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Nuclear Imaging for Treaty Verification without an Information Barrier

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Abstract

Nuclear imaging systems have been proposed as a technology component for treaty verification between countries. Imaging systems can acquire data that contain both spatial information about the object being probed and spectral information regarding the material composition of the object. Thus it is expected that accurate verification of treaty-accountable items (TAIs) can be achieved using imaging data. A drawback to imaging techniques is that the monitor can use the detector data and knowledge of the imaging system to reconstruct sensitive geometrical information regarding the treaty-accountable item (TAI) being imaged. Thus, it is conventionally thought that a physical or software information barrier (IB) must be used to prevent the disclosure of sensitive information to the monitor. We have developed methods for utilizing imaging data for treaty-verification imaging while mitigating the need for an IB. These methods all rely on the concept of list-mode processing where individual neutron and gamma-ray events are processed immediately after detection and never stored. Thus, an image is never actually formed; instead, a single test statistic is updated as events come in. This test statistic is used to make the final decision as to whether the item being imaged is a TAI or not. The methods used to process this list-mode data, which we call observer models, are designed to be insensitive to specific aspects of the objects being imaged. Thus, even if the monitor has access to the methods being used to make decisions, they would not be able to discover information about the TAI that the host wants to keep hidden. In this paper, we will present an overview of treaty-verification imaging without information barriers. We will discuss our methods in general terms, how these methods might be utilized in a treaty-verification campaign, and the work still needed to achieve the goal of nuclear imaging in treaty verification without an information barrier.

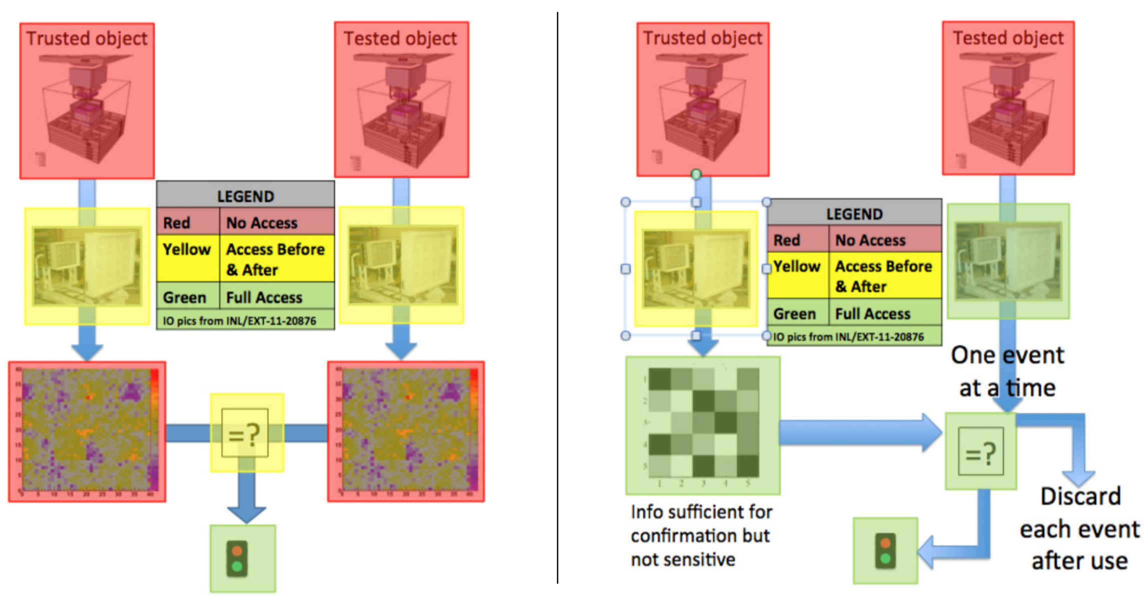
Introduction

Methods need to be developed to verify whether a treaty-accountable item (TAI) is the item it is stated to be. The difficulty is that this verification must be performed by a monitor without revealing sensitive information about the TAI that the host does not wish to reveal. Imaging can provide exquisite spatial and spectral information about the TAI and thus would be seemingly ideal in terms to verification accuracy. However, imaging information would, on the surface, reveal very sensitive information to the monitor and thus would necessitate an information barrier to protect sensitive information. However, information barriers are costly and burdensome to use. Thus, there is a desire to use imaging systems and imaging information without revealing sensitive information while somehow mitigating the need for an information barrier.

In this paper, we present our general methodology for approaching this problem. We will discuss two approaches that, when used in combination, allow image data to be utilized without revealing sensitive information. We will also discuss the limitations of the approaches mentioned and future work needed to be done.

