	3mm
Material of electrode	Silver
Number of electrodes	16
Excitation current	20mA
Electrode's width	6.4mm

The respective channels out of sixteen electrodes based on the multiple excitation sources or single excitation source were chosen for getting an individual map. Here, the electric current source was set at the boundary condition of the respective channels. Then, the model was mesh using normal mesh, and the data was obtained. Before exporting the data, the electric field expression and the desired numbers of pixels for the data were set. The electric field expression used in COMSOL is shown in equation (2). Besides, the number of pixels was applied by using 64 x 64 pixels values of the regular grid data of x and y points.

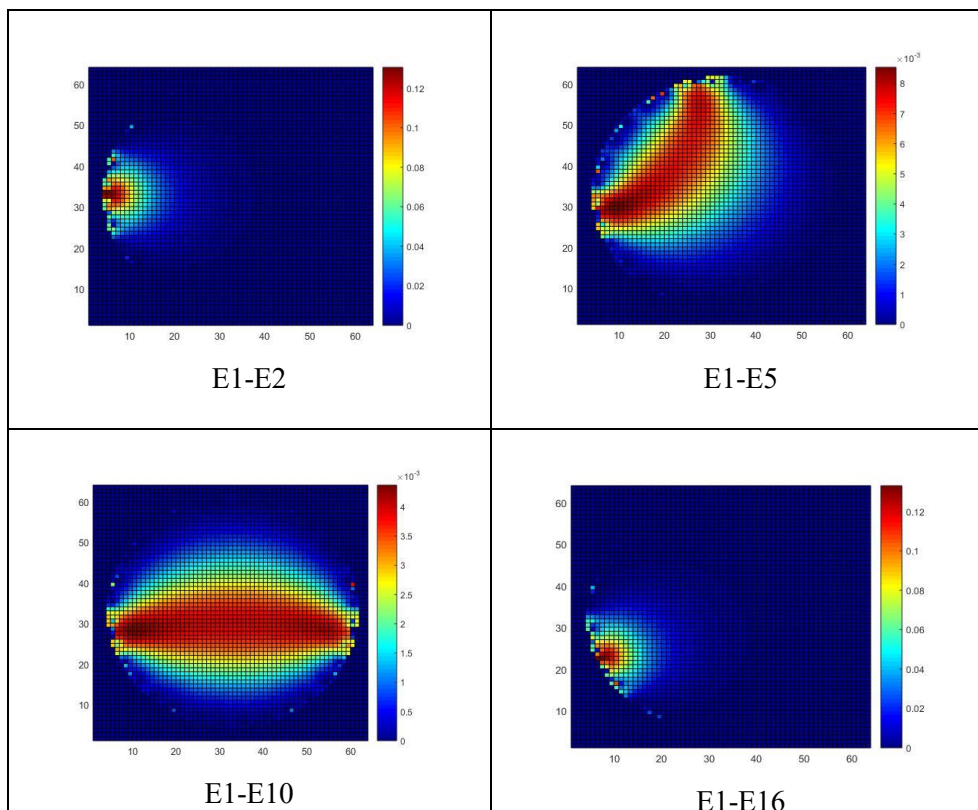
$$e_{(x,y)} = \sqrt{E_x^2 + E_y^2} \quad (2)$$

where $e_{(x,y)}$ is defined as the velocity vector of electric current between the electric field of x-axis and y-axis. E_x is the electric component in the x-axis of the electric field while E_y is the electric component in the y-axis of the electric field. Finally, the output data from COMSOL Multiphysics was exported into MATLAB. The selection data that only consists of the electric field values concerning the number of the pixels was plotted by using 'pcolor plotting' options in the MATLAB. After plotting the respective channels of the sensitivity map of the ERT system, the process was repeated until all the channels have been plotted. Finally, the pre-processing of the data of the sensitivity map was done in the MATLAB.

2.1.1. Normalized map for single excitation source

For the single excitation source technique, each of the pair projection maps was normalized to get the standardized map. This process of normalization sensitivity distribution, $\bar{M}_{i,j(single)}(x,y)$ was done by using equation (3). Figure 2 shows the example of the normalized sensitivity map when channel 1 was set as the source in the single excitation source technique.

