A Model to Promote Interaction between Humans and Data Fusion Intelligence to Enhance Situational Awareness

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Abstract. The operator of a Command & Control (C2) system has a crucial role on the improvement of information that is processed through data fusion engines to provide Situational Awareness (SAW). Through direct access to data transformations, operators can improve information quality, by reducing uncertainty, according to their skills and expertise. Uncertainty, in this work, is considered an adverse condition, which can make the real information less accessible. Although relevant solutions have been reported in the literature on innovative user interfaces and approaches for quality-aware knowledge representation, these are concerned mostly on transforming the way information is graphically represented and on quantitatively mapping the quality-aware knowledge acquired from systems, respectively. There are few studies that deal more specifically with accessibility for decision-makers in safety-critical situations, such as C2, considering the aspect of data uncertainty. This paper presents a model to help researchers to build uncertainty-aware interfaces for C2 systems, produced by both data fusion and human reasoning over the information. Combined to environmental and personal factors, a tailored and enriched knowledge can be built, interchangeable with systems intelligence. A case study on the monitoring of a conflict among rival soccer fans is being implemented for the validation of the proposed solution.

1 Introduction

Major Events require effective and efficient operational responses. Frequently, unexpected incidents arise and demand time-critical decisions from a commander of the state police, security managers or governmental members. Such decisions might involve the deployment of new tactics and the allocation of human resources and equipment. Automatic and semi-automatic monitoring systems for the security and safety of major events can be highly complex; they provide the operators awareness about what is going on at the event location. For that, Data Fusion processes fed by multiple, heterogeneous sources (physical sensors, social networks,

M. Kurosu (Ed.): Human-Computer Interaction, Part I, HCII 2014, LNCS 8510, pp. 399–410, 2014.

databases, etc.), and computational intelligence are used to help providing the operators not only with the perception and understanding of what is going on at the environment, at a certain time and space dimension, but also anticipation of events to come. This is known as situational awareness (SAW) [1].

Devices and innovative interfaces are being devised for better supporting the situational awareness visualization process, what can be a great challenge for two main reasons: such devices might have to be used in harsh conditions, for instance, command and control interactive devices might be used in moving vehicles, poor lighting conditions and noise; and operators might be subject to long hours of work, under emotional stress. Also, considering that commanders are expected to make decisions based on his/her understanding of what is going on, and his expertise, skills, and past experience can be a valuable asset in the comprehension of current and even anticipation of future issues, it is crucial that SAW systems interfaces provide for that expertise/experience to be used as another source of information.

The physical and emotional stress to which SAW systems users/operators can be subject to, besides potential harsh conditions of the environment, the always emerging new technologies [2], and even pervasive multiculturalism, in which commanders from different regions of the world with distinct cultural backgrounds might have to work and make decisions collaboratively, add to the challenge of devising accessible interfaces. Relevant interface solutions to accessibility for users with different abilities, capabilities, needs and preferences in a variety of contexts are reported in the literature. However, as far as the authors investigated, there are few studies that deal more specifically with accessibility for professionals acting under uncertainty and harsh conditions, such as decision-makers in safety-critical situations, as the monitoring emergency situations (incidents) in major events.

This paper introduces a model to promote interaction between humans and the data fusion intelligence to enhance situational awareness. With our model, the data fusion process can be fed the experience of operators/skilled professionals, and imperfections of data and situations can be reduced. The model supports the management of uncertainty-aware information flow, led by the propagation of evidences along the flow, and the operators' belief driven by data transformations across the process. The paper is organized as follows: Section 2 presents Approaches for Improving Information Quality to Enhance SAW; the Model for Promoting interactions between Humans and the Data Fusion Process is introduced in Section 3, followed by Conclusions.

