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Combining uncertain information of differing modalities

Fred Petry [a,*], Paul Elmore [a], Ronald Yager [b]

[a] Geospatial Science and Technology Branch, Bldg. 1005, Naval Research Laboratory, Stennis Space Center, MS 39529, United States
[b] Machine Intelligence Institute, Iona College, New Rochelle, NY, United States

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ABSTRACT

In this paper we consider approaches for combining separately possibilistic uncertainty, probabilistic uncertainty and situations where both forms of uncertainty appear. An approach to probability aggregation using rational consensus with equi-weighting is developed. This aggregation is analyzed with information measures as one way to assess combinations and understand the impact on uncertainty. The analysis is based on combinations of bounding cases of probability distributions. Measures of conflict and the effect on information are developed. Next possibility transformations are used and illustrated by three representative possibility cases. The resultant transformed probabilities are aggregated with general probability distributions and the result evaluated with information measures as before. Finally a general approach to combining possibility distributions directly using quality criteria is described. An example is provided to illustrate the basic possibility distribution aggregation fusion developed.

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1. Introduction

Uncertainty arising from multiple sources and of many forms appears in the everyday activities and decisions of humans. We want to examine approaches that can be used to combine these uncertainties into forms that can become useful for decision making. Effective decision-making should be able to make use of all the available, relevant information about such combined uncertainty. In this paper we consider new approaches for combining separately possibilistic uncertainty, probabilistic uncertainty and situations where both forms of uncertainty appear.

To formalize the discussion, let V be a discrete variable taking values in a space X that has both aleatory and epistemic sources of uncertainty [26]. Let P be a probability distribution P: $X \to [0,1]$ such that $p_k \in [0,1]$,: $\sum_{k=1}^{n} p_k = 1$ that models the aleatory uncertainty. Then the epistemic uncertainty can be modeled by a possibility distribution [47] such that Π: $X \to [0,1]$, where $\pi(x_k)$ gives the possibility that x_k is the value of V, $k = 1, \ldots, n$. A usual requirement here is the normality condition, $\mathrm{Max}_x[\pi(x)] = 1$, that is at least one element in X must be a fully possible. Abbreviating our notation so that $p_k = p(x_k), \ldots$ and $\pi_k = \pi(x_k), \ldots$, we have $P = \{p_1, p_2, \ldots, p_n\}$ and $\Pi = \{\pi_1, \pi_2, \ldots, \pi_n\}$.

We have been motivated to address issues of uncertainty combinations by our consideration of the following application. The Navy's piracy report available to the public, PAWW (Piracy Analysis and Warning Weekly) [24] involves making use of both aleatory and epistemic information [12]. The problem of piracy attacks on shipping is well recognized off of the Horn of Africa (Somalia), but is also a problem in several other areas globally as well (Nigeria and Indonesia) [16,24] (see Fig. 1).

* Corresponding author. Tel.: +1 228 688 4948.
E-mail address: fpetry@nrlssc.navy.mil (F. Petry).

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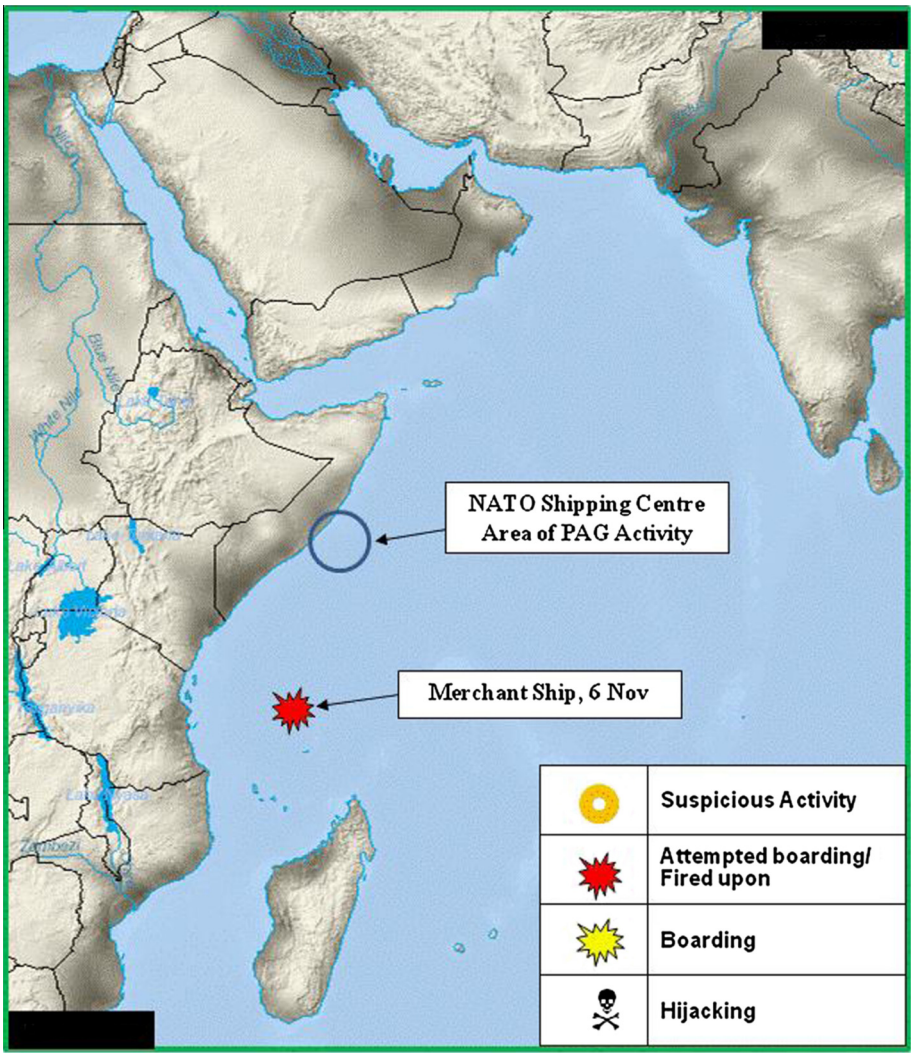

Fig. 1. PAWW piracy attack reports for Horn of Africa area.

The modeling for PAWW developed at the Naval Research Laboratory [12] provides guidance for decision making relative to deployment of limited interdiction resources to prevent such attacks. There are several sources of information input to the system. Here we provide a simplified example. Typically there exists previously collected information that can be formulated by probability distributions. For example the previously observed number of pirate attack groups, n, could be

$$P(n) = \{.4, .3, .15, .15\}, n = 1, 2, 3, 4$$

An important factor for a response decision often involves various sources of human intelligence about current activity in the area of concern. Here sources might provide intelligence about the possibility of the number of such groups active in a certain area and specific time frame. Analysts can then represent this information as a possibility distribution such as

$$\Pi(n) = \{1.0, .7, .6, .3\}, n = 1, 2, 3, 4$$

A decision maker should be able take into account all such information in an informed manner such as by the aggregation of the distributions and assessments of the resulting aggregation.

In combining information from multiple sources, a basic issue that must be considered is whether the resultant combination is somehow "better" than the original information. Some factors such as source reliability, effect of disinformation [23] and conflicting data might have to be considered. The approach we will utilize in this paper is the use of information measures such as Shannon entropy to assess if an aggregated result has increased the information content.

In this paper we first present in Section 2 background and related work on probability and possibility measures and aggregation approaches. An approach to aggregation of probability distributions based on consensual averaging is then