# An improvement of C2 systems performance using *DSmT* and ontology fusion approaches

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*Abstract*—The purpose of this paper is to present a concept of the so called 'intelligent consultant' – that is a tool that provides the C2 system operator a support in case the gathered information (acquired from observation means) is incomplete, imprecise or even conflicting.

It is the intention of the authors to focus on the methodological aspect of the problem which may be formed as: Does Dezert-Smarandache Theory (DSmT) of plausible and paradoxical reasoning enable to deal with difficult target classification which normally happens in maritime C2 systems. For this reason a comparison of hard-decision fusion, DSmT fusion and a combination of DSmT and ontology fusion algorithms has been established. Some numerical experiments have been made and their results have been delivered in this paper.

Keywords: DSmT, ontologies, attribute information fusion, C2 systems.

## I. INTRODUCTION

Nowadays, one of the most important requirements imposed on maritime Command & Control (C2) systems is to deal with a problem of integrating information gathered from diverse sources (e.g. radars, video cameras and visual sightings). The diversity of sensors utilised for acquiring information, useful from the tactical point of view, implies a necessity of reconstruction of the situational awareness at the presence of concise information as well as at the presence of uncertain, incomplete or even conflicted information.

Experience in working with C2 systems shows that there are particular situations, where an indication of incoherent information (ambiguity or conflict) is caused by imprecise processing of information related to target attributes (e.g. target misclassification or attribute conversion errors). In these particular cases the most often step of the fusion algorithms is holding the combination process and an indication of the existing problem. If the number of targets grows, the probability of necessary manual intervention also rises, which in consequence may lead to a degradation of quality of the situational awareness.

An analysis of C2 systems operators' needs shows that an automatic combination of attribute information is not enough requirement imposed on modern fusion systems. The fact the operator is responsible for the quality of elaborated information does not contradict with the idea of supporting him/her with the 'intelligent consultant' software which is to present the optimal solution, according to gathered imprecise and incomplete evidences.

The purpose of this paper is to present a concept and results of numerical experiments, related to the above mentioned intelligent consultant. This tool effectively utilises the relations among target attributes, defined in sensor network ontology [1]. A precise definitions of these relations have been given using elements of Dezert-Smarandache Theory [2], [3].

## II. COMBINATION OF ONTOLOGIES AND DSMT

This section presents a proposition of an ontology framework for a sensor network, dedicated to monitor the target threat. In the solution there were utilised concepts and concept lexicons of *JC3* model [4]. The authors' intention was to show the way relations of three attributes (threat, platform and activity) should be defined, rather than to present the complete Sensor Network (*SN)* ontology.

Table I presents a bijective assignment of concepts to elements of a concept lexicon. As it was mentioned before, this assignment need not be a bijection, however it is desirable especially if sets of values for attributes of platform and activity are numerous.

Table I
*SN* ontology: concepts and concept lexicon

| Concepts | | Concept lexicon | |
|---|---|---|---|
| **Threat** | An OBJECT-ITEM that is assumed to be a friend because of its characteristics, behaviour or origin. | *object-item-hostility-status-code* | ASSUMED FRIEND |
| | An OBJECT-ITEM that is positively identified as enemy. | | HOSTILE |
| | …according to JC3 | | … according to JC3 |

| | Description | Code | Relation lexicon |
|---|---|---|---|
| **Platform** | General designator for aircraft/multi-role aircraft carrier; | *surface-vessel-type-category-code* | AIRCRAFT CARRIER, GENERAL |
| | Craft 40 meters or less employed to transport sick/wounded and/or medical personnel. | | AMBULANCE BOAT |
| | … according to JC3 | | … according to JC3 |
| **Activity** | To fly over an area, monitor and, where necessary, destroy hostile aircraft, as well as protect friendly shipping in the vicinity of the objective area. | *action-task-activity-code* | PATROL, MARITIME |
| | Emplacement or deployment of one or more mines. | | MINE-LAYING |
| | … according to JC3 | | … according to JC3 |

The assignment of relations among attributes to relation lexicons (Table II) is a surjection. In order to define the relations among attributes *DSmT* combining and conditioning rules have been applied. The preferred rule for conditioning is the rule no. 12. When combining evidence, there is a possibility to use many combination rules, depending on the particular relation. However, for simplicity, it is suggested to apply the classic rule of combination (*DSmC*), which has properties of commutativity and associativity.