2 Approaches for Improving Information Quality to Enhance SAW

Situation awareness systems, specially applications of command and control relies on information quality to provide operators a better view of the analyzed scenario for making improved decisions. If imperfect information is provided to SAW systems, the operator may be uncertain on what he perceives and understands and the quality of decision will be compromised. For such, this paper presents a model comprising of a user interface and an extended Dempster-Shafer approach for reasoning from uncertain information and storing knowledge about assets and situations obtained with or without transformations. Hence, this combination will provide a model for building accessible interfaces for operators in adverse conditions through the interaction with fusion systems under uncertainty. The State-of-the-Art reveals advances in two main related fields: the development of innovative user interfaces and techniques for the enhancement of operator's understanding of information and the approaches for the management of the knowledge generated by systems and humans.

2.1 Interactive Interfaces and Visualization Techniques

Regarding interactive interfaces and techniques for quality-aware data information exploration and transformation, Xie *et al.* [3] created an interactive interface to enable users to explicitly explore that data quality information. They also created a framework for the coupling data space and quality space for producing multivariate visualizations. Authors also introduced two novel techniques, quality brushing and quality-series animation, to help users with the exploration of this connection between spaces. Their case study they conclude that the solution on quality information is more effective than traditional multivariate visualizations. To improve their framework, they point the creation of a tighter link between data and data quality, whereas brushing data can conduct to quality inferences, that is, to perform tasks related to the quality of the data abstraction. Friedemann *et al.* [4] created an uncertainty interaction model to reduce the probability and consequences of poor decisions on the detection of tsunamis. Such model implies on representing all quality measurements in unique graphs allowing pre-defined combinations. All classification and quantification of imperfect information are done by the system, with no human involved. Summers *et al.* [5] developed a user interface for C2 environments with the capability of visualization customization based on the situation, user role, individual preferences and the size of the display. Clustering and de-clustering were implemented to make information filtering and the integration of new information as the situation evolve. This work generalizes all types of data quality issues and uses the same approach to mitigate them (requesting more and more data).

2.2 Models for Improving and Quantifying Information Quality

Regarding the advances on models for improving and quantifying information quality, Wen and Zhou [6] presented an approach with two comparative experiments on examining how data transformation impacts user task performance in various visualization situations. They proved that data and information transformation significantly improves user performance in both single-step and multistep difficult analytic tasks. They also identified three types of data transformation techniques that help to produce a quality visualization and developed a set of guidelines that suggests when and what types of data transformation are most useful. The effects of data transformation is evaluated only in the end of the process. Angelini *et al.* [7] presented a visualization model to support analytical interactive exploration of information retrieval results with the focus on supporting the failure analysis and the understanding of a system behavior, conducting a *what-if* questions to have estimations of the impact of modifications into the system. The authors overall goal of the paper is to provide users with tools and methods to infer the effectiveness of a system and explore alternatives for improving it. The methods used by authors allow users to dynamically quantify quality improvements and rank gains/losses as the system under examination, instead of the method of the previous approach. The effects of quality assessment are given back to the visualization part, allowing users a smooth interaction of the user with the results. Only real-time evaluations are possible with no temporal analysis allowed. In their work Correa *et al.* [8] proved that when users is about to make decisions under an uncertain environment, it is important to quantify data and present to them both the aggregated uncertainty of the results and the impact of that uncertainty. In such paper, it was presented a new framework to support uncertainty-aware in a visual analytics process, using statistic methods. They show that data transformations, such as regression, principal component analysis and k-means clustering, can be used to take account for uncertainty identification and quantification. This framework leads to better visualizations that improve the decision-making processes and help analysts to perform new inferences. There is no qualitative assessment by this framework.

Authors agree with contributions of their approaches e.g. the interaction techniques to brush data, assess information from new inferences and access associated data quality inferred by a system. Overall limitations are the need for data evaluation on every interaction step for a better data quality quantification, the development of new interaction techniques to assess high level information and a more tight coupling between human judgments and data representation.

