Improvement of terahertz imaging using lock-in techniques

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***Abstract*— We present results of improvement of THz images registered at the frequency of 300 GHz. The improvement is achieved by processing of both phase and magnitude information provided by lock-in amplifier. The active imager uses a continuous-wave tunable radiation source. We investigate capabilities of utilizing phase and intensity information in order to obtain more accurate shape of object. Results of processing images in order to obtain more details are shown. Improvement of the image resolution and quality by composition of selected elements of both amplitude and phase-based images using specific fusion methods is presented.**

I. INTRODUCTION

TERAHERTZ (THz) radiation is a part of spectrum of electromagnetic waves considered to be between 100 GHz and 10 THz [1, 2]. This radiation have unique properties applicable to spectroscopy [4], imaging [5, 6, 9] and non-destructive testing [7]. One of the most valuable properties of the terahertz waves is ability to penetrate various objects because of non-zero transmission through various materials including plastics, ceramics and crystals [1, 2].

THz imagers operate in two modalities - passive and active [8]. In the passive approach the THz radiation measured by an imager is either emitted by an object or reflected from another thermal source, such as the sun or deep space. Lack of additional source of radiation illuminating the observed object limits the ability to penetrate the object and see its profile. In contrast, active imaging employs both a THz source illuminating the observed object and a detector. The active modality is commonly employed for non-destructive assessment of various non-metallic objects.

The continuous wave imaging mostly offers only intensity information. However, the lock-in amplifier can be used to achieve higher signal-to-noise ratio and can provide the additional information – phase difference between detected signal and a reference signal. In the proposed method, amplitude of source of radiation is modulated and synchronous (lock-in) detection is used to register simultaneously amplitude and phase of transmitted radiation. We utilized the value of phase difference between detected signal and reference signal to achieve better shape visualization and higher image contrast. In this paper, we present comparison of both amplitude and phase image as well as results of processing.

II. PHASE AND AMPLITUDE

Most existing terahertz imaging techniques utilize the intensity information to reveal the inner structure of an object thanks to non-zero transmission of radiation through various materials. Other imaging techniques, like TDS imaging utilize phase related to the material's refractive index. The method presented in the paper uses phase related to the intensity of transmitted radiation modulated by a mechanical chopper. The phase is provided by lock-in amplifier and is the phase difference between the detected signal and the reference signal. In the presented method, the signal's phase is changing when the wave is entering material of non-zero optical density because of decrease of transmission.

Amplitude of a signal provides information about the strength of the transmitted signal. Phase difference between detected signal and reference signal provided by lock-in amplifier delivers more precise information about the strength of the signal and can provide precise information about shape of object. This data is more accurate than provided by amplitude of measured signal. Compared with intensity imaging, visualization of phase can offer a higher image contrast and offer more accurate object's contours.

III. DATA ANALYSIS

Image processing techniques employed during the studies consist of contrast enhancement algorithms, speckle removing and segmentation techniques. Figure 1 (a)(b) presents exemplary images (magnitude and phase of synchronous signal respectively) of glasses packed with bubble envelope.

The imaging setup consists of a continuous wave THz source with a frequency of 300 GHz, mechanical chopper, the detector with lock-in amplifier and beam shaping optics. The observed object is mounted on a X–Y translation stage and raster scanned in a plane perpendicular to the object beam axis.

Lock-in's phase data provide the observer with much more accurate shapes and sharper edges than the intensity image. Unlike the phase-based image, the intensity image gives not only the information about the glasses but also about the envelope. The accuracy of projecting shapes in both phase-based and amplitude images is best visible in the images after thresholding - Fig. 1(c) and Fig. 1(d).

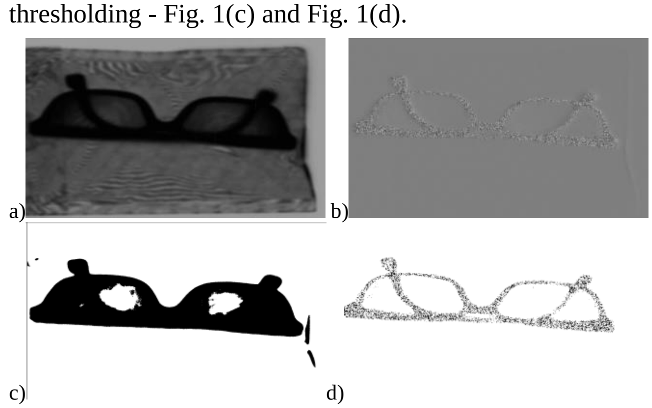

Fig. 1. Images of glasses packed with bubble envelope: (a) intensity image, (b) phase-based image, (c) intensity image after thresholding, (d) phase image after thresholding (e) fused image.