Table II
*SN ontology: relations and relation lexicon*

| Relations | | Remarks | Relation lexicon |
|---|---|---|---|
| **Rel. I:** | *cond(.)* | Based on *DSmT* | *Conditioning* |
| | → | According to distinctive features | *Implication* |
| **Rel. II:** | *cond(.)* | Based on *DSmT* | *Conditioning* |
| | ⊕ | Based on *DSmT* | *Combination* |
| **Rel. III:** | *cond(.)* | Based on *DSmT* | *Conditioning* |
| | ⊕ | Based on *DSmT* (combination rule need not be identical with one in Relations II) | *Combination* |

Below, there have been presented examples of particular types of relations. In case of the relation of type I it is possible to reason about a value of a certain attribute, based on the knowledge about the other ones. However, if the unambiguous deduction of the third attribute is not possible, due to the majority of possible solutions, an application of abductive reasoning (selection of the optimal variant) seems to be justified.

Relations I:
*(Threat, Platform)* → *Activity*:
*(FAKER, FRIGATE TRAINING)* → *TRAIN OPERATION*

*(Threat, Activity)* → *Platform*:
*(FAKER, TRAIN OPERATIONS)* → *TRAINING CRAFT*;
Relations II:
$FAKER = cond(obs(FAKER) \oplus ded(FAKER) \oplus obs(FRIEND))$;
Relations III:
$FAKER = cond(obs(FAKER) \oplus VS(FAKER) \oplus IFF(FRIEND))$;

The abductive reasoning process may be systemized by application of *DSmT*, where the selection of the optimal value takes place after calculating the basic belief assignment.

Example 3:
*(Threat, Activity)* → *Platform*:
*(FRIEND, MINE HUNTING MARITIME)* →
  MINEHUNTER COASTAL (MHC) ∨
  MINEHUNTER COASTAL WITH DRONE (MHCD) ∨
  MINEHUNTER GENERAL (MH) ∨
  MINEHUNTER INSHORE (MHI) ∨
  MINEHUNTER OCEAN (MHO) ∨
  MINEHUNTER/SWEEPER COASTAL (MHSC) ∨
  MINEHUNTER/SWEEPER GENERAL (MHS) ∨
  MINEHUNTER/SWEEPER OCEAN (MHSO ∨
  MINEHUNTER/SWEEPER W/DRONE (MHSD)

Applying *DSmT*, for each of possible hypothesis a certain mass of belief is assigned, e.g.:
$m(MHC) = 0.2$, $m(MHCD) = 0.3$, $m(MH) = 0.1$,
$m(MHI) = 0.1$, $m(MHO) = 0.1$, $m(MHSC) = 0.05$,
$m(MHS) = 0.05$, $m(MHSO) = 0.05$, $m(MHSD) = 0.05$

Based on the obtained *basic belief assignment* (*bba*) belief functions, referring to particular hypotheses, may be calculated. In the simplest case, assuming all of the hypotheses are exclusive, the subsequent belief functions will be equal to respective masses, e.g. $Bel(MHC) = m(MHC)$, $Bel(MHCD) = m(MHCD)$, etc.

## III. EXPERIMENTS ASSUMPTIONS

A relevance examination of the reconstructed attribute information of the manoeuvring target has been made in Matlab environment. Reconstruction was related to the following target attributes: target threat, target platform, and target activity.

The proposed sensor network enables the attribute information reconstruction based on observation as well as on reasoning process.

*A. Simulation of the target's motion*

For the purpose of the experimentation it is considered the target trajectory may be generated deterministically, as well as randomly, according to normal distribution of modifiable parameters.