2.3 Human's Knowledge Management

Regarding approaches for the management of the knowledge generated by systems and humans, McKeever [9] and Zhang *et al.* [10] both presented approaches based on the Dempster-Shafer theory for the recognition of situations under uncertainty environments. The formed included the knowledge about the sensors and their attributes, and the temporal aspect of the evidences as part of the belief functions. The latter created an approach to allow context reasoning from incomplete pieces of information aiming to infer situations. Blasch *et al.* [11] built a complementary model of the well known JDL model involving humans in the process. Such model supports the modeling, method, management and the design of fusion systems that demand high level information fusion and the evaluation of information driven by the humans. Laskey *et al.* [12] built a model that describes the role flow of information since the description of the data quality as it is acquired, the storing quality into metadata, the propagation of uncertainty by fusion process, the exploration with decision support tools until the communication to users as the final product. This model considers the whole process but does not takes into account the information judgment by experts.

Although several attempts succeeded on infer and reason on contexts that aim to include data quality with known evidences and beliefs, authors agree on suggesting that the human judgment is essential to infer data quality from an expert point of view. All quality attributes must be know as new evidence arise and be applied by human input. We envision that our work innovate in the human-information discourse propagating and refining uncertainty information previously identified by systems. From user interfaces, operators iteratively interact and transform information and its representation requesting functions of the fusion process, and then re-evaluate the information based on their own conceptions. A new knowledge involving interactive visualizations and the transformed information will be conceived and can be used to enrich system's intelligence .

3 A Model for Promoting Interactions between Humans and Data Fusion Intelligence

The main goal of our work is to devise interfaces to critical security systems that takes in consideration operators' skills and experiences to enhance the decision making process even in harsh conditions. For that, a model is being created to support human's knowledge as input to the data fusion process via novel and accessible interfaces to be used also in challenging environmental, physical and emotional conditions. Figure 1 depicts an overview of the model, which comprises two main modules: SAW-oriented user interface and a DSET (Dempster-Shafer Evidence Theory)-based knowledge manager, which are described below:

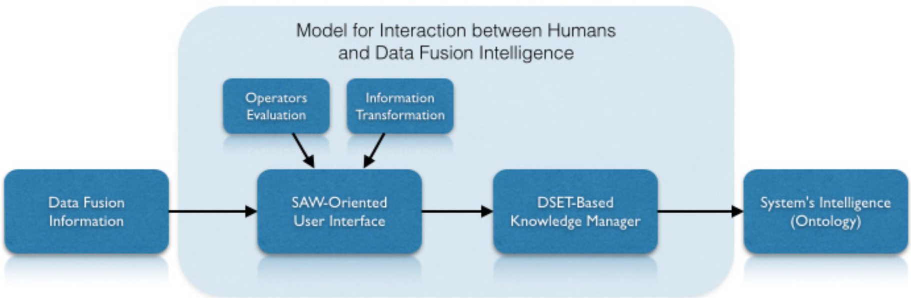

Fig. 1. Model for Promoting Interactions Between Humans and Data Fusion Intelligence

– SAW-oriented user interface*:* A user interface that supports information acquisition from the Data Fusion systems (fused or not) about one or more assets. The way this information is acquired and processed can present imperfections on its structure, composition and meaning - thus, uncertainties can arise on the operators' SAW. Operators must re-evaluate information to update the previous evaluation made by the systems intelligence. To obtain more evidences on the quality of information and provide more reliable evaluation, operators must be able to perform transformations with new combinations and corrections of data.

- DSET-Based knowledge manager: An approach for acquiring, processing and storing the knowledge generated from operators via the proposed interface, considering the used sources, discovered assets, applied transformations and the revealed situations. The product of this module is an uncertainty-aware information flow, driven by the users interactions to apply information transformations on-demand to reduce such uncertainty. The combination of these two modules aim to enhance SAW by providing means for humans to iteratively improve the quality of the information that operators rely on to make critical decisions, reducing her/his uncertainty on what s/he perceives and understands by her/his own choices on how information is obtained and presented.