Figure 2. Example of the normalized map for single excitation source technique



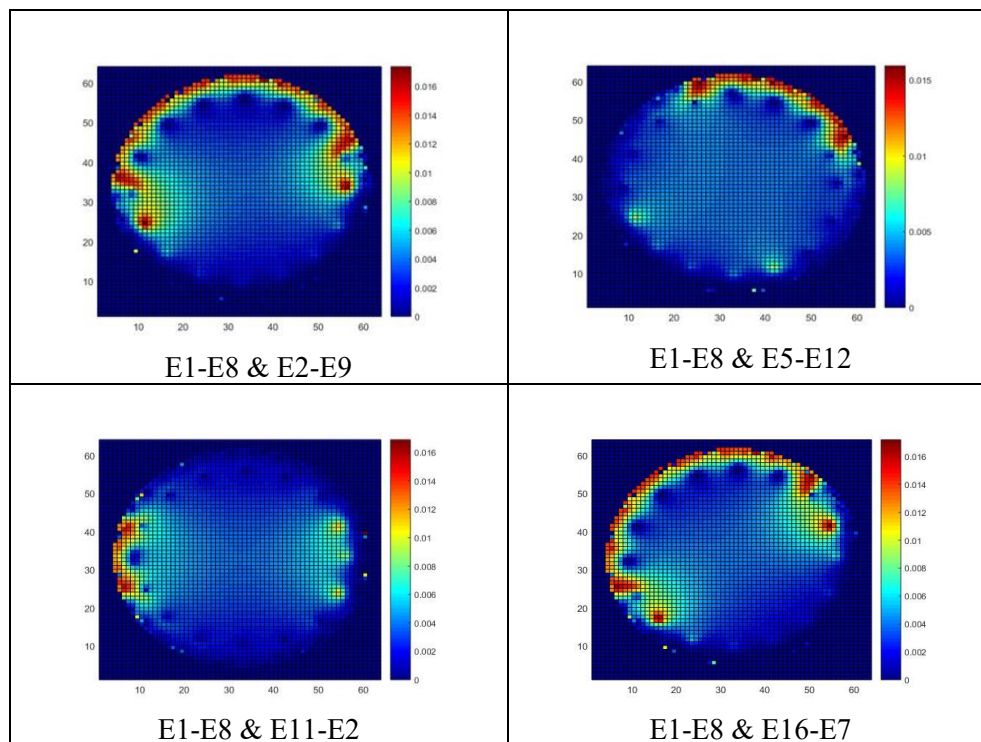
$$\bar{M}_{i,j(\text{single})}(x, y) = \frac{M_{i,j}(x, y)}{\sum_{i=1}^{16} \sum_{j=1}^{16} M_{i,j}(x, y)} \quad (3)$$

2.1.2. Normalized map for multiple excitation sources

For multiple excitation sources technique, the same steps were similar to sub-topic 2.1.1, but the difference is the number of the electrode for exciting and detecting were 8 electrodes, respectively. For the pair projection mapping, the multiple excitation sources would be paired up with the multiple receivers to produce a pair projection map. After the pair projection map, $M_{a,b(\text{multiple})}(x, y)$ is obtained, the next step was to produce the normalized map, $\bar{M}_{a,b(\text{multiple})}(x, y)$ as in equation (4). The a and b are the pair electrodes for each of the pair projection map. The difference between equation (4) and equation (3) is in term of the number of transmitter and receiver used in the ERT system. Figure 3 illustrates the normalized map for multiple excitation sources technique.

$$\bar{M}_{a,b(\text{multiple})}(x, y) = \frac{M_{a,b(\text{multiple})}(x, y)}{\sum_{a=1-8}^{16-7} \sum_{b=1-8}^{16-7} M_{a,b(\text{multiple})}(x, y)} \quad (4)$$

Figure 3. Example of the normalized map for multiple excitation sources technique