Kinematic parameters of the target are not considered. Therefore the above mentioned assumptions seem to be adequate for the experimentation since the varying target to

source distance, that influences the observation quality, is modelled.

### B. Sensor network organisation assumptions

For simplicity it is assumed the considered sensor network consists of three sensors each of which enables to acquire information about target threat, target platform and target activity. Due to the fact that the experimentation is based on simulations no requirements related to a physical topology of the sensor network have been defined. A logical topology is assumed to be of tree type. This results directly from the dynamic fusion since the selected combination rule has been defined for two sources.

It is worth of notice that the assumption that each sensor enables to gain information about each of the considered attributes may be regarded as each of the sensors performs a subnet of fully connected sensors. In case of *DSmT* ontology fuser interactions among particular attributes are considered.

### C. Information fusion assumptions

Three fusion algorithms have been put to the examination:
- Hard-decision fusion with *Majority Rule* (*MR*) [5], implemented, separately for each of the attributes;
- *DSmT* fusion based on the hybrid combination rule
- Ontology-based *DSmT* , where the interaction among attributes is performer according to *Belief Conditioning Rule no. 1* (*BCR1[1]*).

### D. Sensor network ontology assumptions

For simplicity it is assumed:
- Concept lexicon for the threat attribute is compatible with *Link-16* [6], (partially compatible with *JC3*);
- Concept lexicon for the platform attribute *surface-vessel-type-category-code* of *JC3* model is constrained to mine warfare vessels;
- Concept lexicon for the activity attribute is defined by the authors, consisting of the most representative (in the authors' opinion) values;

Another assumptions are formed for so called ontology fusion.
- Interaction among attributes is performed with respect to belief conditioning rules (according to *DSmT*).
- Possible influences are defined as:
  - single attribute to another single attribute;
  - single attribute to another many attributes;
  - many attributes to another many attributes.

### IV. EVALUATION OF INFORMATION IN SENSOR NETWORK

Information evaluation is performed in two stages [7]:

- Information source evaluation: (0-1), where 1- indicates the ideal source;
- Evaluation of the degree of belief in particular hypotheses - defining basic belief assignment (*bba*);

For the threat attribute the following features are under assessment:
- Hostile/friend classification;
- Hostile/unknown classification (the degree of confidence the target is hostile);
- Unknown/friend classification (the degree of confidence the target is friendly);

For the platform attribute the following features are under assessment:
- Mine-hunter/minesweeper classification;
- Oceanic/coastal classification;
- Equipped with drone/not equipped with drone classification;

For the activity attribute the following features are under assessment:
- Military/non-military classification;
- Training/real classification;
- Assault/defence classification;

The example of the resulting assessment of target threat attribute (threat *bba*) is shown at Figure 1.



Figure 1. *Bba* for the threat attribute based on the sensor-originated information respectively: visual sightings, video camera and radar.

### V. INFORMATION FUSION IN SENSOR NETWORK

The hard-decision fusion is realised with *majority rule (MR)* implemented. It is assumed the *MR* algorithm is supplied with data from *the evaluator[2]*, which means that as well as the primary hypotheses, the secondary hypotheses (made with union and intersection operations) are to be utilised. The degree of knowledge about the target is specified according to the following formula:

$$K = 1 - (1 - P_{max}^{I})(1 - P_{max}^{II}) \qquad (1)$$

The *DSmT* fusion is realised with the hybrid rule of combination. The respective frames of discernment are

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[1] BCR1 has been implemented for simplicity reason. An application of BCR12 is planned in the next phase of experimentation.

[2] Block of the information processing scheme, where the evaluation of information is performed, according to the rules described in section 4.

defined as follows:

$$\Theta_{Thr} = \{HOS, UNK, FRD, NEU\} \qquad (2)$$

$$\Theta_{Pla} = \{MHC, MHI, MHO, MSC, MSO, D\} \qquad (3)$$

$$\Theta_{Actr} = \{ATC, MINE, UNK, FISH, DN\} \qquad (4)$$

For each attribute the separate fusion process is performed. The resulting characteristics decision is a superposition of partial decisions, related to each of the attributes. The degree of knowledge about the target is specified in accordance to the belief function value of the accepted hypothesis.