3.1 The Problem

The application domain considered in this work focus on C2 for the monitoring of large events. A case study is being developed considering incidents of social disorder (e.g., hooliganism) inside a subway station that can occur after a major event (e.g., soccer game). The goal is to monitor assets for the maintenance of public order and safety, given high population density and constraints of the contingency plans. Rival soccer fans meet inside the subway station, starting a conflict. Information on the conflict can arrive from different sources: from physical sensors deployed in the environment (cameras, microphones, movement detectors, etc) to messages from witnesses via social networks, to integrated systems that can estimate group sizes, crowd simulation systems that can infer crowd behavior, reports from police members, subway security team and so on. At the police central, the event is assigned to an occurrence and reported to the commander for a more detailed analysis, thus installing a C2 operation.

3.2 The Design of a User Interface for Enhancing SAW

In our scenario, a method called GDTA (*Goal Driven Task Analysis*) [1] was adopted in order to elucidate the information required for each decision commanders must make. All decisions are stablished in order to accomplish tasks to reach minor and major goals. Such goals were determined following guidelines from literature and validated with a São Paulo State Police commander.

One of the major goals is "*Monitoring*", which can be specified into the goal of "*Evaluating activities at the subway station*", or even more specified, "*Evaluating the event status at the subway station*". Based on these goals, at least one decision must be made, such as "*Should commander take any additional action besides the stablished contingency plans*?" This question leads to a set of information required to make such decision, divided by SAW levels. With this set of required information to make the decision, a user interface and visualizations can be designed. For the accomplishment of this design, the guidelines for user-centric user interface design by [1] were adopted. In their work, eleven principles are depicted. Also, new interactive visualizations were conceived to overcome the uncertain information that may cause mental confusion on operators. Such visualizations were based on the work of [13] and [14].

Quality-Aware Interactive Visualizations

The user interface (Figure 2) accommodates quality-aware interactive visualizations to perform the information transformations. If the information looks uncertain to operators, new inferences must be revealed for building new knowledge and contributing to a better SAW [13,14].

The first action the operator must take is to tell the system about his first impression on information. If the operator indicates that the information is imprecise, incomplete or even vague, the system will be able to provide a transformation toolbox, aiming to empower operator toward the experience of building his own awareness. The main objective of using information transformation is to provide better suitable contexts to reach the required goals by means of his will in an iterative fashion. Hence, operators are able to refine, correct or compose new information that may be uncertain to him or just represent it again in a better way to reach SAW.

Our approach envision to apply transformations in a way to promote what authors call high-level information fusion (HLIF) [15]. Such concept emerged once information is already produced but it wasn't enough for human purposes, being needed new information to be brushed, inferred or just aggregated once data fusion systems already provided initial results. Hence, users can acquire new data by choosing new sources in the side panel, to populate the interface with new perception items; aggregate the new data into the current data/information, promoting HLIF; split already fused data/information, useful to reveal SAW hierarchy of information and start a whole new HLIF; filter relevant information, for reducing cognitive workload; and correct data/information that system and/or humans can acquired or process. Transformations can trigger operations that a data fusion system performs through its phases in a high level manner, such as data acquiring and pre-processing (e.g., image/signal processing), information processing (e.g., mining, correlation, fusion), visual representation (e.g., filtering, presenting) and user refinement (e.g., insertion, evaluation and correction).

By the end of the user interface development we will be able to provide guidelines for the design of user interfaces for uncertainty mitigation by interacting with visualizations.

The Human in the Information Evaluation Process

System's intelligence may be capable of inferring quality-aware data, allowing user to reason over pre-evaluated information. Such a priori evaluation may be derived from past experiences from other users or by automated process