Based on Figure 2 and Figure 3, it can be seen that the single excitation method produced a better-normalized map compared to the multiple excitation technique. It can be observed that the normalized map produced by using the single excitation method had a clear curved line. The curved line presented owing to the soft-field behavior of the electrical resistance tomography. For multiple excitation method, the sensitivity distribution produced was not uniform and even. It is believed that the increasing number of excitation source affect the nature of soft field behavior. As for example between

the group of source channels, E1-E8 and the group of receiver channels, E16-E7; due to the very high values of electric field at the group of source channels and a very small electric field values at the group of receiver channels, the pairing results caused the highest value of electric field at only at the source part and consequently it did not produce a clear curve line between that pair projection. Hence, it is predicted that the tomogram that can be obtained in the image reconstruction part would also not clear for multiple excitation source method. To proof, this hypothesis, the normalized map for both methods were implemented in the inverse problem solving to reconstruct the image of the ERT system.

2.2. Inverse problem solving

In this project, the linear back projection (LBP) algorithm was applied as a basis for the image reconstruction part. LBP algorithm is widely used in many tomography processes [9]. The advantages of the LBP algorithm are its supply of low computational complexity and can produce an image at a high speed [11]. In reconstructing the image using the LBP algorithm, each of the corresponding sensor reading is being multiplied with each of the sensitivity matrices. Thus, the disadvantage of the LBP algorithm is it generates a blurred effect or also known as smearing effect. The tomogram can be produced based on equation (5) [11].

$$V_{LBP(single)} = \sum_{T_x=1}^m \sum_{R_x=1}^m \bar{S}_{T_x,R_x} \times \bar{M}_{T_x,R_x} \quad (5)$$

where

$$\bar{S}_{T_x,R_x} = \frac{S_{FullLiquid_{T_x,R_x}} - S_{Object_{T_x,R_x}}}{S_{FullLiquid_{T_x,R_x}}} \quad (6)$$

$V_{LBP(single)}$ is defined as a voltage distribution for a single excitation technique, m is the number of electrodes, while \bar{S}_{T_x,R_x} is the sensor loss values between the transmitter, T_x and receiver, R_x , and \bar{M}_{T_x,R_x} is the normalized sensitivity maps of the transmitter and receiver. The equation (5) is the common LBP algorithm that mainly used in many tomography processes especially in the common method strategies or also known as a single excitation source. As for equation 3, $S_{FullLiquid_{T_x,R_x}}$ is the sensor values of full liquid applied into the steel pipe while $S_{Object_{T_x,R_x}}$ is the sensor values when the steel pipe consist of the object. Equation (6) was used to obtain the standardized value for the sensor loss performance of the steel pipe application.

The tomography image for multiple excitation source method is produced based on equation (7). The equation (7) was a modified equation based on the equation (5).

$$V_{LBP(multiple)} = \sum_{T_x=1-8}^n \sum_{R_x=1-8}^n \bar{S}_{T_x,R_x} \times \bar{M}_{T_x,R_x} \quad (7)$$

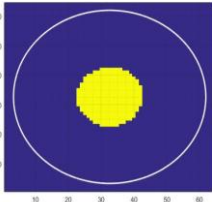
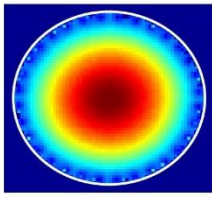
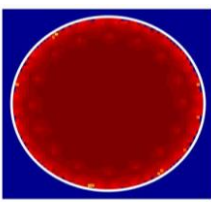
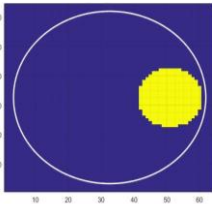
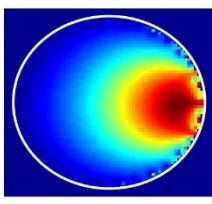
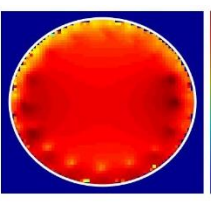
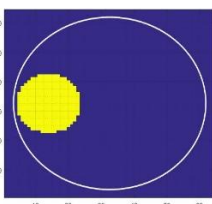
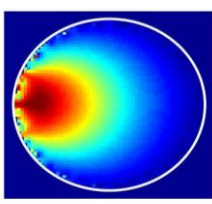
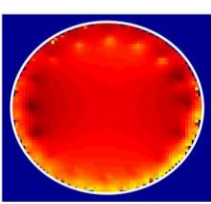
where $V_{LBP(multiple)}$ is defined as voltage distribution using multiple excitation source method, n is 50% number of electrodes out of the total electrodes for each process, while \bar{S}_{T_x,R_x} is the sensor loss value of transmitter and receiver, and \bar{M}_{T_x,R_x} is the normalized sensitivity maps of transmitter and receiver. The distinguish from its common method is that the channel 1 till channel 8 will group as an excitation source and the measurement is obtained at the group of the detection channels (channel 9 till 16). Here, the detection channels that redundant with the source channel were set as a zero value. Next, the process will be repeated until all channels have become as transmitter and receiver.