The ontology *DSmT* fusion effectively utilises the additional information about some of the attributes based on the decisions made previously. For instance: *(Threat, Activity)* → *Platform*. In order to do that a *conditioning* operation is performed. For the numerical experiments the *BCR1* has been used. In case the particular decision implicates several values of another attribute the condition is defined as an alternative of these values. For example:

(*FRIEND, MINE HUNTING MARITIME*) →
   *MINEHUNTER COASTAL (MHC)* ∨
   *MINEHUNTER COASTAL WITH DRONE (MHCD)* ∨
   *MINEHUNTER GENERAL (MH)* ∨
   *MINEHUNTER INSHORE (MHI)* ∨
   *MINEHUNTER OCEAN (MHO)* ∨
   *MINEHUNTER/SWEEPER COASTAL (MHSC)* ∨
   *MINEHUNTER/SWEEPER GENERAL (MHS)* ∨
   *MINEHUNTER/SWEEPER OCEAN (MHSO)* ∨
   *MINEHUNTER/SWEEPER W/DRONE (MHSD)*

The conditioning operation is usually used in *DSmT* for updating bba, based on some objective facts (theses), on the contrary to the *combination* (fusion), where bba is augmented with a new uncertain (subjective, by definition) evidence. In the considered case the goal is to achieve the coherent information about the target. Thus, the decisions made regarding one attribute may be treated as quasi-objective and used for 'homing' the decisions (made by combination) related to another attribute.

This operation enables to obtain more concise target model consuming the same pieces of information and constrain the uncertainty while decision-making, comparing to the rest of the considered fusion techniques.

## VI. SENSOR NETWORK ONTOLOGY

The attribute relation G functions have been defined as follows:

$$\begin{cases} G_{Thr}(pla, act) = Cond(Thr, \{pla, act\}) \\ G_{Pla}(thr, act) = Cond(Pla, \{thr, act\}) \\ G_{Act}(thr, pla) = Cond(Act, \{thr, pla\}) \end{cases} \qquad (5)$$

where:
   *Thr³, thr* – target threat;
   *Pla, pla* – target platform;
   *Act, act* – target activity;

All possible implications among attributes are defined in so called implication tables. These tables perform the deterministic base of the relations among attributes. For the purpose of the experimentation these tables have been determined by logic only, however their modification is possible if any additional (e.g. mine-warfare or SAR[4] domains) expert knowledge appears. According to assumed implication tables possible implications are listed below:

$$G: \begin{cases} Thr \to Pla \\ Thr \to Act \\ Pla \to Thr \\ Pla \to Act \\ Act \to Thr \\ Act \to Pla \\ Thr \to Pla \to Act \\ Thr \to Act \to Pla \\ Pla \to Thr \to Act \\ Pla \to Act \to Thr \\ Act \to Pla \to Thr \\ Act \to Thr \to Pla \\ Thr, Pla \to Act \\ Thr, Act \to Pla \\ Pla, Act \to Thr \end{cases} \qquad (6)$$

Based on the implication tables, due to the selected conditioning rule bba may be updated. Thus the resulting *bba* becomes conditioned according to *DSmT*, without disturbing its random nature (see [3]).

## VII. EXAMINING OF THE ADVISABLE SOLUTION

For the suggested sensor network a number of numerical experiments has been performed with respect to:
- Random and
- Deterministic target trajectory;

There has been considered both:
- FRIEND and
- HOSTILE target attribute;

Fusion methods have been compared using diverse information sources:
- Video camera;
- Radar;
- Visual sightings;

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[3] The following distinction is introduced to distinguish resulting attributes (capital letters) from arguments of conditioning functions (small letters).

The examination has been performed with various values of sensor reliability parameter and with number of sensors.