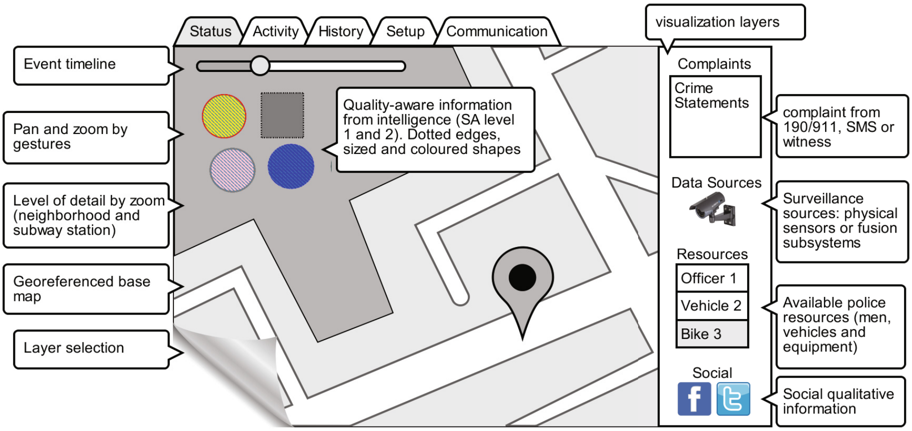

Fig. 2. User Interface to accommodate quality-aware interactive visualizations

of identifying quality issues on data or information, such as incompleteness or imprecision, which both can lead to uncertainty.

Such users evaluation on C2 information can confirm, contradict or even improve systems evaluation and is based on observational evidences of the warfare environment or on his personal experiences on similar situations. Stress, experience and workload are factors that can be weighted and accounted as evidences for determining certainty on information. Such factors directly influences how commanders see and process information, improving or decreasing their trust on the information and its source.

Consider the following example of our scenario: surveillance sensors and system's intelligence determine that in a specific region of the subway station there is a set of tracked persons denoted by {team1_fans, team2_fans, passengers, officers, offenders}. The tracking system determine (in a range of 0.0 (imperfect) - 1.0 (perfect) possibilities in a Likert scale) that in a certain group there is a possibility of 0.7 that they are team1_fans; 0.8 they are offenders and also they represent a 0.9 possibility of threat to a group of team2_fans, considering their attitude and position at the station. The system also detected a 0.7 chance that team1_fans is carrying sticks and stones. Furthermore, experience is crucial to trust or contradict the situation that has been presented. Analyzing the images from the surveillance system, the operators experience can lead his assessment to reason over the information that has been presented, e.g., the operator can conclude that the persons must be offenders by only 0.3 possibility and then represent a 0.1 chance of threat, given the isolated area and the 0.8 chance of presence of officers near the analyzed area. Also, by requesting another source of data (witnesses for instance) or a new fusion event, the operator can discover, for instance, that there is a chance of 0.1 of presence of sticks at the scene. Such inferences by the operator also obey the scale used by the system and the evaluation possibilities will be suggested through the interface.

Making the interface accessible for human participation in the information evaluation process is in progress, as much as the evaluation of the impact of physical and emotional stress of operators on the decision-making and how this can affect SAW. SPAM (Situation Present Assessment Method) will be adopted to measure such impact.

3.3 The Operator's Knowledge Management

The knowledge obtained from the interaction with information over the interface may enrich modules of intelligence services (or inference engines) of Data Fusion systems. Such services can "learn" from operators past experiences and help other operators to improve comprehension under C2 critical domain in cases of similar contexts and situations. The knowledge manager module shown in Figure 1 deals with the management and display of the knowledge obtained from evidences. Dempster-Shafer Evidence Theory (DSET) [16] is used, with changes on how evidences are propagated as masses change. Inspired by [10] we model knowledge as a set of sensors, assets, transformations and situations. In the example shown in Figure 3 the asset A2(a gun) is inferred from the transformation T1(image processing) applied to A1(a man carrying an object captured by image); the asset A4(a group of fans of team 1 at the left side of the station) is inferred from the transformation T2 (aggregation of new information) applied to A3 (incomplete information about the presence of team 1 fans); both A2 and A4 combined provide the situation U1(armed group of team 1 fans); A7 is comprising from A5(passengers) and A6(persons in green shirts) just by observations; A8 (possible group of team 2 fans) is inferred from the transformation T3 (disaggregation) applied to A7(unarmed people) and result on the situation U2 (presence of team 2 fans); both U1 and U2 can be used to infer a new situation U3 (imminent threat and risk to life).

