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ENERGY SENSITIVE X–RAY IMAGING WITH PIXEL STACK DETECTOR

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Abstract: *Material decomposition based on dual energy X–ray radiography which was primarily developed for tissue differentiation in medical imaging can be favorably used for composite material examination. The principle of this method is obtaining several absorption images of the sample with different energy spectra which allows for the identification of main material components. The need of measurement at several X–ray spectra can be achieved either by alternation of the tube voltage and/or by the use of additional filters. The single photon counting pixel detector Medipix allows direct energy discrimination of registered radiation enabling spectrum selection at the detector side without the need to first modify the X–ray source spectrum. Our approach provides moreover low noise images with broad dynamic range and thus high sensitivity and enhanced contrast. Utilization of a 3D voxel detector with two or more sensor layers allows obtaining all required images simultaneously in a single exposure. The results of the material decomposition obtained with the Medipix detector are presented and discussed in this contribution.*

Keywords: ***energy sensitive X–ray radiography, Medipix, signal to thickness calibration, material decomposition***

1. Introduction

Transmission X–ray radiography is a well-established method for the inspection of the inner structure of objects. The method as such is non-destructive and can be used for a wide variety of sample materials with low and intermediate atomic number (other methods are preferable for materials with high atomic number). The radiograph registers the changes in the intensity of the transmitted beam. These changes are caused by the differences in the inner composition of the sample.

For the registration of the transmitted X–ray radiation we utilize in our work the single particle counting 3D voxel detector based on the Medipix chip (details can be found on the **Medipix Collaboration website**).

To evaluate material differences it is necessary to measure the same sample in several energy ranges (the differences in material attenuations are then pronounced). One of the ways how to achieve this is to use the 3D voxel detector structure. Individual detector layers then work as spectrum filters – only the first layer is illuminated by the original spectrum while the others are illuminated by the spectra filtered by previous layers. This filtering effect can be further enhanced by the change of the individual sensitivity of the detector layers (by threshold shifting). Intensity data measured with the 3D voxel detector are measured on all layers at the same time. Then it is necessary to convert them to the equivalent thicknesses of the reference material (described in ref. Jakubek, 2007). The material separation is done by the decomposition of the measured material vector to the chosen (base) material vectors (see ref. Soukup, 2011b).

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2. Materials and Methods

2.1. Medipix Family Detectors

The Medipix and Timepix chips are hybrid semiconductor pixelated detectors developed in the framework of the Medipix collaboration. These devices are composed of a standard semiconductor sensor which can be fabricated of different materials (Si, CdTe, GaAs) and thickness (e.g. 300 μm, 700 μm, 1 mm) coupled to a pixelated electrode and a readout chip with integrated micro-electronics for signal processing chain for each pixel. The Medipix2 detector used in this work consists of a 256 × 256 pixels chip (each pixel of 55 × 55 μm^2 size) bump-bonded to a silicon sensor of 300 μm thickness.

Direct per pixel digitalization of the measured signal together with the possibility to set threshold in each pixel above the noise level allows single photon counting with no dark current and practically unlimited dynamic range (see ref. Jakubek, 2005). These features cannot be provided by charge integrating devices (such as CCD and CMOS). No sensitivity to dark current and readout noise allows obtaining high sensitivity and very high contrast in radiographic images even under low illumination intensity which is very desirable, for example, in medical applications (e.g. Master Thesis Dammer, 2005)

Visualization and high portability of the detectors are provided by the possibility to operate them from a standard PC via the Pixelman software (see ref. Holy, 2007, Turecek, 2011). Detector data acquisition, power and control are provided by the USB readout interface FITPix (see ref. Kraus, 2011).

2.2. 3D Voxel Detector Based on Medipix Chip

The 3D Voxel detector is a modular device consisting of several layers of Medipix chips (each layer can be considered as a 2D detector), interconnected in a daisy-chain structure (see figure 1, details can be found in ref. Soukup, 2011a). The readout chips used for this device were thinned to 120 μm (from their manufactured standard thickness of 740 μm) to decrease the thickness of the insensitive material between the individual detector layers.

Originally planned applications for this type of device are particle tracking and X–ray imaging with increased efficiency (ref. Soukup, 2011b).When used for imaging one limitation of this geometry lies in the fact that the first layer works as a spectrum filter for the second layer and so on. Nevertheless this situation can be advantage for material sensitive imaging which is the main reason why such device was selected for this work.