Sensor network parameters:

- Organisation:
  - Physical topology: N/A (simulation);
  - Logical topology: tree type;
  - Transmission medium: N/A;
- Information evaluation:
  - Threat attribute;
  - Platform attribute;
  - Activity attribute;
- Fusion methods/techniques:
  - Hard-decision fusion (*MR* implemented);
  - Soft-decision fusion (*DSmT*);
  - Ontology *DSmT* fusion;
- Ontology:
  - Lexicons: Link16, JC3, test lexicon for threat, platform and activity attributes respectively;
  - Relations have been defined using *Belief Conditioning Rule* no. 1 (*BCR1*);

### A. Results of sensor network experiments

Due to the constraints, referring to the space of this paper, as the most interesting in the authors' opinion there have been selected the results, which had been obtained with simulation of the deterministic target trajectory.

Figure 2 shows the comparison of the examined fusion methods when the observation conditions were convenient (in terms of target distance, azimuth and aspect), that is no measurement has been lost.
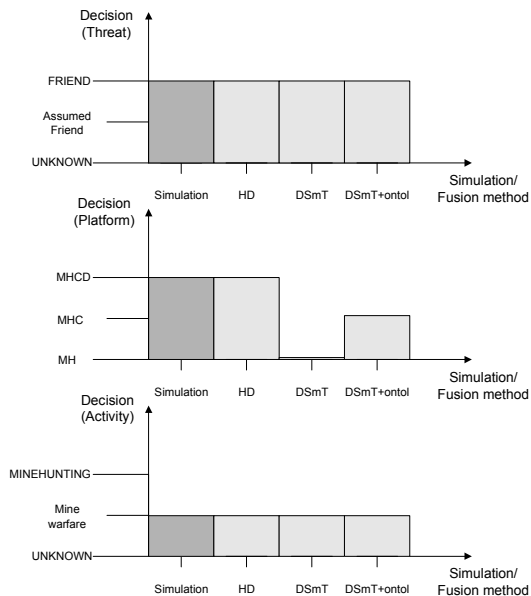


Figure 2. Comparison of decision adequacy of the examined fusion methods - perfect observation conditions.

[4] Search and Rescue.

In this case the attributes of threat and activity have been retrieved by all of the examined methods equally, exactly as they had been simulated. The difference among the fusion techniques resides in retrieving the platform attribute. The hard-decision fusion enabled to reconstruct the complete information about the target platform as the *costal mine-hunter equipped with drone*, while *DSmT* enabled to identify the target as a sort of mine-hunters. The ontology *DSmT* enabled to assess the target threat a bit more precisely, loosing the equipment information only.

In the following experiment the same target had been moved away from the sensors, which made the observation conditions worse. The threat assessments, performed by all of the examined fusion methods, have not changed, as shown at Figure 3.
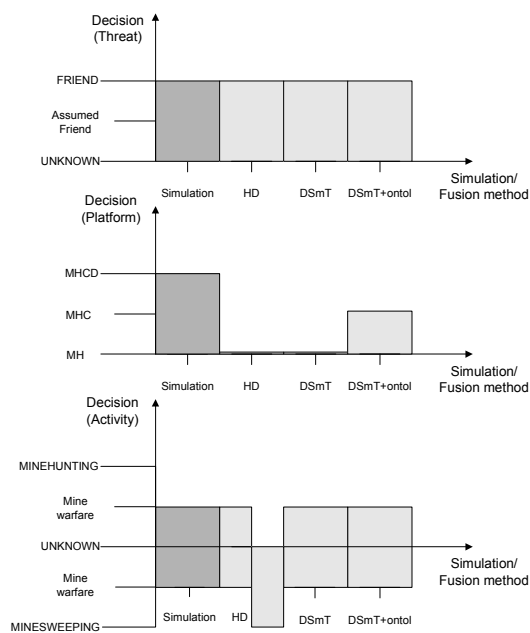


Figure 3. Comparison of decision adequacy of the examined fusion methods - bad observation conditions.