3. Results & discussion

The image reconstruction for liquid-gas regimes at three different positions and sizes using common technique and multiple excitation technique were done to identify the regime. The sensor values for each of the tested medium were done by using dummy data. It means that, if there is an obstacle, the receiver will receive 0 value and vice versa. Later, the multi-scale structural similarity (MSSIM) [12] was applied in the analysis part. The indexes output of MSSIM results is between zero (0) to one (1) [12]. It means that, the larger the value of the MSSIM index, the closer the reconstructed image to the reference image.

Figure 4 shows the tomogram for 10 mm bubble at 3 different positions. As provided in Figure 4, between both methods, it can be seen that the reconstructed images produced by the single excitation source method were better than the multiple excitation sources method. Besides, the bubble at three different positions can be recognized easily using the single excitation source technique. The MSSIM index also indicates that the single excitation source method gave a higher value rather than the multiple excitation method. Also, the images produced by the multiple excitation method did not give any closer images to the reference images.

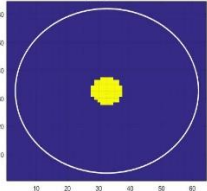
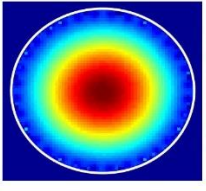
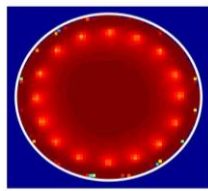
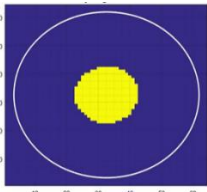
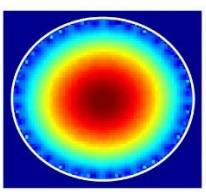
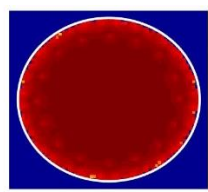
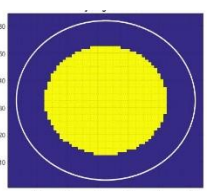
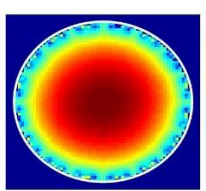
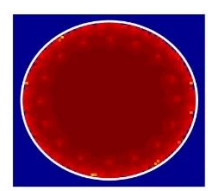
Figure 4. Bubble (10mm) at 3 different positions for single versus multiple excitation technique

Reference image	Single excitation	Multiple excitation	MSSIM
			Single=0.1086 Multiple=0.0682
			Single=0.1203 Multiple=0.0726
			Single=0.1228 Multiple=0.0729

Moreover, tomogram at three different sizes which were 5mm, 10mm, and 20mm in diameter were also compared for both methods. Based on the results shown in Figure 5, again it was proved that the single excitation method produced a better tomogram than the other technique. Images reconstructed by the single excitation source method had a lot of similarity with the reference images. Apart from that, MSSIM index for a single excitation source method also gave a higher value if compared with the

multiple excitation source approach. Multiple excitation source method sat at the lowest bottom of the chart when it comes to the tomogram and as well as the MSSIM index values.