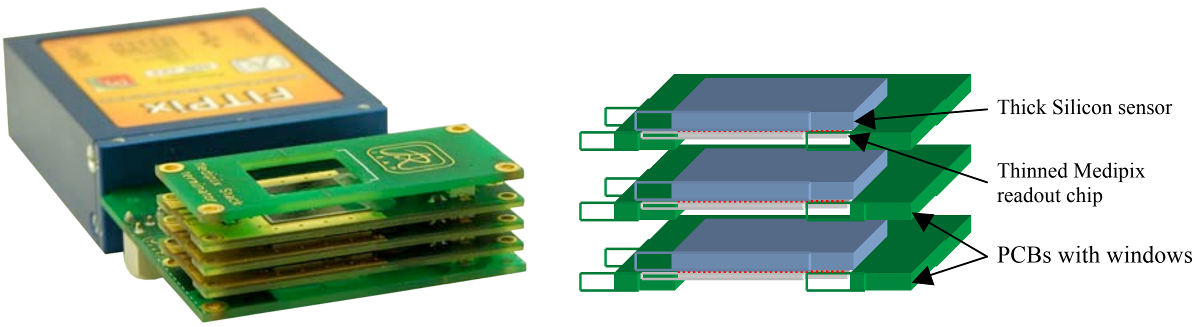
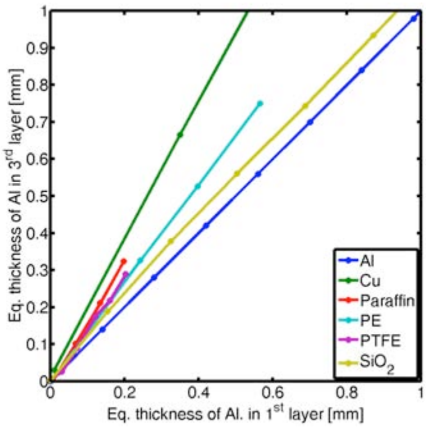


Fig. 1: 3D voxel detector consisting of 3 layers of Medipix chips on a single board attached to a FITPix readout interface (left). Schematic illustration of the stacked architecture (right)(Soukup, 2011b).

2.3. Signal to Thickness Calibration (STC)

For the purpose of imaging with the pixel detector it is necessary to correct the registered raw images for the individual pixel sensitivity (flat field correction) or to directly calibrate the detector response to a reference material thickness (signal-to-thickness calibration (STC)). The STC provides linearization of the detector signal taken with a polychromatic X–ray beam (transformation of intensity to equivalent thickness of the reference material). This linearization is very useful for 3D object reconstructions such as computed tomography and laminography.

In case of the 3D voxel detector the STC is measured for all its layers at the same time. The equivalent thicknesses obtained from the detector layers are identical only for the reference material (measured material response in equivalent thicknesses on the first and second detector layers is illustrated in figure 2). Other materials will show different thickness in different layers. The alteration between equivalent thicknesses obtained from detector layers can be used as a measure of the differences between the sample and reference materials. The obtained difference between materials can be pronounced by threshold (THL) shift of the second layer (the low energies are cut off) as illustrated in figure 4.



Measured points correspond to thicknesses of:

Al – 140, 280, 420, 560, 700, 840, 980 µm

Cu – 17 µm, (35 µm)

Paraffin – 2.5, 5.2, 7.5 mm

PE – 2.5, 5, 7.5 mm

PTFE – 1, 2, 3, 4 mm

SiO_2 – 150, 300, 450, 600, 750, (900 µm)

Fig. 2: Response vectors obtained by STC technique (reference material was Al). The differences in equivalent thicknesses in the first and second detector layers are shown for several materials (taken from Soukup, 2011b)

Two equivalent thicknesses are calculated for each point in the sample when two stacked layers are used. By the decomposition of the obtained data to base material vectors (real or chosen) it is possible to visualize the distribution of base materials inside the sample (for details about decomposition see article Soukup, 2011b).

3. Results

3.1. Decomposition into Two Base Materials

The basic test for the estimation of reliability of this method can be measured on an overlaying segmented phantom. The chosen phantom was composed of perpendicular aluminium and paraffin segments which is shown in figure 3 (left) together with equivalent thickness images reconstructed on the first and second layers (figure 3 right). Each combination of thicknesses can be used as one validation point (the mean values from each thickness combination were taken). Individual acquisitions took 5 seconds, the distance between the X–ray tube and detector was 10 cm and the Xray tube was configured to 60 kV and 350 µA.