Approach

A template matching scheme is one where a “trusted item” is used to verify that another “tested item” is equivalent to the trusted item. Using conventional imaging systems, a template matching approach is illustrated in Figure 1a. Here we see that the trusted and tested object are behind information barriers. The imaging system can be inspected before and after acquisition. Finally, the image data used to form the template and the testing image data are behind an information barrier. The only piece of information not behind some sort of information barrier is the final decision. This approach is expected to be accurate since the imaging system can respond to both spatial and spectral information about the objects being imaged. However, much of the process must be performed behind an information barrier.



We are working on pushing back the need for information barriers by performing two different types of operation. First, we will process data in list-mode format. Many nuclear imaging systems including the ones we have tested are event driven which implies that individual gamma and neutron events trigger and event which then processed. Thus, image formation generally takes place by aggregating many events and adding individual events to particular spatial and energy bins. We propose to never generate this projection image; instead, we will use the list-mode event data to update a test statistic which is used to make a decision about the template match. Thus, we are imaging without ever forming an actual image. Access to the imaging system while data are being acquired must be limited but there is never an image generated that can be used by the monitor to access sensitive information about the object being imaged.

While processing list mode data help mitigate the need for an information barrier, the methods used to process this data may themselves reveal sensitive information. That is, the "template" used may need to be placed behind an information barrier. Thus, our second approach is to design decision-making strategies that do not reveal any sensitive information about the object.

The approach we have taken to treaty verification does have limitations and it is useful to illustrate these limitations. First, we note that a list-mode entry may contain information about the position of interaction, the energy of the event, the particle type (neutron or gamma ray for example), and the event time. Because this information can never be aggregated, our methods for decision making must be some weighted combination of any function of these entries. That is, our processing must be linear with respect to some function of the event output. Any type of non-linear processing requires that data be aggregated in some manner which implies that an image is stored somehow. So our decision must take the form,

$$t = \sum_{i=1}^{N} w_i \mathcal{T}(A_i)$$

where A_i is the information contained in the *i*th list-mode entry, $\mathcal{T}$ is any non-linear operator, w_i is a set of linear weights, and *t* is the final decision variable which is thresholded to make a decision. Specific forms for this type of processing has been discussed in our previous work [1] and in a companion paper to this proceedings [2].

From the previous equation it is clear that the weights w_i are stored and thus, should not reveal sensitive information regarding the TAI. The achieve this, we have first simplified the task. Instead of performing a template matching, we are performing a binary signal-detection task in which we determine whether the object being imaged is of one of two types. The form the weights take to optimally perform this detection task is well known and would contain information regarding the differences in the means between the two types of objects as well as the average covariance. This information is likely sensitive. Thus, our approach has been to specifically optimize out any sensitive information from the weights. To put in mathematical terms, we design the null space of the weights such that sensitive information falls into that null space. More details are presented in [2]. However, when sensitive information is part of the null space of the linear operator, this linear operator can be shared since it contains no sensitive information.

In combination, these two approaches ensure that 1) no image is ever formed during verification and 2) the method used to make a decision does not contain sensitive information.

Discussion

One difficult aspect of treaty verification imaging is the presence of nuisance parameters. A nuisance parameter is anything that effects the measured data but is of no interest for the treaty-verification task. For example, the orientation of TAI should not effect the decision but may change the data if the TAI is asymmetric. In addition, the age of the material in the TAI, detector drifts and other calibration issues, object position are all considered nuisance parameters just to name few. The methods we are developing are designed to directly account for nuisance parameters. Nuisance parameters will lower overall performance and thus we need to carefully consider which nuisance parameters we will include in the model and which need to be assessed and known before imaged. For example, it may be the case that performance is very low if the orientation of the object is a nuisance parameter in our model. If this is the case, it implies that the host and the monitor must have agreed upon alignment methods to ensure that the objects are in the same orientation before imaging. A study of which nuisance parameters have the biggest effect on performance needs to be performed for the methods discussed in this paper.

Another difficulty of the methods presented is that need for calibration. The host must calibrate the decision-making strategy. This is, they must determine the set of weights w_i that do not reveal sensitive information and account for nuisance parameters. This calibration will rely on both measurements performed by the host as well as simulations to average over nuisance parameters. Thus, there is a extra burden put on the host to produce the template weights.

We have presented a general strategy for performing treaty-verification imaging while mitigating the need for an information barrier. Future work includes assessing the relative importance of nuisance parameters as well as measured demonstrations of our techniques.

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