In order to visualize the relation between phase and amplitude a single raw (every raw consists of 1500 pixels) of image is presented in graph. The relation is demonstrated in Fig. 2. Presented raw is placed in the middle of the image.

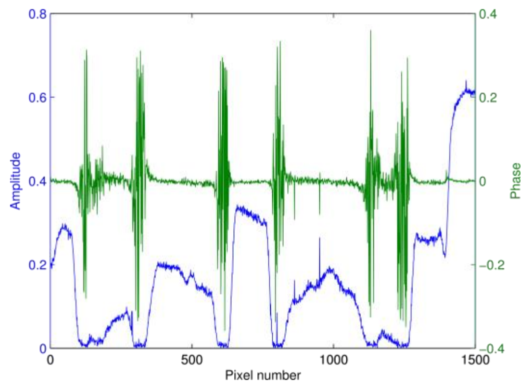

Fig. 2. Complementary signals of phase and amplitude of one raw of image.

Analysis of the relation between the phase and the amplitude indicate that we can verify the correctness of data by analysing complementary values. Our approach is to verify the correctness of amplitude values by analysis of phase values. We can find that phase values presented in Fig. 2 are steady or oscillating. When the phase is unsteady and oscillating, measured signal is too weak and lock-in amplifier is not able to properly determine the phase difference with respect to the reference signal. The phase cannot be determined and value of amplitude should be zero. In such cases, if the amplitude is greater than zero, it's value should be rejected.

In order to improve quality of image, enhance contrast and provide accurate shapes of observed object, acquired data are verified. Faultless data are then combined into single image using fusion [10] methods as presented in Fig. 3. The resulting image provide accurate visualization of shapes (the content of an envelope).

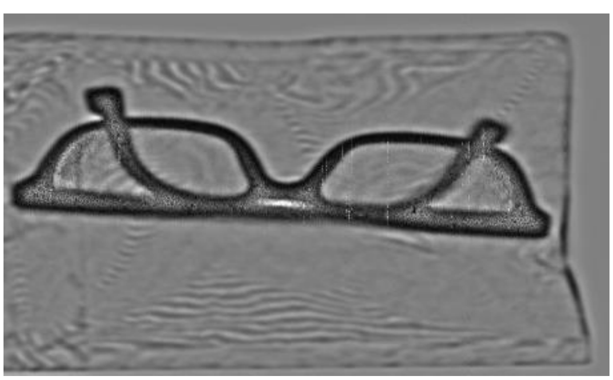

Fig. 3. Fused image – combination of amplitude and phase data.

IV. ALGORITHM

We present the algorithm of proposed method of image quality improvement in Fig. 4. The two types of data – phase and amplitude can be considered as two separate modalities or complementary data. Both types can be visualized in the form of two images – phase and intensity, respectively. Data correctness criterion is used to verify correctness of acquired values. Both phase and intensity images are segmented in order to extract objects of interest before the fusion. Selected elements of both images are combined to provide the resulting image.

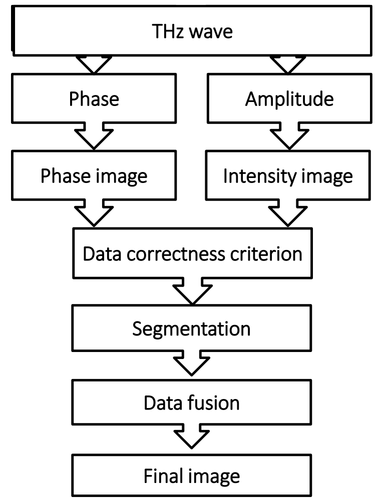

Fig. 4. Algorithm of image quality improvement.

V. SUMMARY

By measuring both amplitude and phase of synchronous modulated signal, we can improve quality of images and accuracy of shapes projection. Both amplitude and phase of signal provide rich information about the investigated subject. In order to exploit the potential of both measures, we propose to use phase data to validate values of amplitude. Verified data are synthesized in the form of image with accurate shapes of objects and high contrast.

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