論文の内容の要旨

論文題目 Dual energy X-ray imaging for material recognition using 950 keV X-band Linac

（ 950 keV X-band Linac を用いた 2 色 X 線イメージング　物質識別研究 ）

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X 線胸部撮影や X 線非破壊検査のように単なる X 線透過画像だけでは白黒のコントラストでしか中身を判断することができない。しかもこの判断というのは人による判断なので人や撮影環境によってそれぞれ異なる可能性がある。もっと詳細な判断が要する場ではこういった人の判断より誰もが見て納得できる具体的なデータが提示されなきゃいけない。そこで 2 色 X 線による物質識別法が新しい画像検査法として現れた。2 色 X 線というのは二つの異なるエネルギー分布の X 線を意味していて、この二つの X 線を 2 回照射することで物質識別が可能になる。つまり二つの X 線によって二つの透過画像が得られ、二つの画像の各ピクセルの画像数値計算により画像再構成が行われて、タケット物質を識別することができる。

2 色 X 線の線源やその発生方法はいろいろあるがここでは加速器を用いた金属識別実験と X 線管を使った医療用ファントムの実効原子番号特定実験に付いて述べる。

まず加速器を用いた金属識別実験では 950 keV X-band 加速器を線源として採用した。この加速器は 1 MeV 以下の X 線を出すので空港のような公共場所で放射線取扱者が常駐しなくても運用できる。そして X-band の高周波を用いることによってコンパクトなシステムが実現できるメリットもある。

ディテクターとしては 2 段シンチレータアレイを開発した。

2 段シンチレータアレイは 500 µm の CsI と 15 mm の CdWO4 シンチレータを前後に重ねた構造であり、前の薄い CsI には低エネルギーX 線が吸収され、後ろの厚い CdWO4 には CsI を抜いてきた高エネルギーX 線を吸収されるようになっている。この構造によって 1 回の X 線照射で二つの透過画像を得るようになる。950 keV X-band 加速器を用いた物質識別実験では軽金属である鉄と重金属である鉛を識別することを目標とした。従来空港で利用される手荷物検査装置は重金属の識別が難しいのでそれに比べエネルギーが高い、加速器からの X 線で軽金属と重金属の識別に挑んだ。

X 線管を線源とした実験では X 線のエネルギーが高くないため重金属のような密度が高い物質は通過しにくい。なので医療用装置のような X 線管を使った実験では原子番号 10 前後の低原子番号物質をタケットすることが多い。ここでは加速エネルギー65 kV の X 線管を使って医療用ファントムやアクリルなどの実効原子番号を求めた。特にこの実験では CT 撮影を行い、2 色 X 線 CT による物質識別に挑んだ。勿論 X 線管から 2 色の X 線が出るわけではないのでフィルタを線源の前に置いて特性 X 線が出るようにした。つまりフィルタの材質を変えることで違う特性 X 線が出るので二つのフィルタで 2 色 X 線を得ることができる。

The significance of security-check in an airport draws attention all around the world after 911 attacks. The research to detect the prohibited items has suggested new inspection system mostly by changing the radioactive source. In general, the established inspection system utilizes the X-ray tube as an X-ray source. High energy X-ray from linear accelerator (Linac) are appeared as alternatives to X-ray tube due to their ability. It can widen the inspection range of target samples from low atomic material to high atomic material and deepen the possible thickness of inspection. In particular, we have developed X-band Linac which generates maximum 950 keV X-ray in 2 μm pulse width with multi electron bunches. The maximum X-ray energy 950 keV allows the inspection system to be placed in a public space such as an airport under the laws concerning the prevention from radiation hazards due to radioisotopes and others. This energy is higher than ordinary X-ray tube which generates the maximum 500 keV at this writing and thus we expect higher transparency with a target of high atomic number and a thick target. We set our goal to distinguish light metal, Fe from heavy metal, Pb that has been impossible with X-ray tube due to its low X-ray energy. Another feature of X-band Linac is its compact size of the entire system. That is why we employed 9.4 GHz X-band system as X-ray source. The size of magnetron is $0.1\times0.2\times0.2$ m^3 supplying 250 kW power to accelerating tube. With high frequency of acceleration, the length of the accelerating tube is just 30 cm. We plan to complete the final version of system within the size about $1.0\times1.0\times1.0$ m^3 finally and that is another reason we can place the system in an airport.

Dual energy X-ray system is capable to figure out the information of atomic number in a target. Actually the system is applied to custom inspection system in an airport and a port commercially and shows promising results of material recognition in a container and baggage. In the case, Linac generates two-times irradiation of X-ray to a target to get two images which has different transparency each other. However we suggested two-fold scintillator in a detection part to get two X-ray images by one-time irradiation not two-times. Two images in different transparency can be obtained from two scintillators according to their thickness. Monte carlo simulation is performed to decide parameters for the better condition of two transparencies. For example, the composition and thickness of scintillator are determined to search the transparencies of two images from two scintillators for better material recognition.

Two images with different transparency each other are used to reconstruct the atomic number image through calculating the pixel values of them. The information of atomic number is appeared on the image with colors which express certain atomic number according to the color profile.

The experiment was performed with Fe, Pb samples in various conditions such as without concealment, with concealment. They proved the ability of material recognition of our system within certain disagreement with theoretical values. For instance, the difference between experimental value and theoretical value for Fe is from 3 to 10 and for Pb 2 to 5 in the polyethylene container. In the polyvinyl chloride container, Fe and Pb have the difference of atomic number from 9 to 12 for Fe, 1 to 3 for Pb.

We performed CT imaging in the system of radiography changing the position of line sensor in which two-fold scintillator is equipped. However there are several problems on the images which interrupted to figure out the atomic number. First, the structure of CsI scintillator was composed of sets with every 4 channels. The scintillation light within a set can go any channel of 4 because there is no separator between channels. New two-fold scintillator will be composed of every channel separately by inserting the separator between channels. The photodiode is 2 mm thickness. It is too thick to express the object specifically, in particular, items in baggage. The thickness of photodiode is diminished to 1 mm for next version and thus we can inspect the inside of baggage. Finally, the gap between two collimators which is placed in line sensor will be reduced to 2 mm to suppress the scattered X-ray.