Figure 5. Bubble at the center with different sizes for single versus multiple excitation technique

Reference image	Single excitation	Multiple excitation	MSSIM
 <p>5 mm</p>			Single=0.0723 Multiple=0.0352
 <p>10 mm</p>			Single=0.1086 Multiple=0.0682
 <p>20 mm</p>			Single=0.2778 Multiple=0.2986

4. Conclusion

Throughout this research, the main objective of this research is to investigate whether the multiple excitation sources can produce a good and high quality of the reconstructed image or not. Research had been done, sensitivity map and comparison of the reconstructed images between the single excitation source, and multiple excitation sources also had been done, and various types of bubbles also had been implemented throughout this research. Many things had been considered throughout this paper, and all those things lead to one conclusion, which was the multiple excitation sources cannot improve the tomogram of the ERT system. It was recommended to use a single excitation source to reconstruct the image of the medium of interest. Even though the sensor reading performance was increased as stated in [6] by using this idea, but the image reconstructed showed them otherwise. The reconstructed image by using this method was not similar at all with the reference images. However, the outcomes of this research are the preliminary result and a further investigation is needed in this research. A different approach of the algorithm can be considered for the future work to get a better tomogram of the medium of interest.

Acknowledgement

This research was supported by the Universiti Malaysia Pahang internal grant (RDU170368).

References

- [1] Abdul Wahab Y, Abdul Rahim R, Fazalul Rahiman M H, Abdul Rahim H, Ridzuan Aw S, Mohd Fadzil N S and Jamaludin J 2014 A Review of Process Tomography Application in Inspection System *J. Teknol.* **70** 35–9
- [2] Ridzuan Aw S, Abdul Rahim R, Fazalul Rahiman M H, Mohd Yunus F R and Goh C L G 2014 Electrical Resistance Tomography: A Review of The Application of Conducting Vessel Walls *Powder Technol.* **254** 256–64
- [3] Deng X, Dong Z, Chen L and Liu H 2014 Research on Excitation & Measurement Strategy of Tuber Electrical Resistance Tomography System *Appl. Mech. Mater.* **577** 701–4
- [4] Ridzuan Aw S, Abdul Rahim R, Fazalul Rahiman M H, Mohamad E J, Mohd Yunus F R, Abdul Wahab Y, Fadzli N S and Jamaludin J 2015 Simulation Study on Electrical Resistance Tomography using Metal Wall for Bubble Detection *J. Teknol.* **73** 31–5
- [5] Wahab Y A, Rahim R A, Fazalul M H, Aw S R, Rahman F, Yunus M, Muzakkir N, Ayob N, Ling L P, Abdul H, Ahmad I L, Jonet A, Seng C K and Sek T K 2017 Inverse Problem : Comparison between Linear Back- Projection Algorithm and Filtered Back-Projection Algorithm in Soft-Field Tomography *Int. J. Integr. Eng.* **9** 32–6
- [6] Abdul Wahab Y, Shakyeen S A, Md Zain Z, Abd Ghani N and Mat Noh M 2018 Initial Study of Multiple Excitation Source for Electrical Resistance Tomography in Steel Pipe Application *Proc. of the 10th National Technical Seminar on Underwater System Technology* **538** 353–60
- [7] Saad F O, Sdayria A, Madiouli J, Sghaier J and Fudym O 2017 Quadrupole method: A New Approach for Solving The Direct Problem of Electrical Resistance Tomography *J. King Saud Univ. - Sci.* **29** 360–70
- [8] Shaw G R, Goussard Y and Guardo R 1993 Linearization of The Forward Problem in Electrical Impedance Tomography *Proc. of the IEEE Int. Conf. on Engineering in Medicine and Biology Society* 82–3
- [9] Abdul Wahab Y 2017 *2 MHz Electrical Resistance Tomography for Static Liquid- Solid Profile Measurement* (Universiti Teknologi Malaysia)
- [10] Shakyeen S A 2018 *Initial Study on Multiple Excitation Source of Electrical Resistance Tomography for Liquid Gas Regime Identification in Steel Pipe* (Universiti Malaysia Pahang)
- [11] Wahab Y A, Rahim R A, Hafiz M and Rahiman F 2017 Image Reconstruction for Solid Profile Measurement in ERT Using Non-invasive Approach *Indones. J. Electr. Eng. Comput. Sci.* **15** 1554–64
- [12] Wang Z, Bovik A C, Sheikh H R and Simmoncelli E P 2004 Image Quality Assessment: From Error Visibility to Structural Similarity *IEEE Trans. Image Process.* **13** 600–12