Non-contacting Localisation of Dielectric Objects with UWB-Pulses

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Abstract — This paper deals with the localisation of dielectric objects using ultra-wideband pulses with a width of approximately 400 ps. Dielectric obstacles are irradiated with antennas using sub-nanosecond pulses and transmission techniques. In the receiver, the signals are sampled after interfering with the object under test (OUT) and processed with a PC using artificial neural networks. The accuracy of the spatial resolution is examined for various measurement examples. The obtained non-contacting localisation accuracy is much less than the involved wavelengths anticipate, and is independent of the permittivity of the material and adaptable to different shapes.

I. INTRODUCTION

Microwaves are frequently used for determining the position of objects for example in industrial processes. For this purpose FMCW- and carrier frequency pulse-radars are widely used. Compared to mechanical, optical or ultrasonic methods the microwave radars have the advantage of being largely independent of environmental influences and of having a greater penetration depth. Unfortunately, the microwaves are susceptible for interference caused by resonances and multiple reflections because of limitations due to narrow bandwidths.

This paper attempts to solve this problem by using baseband pulses as the interrogating signal. The corresponding spectrum of sub-nanosecond UWB pulses covers a frequency bandwidth of several GHz and is thus much more resistant against unwanted interferences. Pulses with a width of 400 ps are radiated by antennas. They then interact with scattering objects which may be located for example on a conveyor belt. Finally they are received by a small line array of antennas. In the cases under consideration, the longitudinal position of the OUT is known. The transversal position, however (dimension b in Fig. 1), is to be determined. After reception the signal has a duration of 800 ps due to the differentiating characteristics of the antennas. It is subsequently sampled and processed. The signal processing extracts the changes in amplitude and the pulse widening. Only the alterations relative to a reference measurement are taken into account in order to allow for changes in the environment. An artificial neural network is trained with a number of reference measurements and objects and then estimates the position of the OUT.

The feasibility of the new approach is demonstrated by locating cubes of different dielectric materials with varying permittivities. Being based on dielectric contrasts, the proposed method can be applied in practise, for example, for the detection of foreign bodies which may contaminate otherwise homogeneous materials.

II. EXPERIMENTAL SETUP

The experimental setup (Fig. 1) consists of three subsections. In the first sub-section a very short pulse is generated using the technology of [1]. The emitted pulse interrogates the OUT, which is located between the transmitting and receiving antennas in the second sub-section. Finally the received pulse is sampled and analog-to digital converted in the third sub-section.

![Fig. 1. Block circuit of the experimental setup including transversal length b.](image-url)
In order to obtain a high spatial resolution, the present receiver applies a line antenna array. In order to enable a small geometrical shape, antipodal Vivaldi antennas [2,3] are used. The antennas are manufactured from RO 5880 RF-substrate with a permittivity of $\varepsilon_r=2.2$ and a thickness of $d=1.575\text{ mm}$ using etching technology. The return loss is less than $-10\text{ dB}$ for frequencies above $1\text{ GHz}$. The antennas have a size of $80\times100\text{ mm}$. While propagating across the known distance between the antennas the transmitted pulse interrogates the scattering objects, which are located in an unknown position transversal to the direction of propagation (Section 2). As mentioned before the receiver consists of an array of 4 antennas lined up with a spacing of $50\text{ mm}$. The array is positioned approximately $50\text{ mm}$ below the plane of the dielectric obstacles. A switch allows the connection of the receiver electronics to the individual antennas and to record 4 measurement signals successively.

The third sub-section comprises the circuitry for sampling the received pulse and applying further processing as shown in Fig. 3. Because of the hardware properties the compliance with the Nyquist criterion is not possible in real time. Therefore the sequential sampling technique is used, which allows for the reconstruction of a periodic signal under special circumstances even if it is sub sampled [e.g. 4]. Using a miniaturised sampling bridge composed of 4 diodes in beam-lead technology and a holding capacitor, the instantaneous pulse amplitude is stored and then digitised in a fast analog to digital converter. The sampling bridge is operated with short sampling pulses of $70\text{ ps}$ duration. The frequency response of the gate is shown in Fig. 4. To prevent the sampling diodes from being switched by the measurement signal unintentionally, an additional reverse voltage is applied. The charging time of the capacitor is below $1\mu\text{s}$, corresponding to 20 samples, using a frequency of $20\text{ MHz}$.

III. MEASUREMENTS

During first measurements, various materials were investigated with the experimental setup. The objects under test were for example cubes with an edge length of 1 inch. The homogeneous materials consisted of ceramics and plastics with permittivities of $\varepsilon_r=4, 6, 9, 10, 12$ and $16$. The cubes were measured separately at different positions between transmitting and receiving antennas.

Their position was varied continuously along the direction of the array transversal to the direction of pulse propagation. Due to the fact that the received pulses are compared with reference pulses, which were applied to the undisturbed space between the antennas, the influence of a surrounding material, in the present case air, cancels. It has no influence on the result, except it is very lossy or obscures the OUT by having a similar permittivity.

IV. DATA-PROCESSING AND ANALYSIS

In order to determine the position of the OUT, the signals of the 4 antennas were recorded successively and 80 values (amplitude) were transmitted to the controller. As many calculations as possible were made on the microcontroller, because of the slow transfer rate between the controller and PC, which limits the measurement speed. A more elaborate version of the measurement set-up could be increased very much in the data transmission rate. The signal carries information like attenuation, dispersion and multipath scattering. It is advantageous to find the position of the obstacle in two steps. At first the decision is made which pair of antennas carries most of the information content. These two antennas yield the best results for determining the position of the obstacle. Subsequently a non-linear data-processing, especially an artificial neural network performs the detailed analysis. Each pair of antennas has its own trained net for the corresponding positions. The nets used for this decision are RBF–nets (radial basis function nets). They provide continuous output values.
and are deterministic. Therefore the same network is obtained after each training under identical conditions.

The location of $b$ for the OUT in front of the four antennas varies over 250 mm. To check the data-processing (net), there are different datasets for training and validation [5,6]. The accuracy of determination of the location is independent of the permittivity of the object. The root mean square error for trained values (RMSE$_{\text{train}}$) is approximately 4 mm. For untrained position the RMSE$_{\text{val}}$ is smaller than 7 mm. The predicted and the true positions are plotted versus each other in Fig. 5.

The obtained spatial resolution is much higher than the directional characteristic of Vivaldi antennas anticipates.

V. CONCLUSION

A new method of localisation of objects independent of the dielectric properties has been presented. Ultra-wideband pulses illuminate the object in a transmission measurement. By expanding the receiver array with more antennas a larger geometrical width can be obtained. The flexible analysis using artificial neural networks makes a quick and easy adaptation of the setup to different materials possible. Measurements show a root mean square error of validation of less than 7 mm over an observation range of 250 mm. Beside of localisation a distinction between different objects seems also to be possible.

REFERENCES