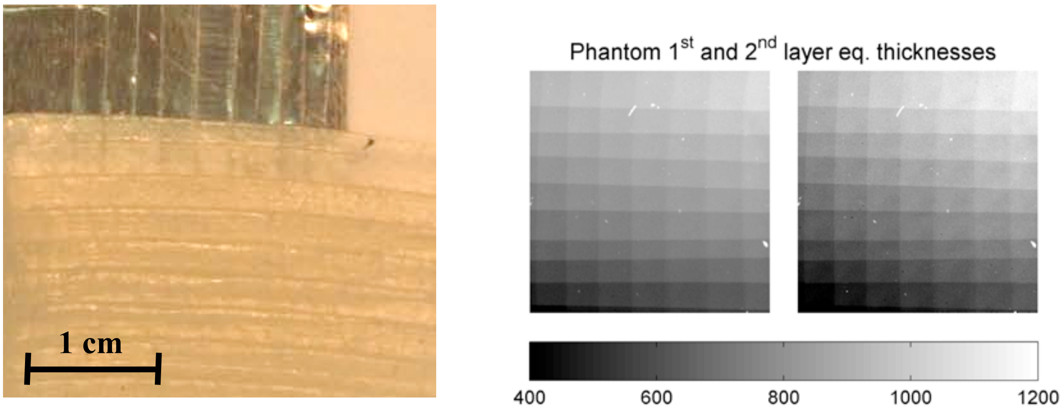


Fig. 3: Photograph (left) and equivalent thickness images obtained for first and second detector layer after the signal-to-thickness calibration (right). The scale is in µm equivalent of Al.

A shift of the energy threshold on the second detector layer cuts off the low energy spectrum and enhances the differences in materials. Figure 4 shows the obtained equivalent thicknesses at the validation points (line colours are noted above) for standard settings of the energy threshold and for energy threshold shifted by 50 THL points (about 20 keV). The slope of blue (aluminium) lines is close to 45 degrees because the aluminium was used as a reference material for STC.

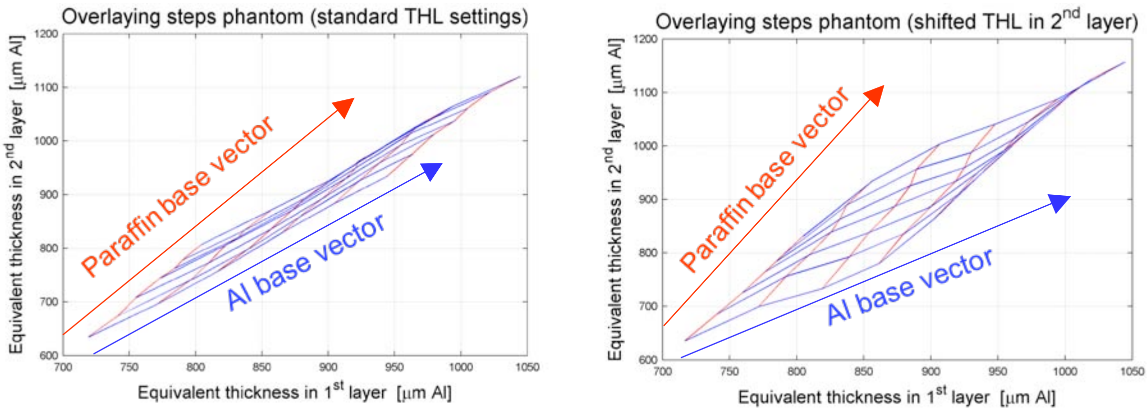


Fig. 4: Equivalent thicknesses for the overlaying segmented phantom: standard THL settings (left) and THL shifted by 50 points - about 20 keV (right). Red lines represent paraffin steps (constant aluminium thickness) and blue lines represent aluminium steps (constant paraffin thickness). Equivalent thicknesses obtained with

It can be seen that material vectors (colour lines in image 4 above) are not perfectly linear over the entire thickness range – linear approximation was used for the decomposition. The irregularities are caused mainly by the presence of moiré pattern on the second detector layer (created by first detectors metal bump-bonding balls beneath each pixel). This side effect of the use of 3D voxel detector can be strongly suppressed by increasing the distance between X–ray tube and the detector.