Such mapped contexts and situations can be used to establish the basis of a knowledge about to be formalized by the DSET-based theory. Besides managing the transformation-driven knowledge until it reaches a situation, our approach registers a quality index (measured by system) before transformations and a quality index (measured by operator) after information transformation. Such indexes reflect directly on the masses that represent beliefs on hypothesis of what assets A are or what situations U represent. Figure 3 also shows the stored knowledge with the quality index update.

3.4 Accessibility and Uncertainty as an Accessibility Dimension

The goal of Command and Control systems is to support operators in complex tasks for safety-critical decision-making in a highly restrictive environment [17]. Most of the restrictions arise from the usage of user interfaces that need to be "aware" of the amount of data, operator's physical and cognitive factors and the inherent aspects of the information, such as quality attributes. Besides, multi-sensors for C2 systems typically produce big data and the assessment of current situations can be severely compromised if relevant information is not

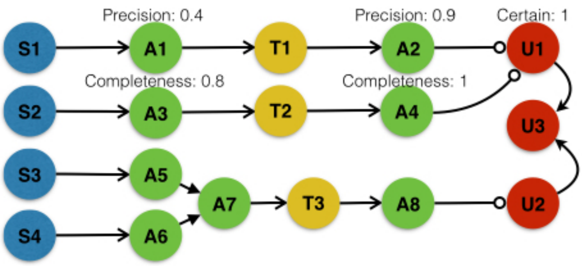

Fig. 3. An example of the working model for the management of the operator's knowledge. The organization of the information flow and the quality index updating after transformations.

properly presented to operators in a timely fashion [18]. Operators may not be prepared to deal with such burden and may not know how to handle it. User Interfaces must provide means for users on qualifying information. Moreover, environment impairments situationally induced [19], i.e., adverse conditions regarding the operation environment of the interface may influence how operators perceive and understand information, e.g., noisy surroundings, poor lighting conditions and devices used on moving vehicles. Also, physical limitations such as motor disabilities, stress, fatigue and emotions must be known and captured by such interface [20]. To overcome such conditions, adaptive interfaces become inevitable to support access to information regardless the context of use, providing timely information on demand and formatted to specific information, operator and environment [21].

Furthermore, during the processes of information acquiring, computation, representation and refinement in a multi sensor scenario, imperfect information may be propagated until it reaches the user interface. Added to other human constraints, the result may not be promising. Uncertainty about information is also an adverse condition and can make the real information less accessible. The presence of uncertainty can lead to a poor SAW about what the assets are and what is going on with them. Reducing such uncertainty is crucial for decision-making and part of this is humans' responsibility [22]. For such, it must be accounted, besides the other factors, the experience, expertise and the operator's training, which may guide operators in their tasks, help them to infer new information and customize the interface. Hence, interacting with and transforming the uncertain information can become an additional instrument for reaching accessibility due to its potential for adapting the way information is composed or visually represented.

The model presented in Section 3 provides the support for the interaction and transformation required to reduce information uncertainty. Further research is now underway to integrate our model to an interface solution for users operating under the adverse conditions presented in this sub-section. The necessary dimensions (e.g., disability types) were identified and will be mapped against required context processing and adaptation rules.

4 Conclusions

The physical limitations of users, their different capabilities, needs and preferences, besides the situationally induced environment impairments, make accessibility a critical and challenging issue, especially when users access a critical security system. Added to that, uncertainty about information is also an adverse condition and can make the real information less accessible. Human intervention on the information flow can reduce uncertainty. For that, interfaces that support such intervention are necessary. This paper introduced a model that can offer operators of critical security systems, interface for direct access to data transformations to improve information quality according to operators' skills and expertise. The model also provides support for the knowledge management from the uncertainty-aware information flow – the used sources are mapped, the assets are identified, transformations are applied and patterns and situations are revealed. As a result, system's intelligence can be enriched and the operators' situational awareness potentially enhanced. The interface is being implemented and will be validated by Sao Paulo police commanders. As future work, our model will be integrated to an interface solution for users operating under different dimensions of adverse conditions.

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