The decisions by *DSmT* and ontology *DSmT* have stayed stable, whereas the precision of hard-decision technique have reduced. Another very interesting effect has also been noticed: in about 50% of cases, depending upon the exact observation noise realisation, the target activity assessments, performed by hard-decision fusion, have led to incorrect decision that the target had been mine-sweeping.

In the next experiment a training target trajectory had been simulated. The target intended to be hostile. Figure 4 shows that the activity of TRAINING has been successively retrieved by all of the fusion methods. Due to the inconvenient observation conditions the hard-decision fusion and *DSmT* have identified the target as a sort of mine-hunter, whereas the ontology *DSmT* enabled to gain a bit more precise information, that the target is a costal mine-hunter.

The most interesting was the impact of the ontology during retrieving the information about the target threat. According to [6] evidences that the target is simultaneously hostile and training are contradictory. Due to the usage of the attribute relations from the sensor network ontology, the ontology has allowed to correct the input inconsistency by setting the target threat as FAKER, which by the [6] is the most adequate decision.
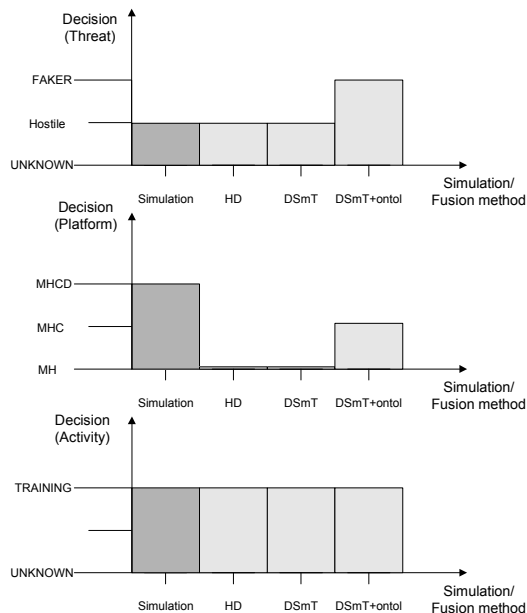


Figure 4. Comparison of decision adequacy of the examined fusion methods - inconsistent simulation information.

## B. Examination summary

In case the number of sensor rises the hard-decision fusion delivers better results than other methods. That is in accordance to the expectations, since this method introduces relatively low rate of uncertainty. *DSmT* fusion provides more 'general' solution. However it is important to notice that the considered methods are not equipped with the same mechanism of the evaluation of knowledge about the target. Although it is reasonable to assume that both *DSmT*-based methods have the identical mechanisms, in case of the hard-decision fusion the degree of knowledge about the target is calculated due to the formula (1), which strongly reduces the uncertainty of the final decision. The hard-decision fusion offers more precise solution comparing to the rest of the considered techniques, however the risk of wrong decision is also relatively bigger due to the exclusive nature of this technique.

It is also worth of notice that during experimentations all of the techniques have been supplied with information originated from *the evaluator*, which is quite unusual for the hard-decision fusion. It is expectable that in typical application, this technique would provide a higher rate of wrong decisions.

Based on the numerical experiments it is easy to notice that the ontology *DSmT* provides satisfactory results. Due to the *DSmT* engine the decision is 'secure' - that is adequate to the simulation, however not very precise. The ontology, on the other hand, enables to adjust the reasoning process, which results in increased precision of the final decision.

## CONCLUSION

The concept and numerical experiments presented in this paper have given some viewpoints, related to an application of *DSmT* in C2 systems. They also have provided some basic verifications of the effectiveness of *DSmT*-based fusion techniques, showing their advantages like 'security' and 'adequacy' of the elaborated decisions, and disadvantages like relatively low precision of the final decision.

The synergy of two approaches: *DSmT* and ontology, presented in this paper, seems to have good prospects for the future application in real C2 systems. However, it requires some further examination, particularly related to specification of hybrid *DSm* models, and also selection of combination and conditioning rules.

## ACKNOWLEDGMENT

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