The result of equivalent thickness decomposition to two base vectors (aluminium and paraffin) is shown in figure 5 below together with the decomposed aluminium thickness in the phantom.

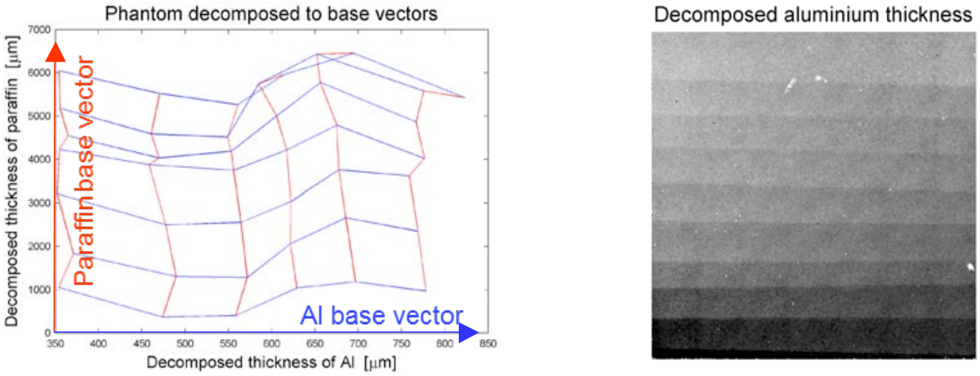


Fig. 5: Decomposed thicknesses for overlaying segmented phantom (left). Red lines represent paraffin steps (constant aluminium thickness) and blue lines represent aluminium steps (constant paraffin thickness) (left). Area distribution of aluminium in the sample (right).

3.2. Practical application of the method – composite sample

This method can be used for composite samples where the exact composition is not known or when it would be very hard to create reference samples of pure materials contained in the inspected object. The idea then is to do the decomposition to pseudo-materials (simply soft and hard components in this article but it can be as well a characteristic mixture of materials (colour pigment etc.))

As a testing object for the pseudo-material decomposition, the replica of a painting was used (painted with metallic pigments). The distance between the X–ray tube and the detector was increased to 100 cm to avoid moiré pattern on the second detector layer (the period of the pattern increases with distance). It was necessary to scan the sample in two positions to capture the image of the larger segment (area with the eye) of the painting. The radiography of the selected area is shown in figure 6 together with the result of the material decomposition into two components (soft and hard). Similar results were initially obtained with a less complex dual energy method (see ref. Zemlicka, 2010), the measurement with the 3D voxel detector composed of N-layers brings the possibility to measure the sample directly with N different energy filters at once.

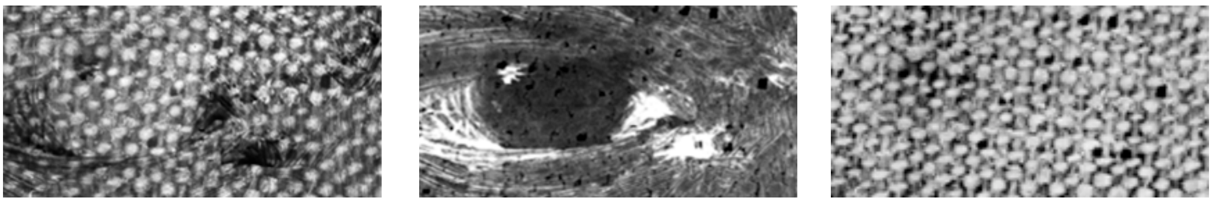


Fig. 6: Radiography of the eye area in the painting (left) and the result of the material decomposition into two components. The hard component group (middle) and soft component group (right) were separated. Two acquisitions were needed for this decomposition – the sample was shifted after the first acquisition to double the inspected area.

4. Summary

It has been demonstrated that material decomposition method can evaluate the radiographic data obtained with the 3D voxel detector assembled from Medipix family detectors. The advantage of this device lies in the possibility to take pictures in all subsequent detector layers at once. Moreover the front layers themself work as an energy filter for the layers behind. When the material composition of the sample is known it is possible to directly calibrate the method and to carry out the material decomposition into the chosen components. In other cases when the sample composition is too complex it is still possible to group all materials with similar properties into pseudo-materials and use them for the decomposition.

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