Team Situation Awareness and Its Assessment

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ABSTRACT

Team Situation Awareness (TSA) is a key factor in team cooperative activity. In this study, we proposed a new notion of TSA, which is reducible to mutual beliefs as well as individual SA in three levels. Further we developed a TSA inference method based on the inferring practices of humans and developed a TSA simulator. Using the simulator, TSA in team operation of DURESS was evaluated from two points of views: soundness and completeness of inferred SA. The result demonstrated that our definition of TSA reflects more realistic aspects of team cognitive process than the conventional TSA definition as the overlap of individual SA.

KEYWORDS

Team performance, team situation awareness, TSA, mutual belief, computer simulation

INTRODUCTION

A notion of Situation Awareness (SA) is becoming a locus of interest in various domains of process control. Situation awareness is defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” (Endsley, 1995) How appropriate SA one obtains can be an effective measure for assessing human performance. Most previous studies on SA, however, dealt with Individual SA (ISA). Situation awareness under cooperative work conditions, Team Situation Awareness (TSA), has been thought of as the intersection or overlap of SA shared by the members of a team (Salas and Prince, 1995; Gabris, 1998; Endsley and Jones, 2001), but this way of TSA definition is too simplistic compared with previous studies on team intention (Tuomela and Miller, 1987; Bratman, 1992).

In this study, aiming at assessment of advanced human interface used for cooperative works as the final goal, we will propose a definition of TSA and its formulation by modal logic, and develop an inference method of TSA. We will then develop a TSA simulator equipped with a TSA inference engine to conduct computer simulation for assessing TSA. The result of test simulation applied to
team operation of DURESS will be presented to demonstrate the usefulness of the proposed approach.

**DEFINITION AND FORMULATION**

First we are going to define TSA as “Two or more individuals share the common environment, up-to-the-moment understanding of situation of environment, and another person’s interaction with the cooperative task.” Endsley proposed a three-staged definition of SA: perception of elements of the environment, comprehension of the current situation, and projection of future states. The above definition of TSA includes not only SA of Endsley’s three levels, but also aspects of other members’ actions such as intention.

Next we will formalize the definition of TSA by modal logic. We use ordinary symbols for the first order predicate logic and a modal operator BEL in an expression like $BEL(m, P)$, which represents belief of a person $m$ on a predicate $P$ (Levesque, Cohen, and Nunes, 1990). A modal operator $EBEL$ stands for “everybody believes” and it is defined as

$$EBEL(g, P) \equiv \land_{m \in g} BEL(m, P).$$

Mutual belief $MBEL$ is recursively defined using $EBEL$ as

$$MBEL(g, P) \equiv EBEL(g, P) \land EBEL(g, MBEL(g, P)).$$

The first level TSA, for example, can be formalized like

$$TSA1(g, P) \equiv MBEL(g, hold(P, now)) \land symptom(P)$$

$$= \land_{m \in g} \land_{Pi \subseteq P} (SA1(m, Pi) \land MBEL(m, hold(Pi, now))),$$

where $hold(P, t)$ means that a state $P$ obtains in time $t$, and $symptom(P)$ that $P$ is a perceivable system state. The latter part of the above formula indicates that the first level TSA is reducible to the first level ISA and their mutual beliefs. Similar expressions are obtainable for TSA of the second and the third level. Arguments on team intention are applicable also to the part of action in TSA.

**TSA SIMULATION**

Based on the above TSA definition, an inference method of TSA will be discussed here, considering TSA inferring practices of humans in everyday life. While the first level ISA is obtained through symptom observation by oneself, its mutual beliefs are obtained through verbal communication or inferred from observing other’s action and ones own ISA. This process is represented by the following logical formula.

$$(\text{perceive}(A, \text{observe}(B, Pb, \text{before(now)}), \text{before(now)}) \land \text{BEL}(A, \text{hold}(Pb, \text{now}))) \land$$

$$\text{inform}(B, A, \text{BEL}(B, \text{hold}(Pb, \text{before(now)})), \text{before(now)}))$$
The second and the third level TSA are obtained also through explicit verbal communication or through inference from the lower level TSA. The inference process of TSA for the most basic case for a dyad is shown in Fig. 1.

A TSA simulator is a knowledge base system written in Prolog, and it consists of the inference engine and knowledge bases containing domain specific knowledge. It is assumed in the simulation that each operator monitors the operation panel, perceives symptoms relevant for operation goals, and identifies what is happening in the plant in cooperation with other operators. Each operator is modeled as an autonomous agent, which determines its own behavior referring to information from the environment, that from other agents, and knowledge in its own knowledge base.

Since demonstration of TSA simulation is interested in this study, simulation scenarios on operators’ action and plant behavior are prescribed and given to the simulator. The simulator infers TSA of each operator up to the first order of mutual beliefs using information from the plant, observation of others’ action, and verbal communication from others as input data. The simulator generates SA of the first level, perception, as a result of symptom observation by oneself. SA of the second level, comprehension, is obtained as a result of plant state identification, which is modeled as...
similarity matching between observed symptoms and symptom patterns. Knowledge of association between a symptom pattern and the related plant state is prepared in the knowledge base.

When verbal communication is conducted, ISA is communicated to others to generate its mutual beliefs. Otherwise, other’s SA is inferred from ones own SA and observation of his/her action. Beliefs on other’s perception are inferred from ones own perception and observation of perceptual action of the other. Perception that is not yet obtained by oneself is derived from comprehension by inference in the opposite direction to similarity matching. Beliefs on other’s comprehension are obtained by applying similarity matching to beliefs on his/her perception.

![Architecture of TSA simulator.](image)

**ASSESSMENT MEASURE**

As for a dyadic team, which is made up of two members of A and B, A’s TSA consists of three components, i.e., A’s own SA, A’s belief on B’s SA, and A’s belief on B’s belief on A’s own SA. B’s TSA consists of corresponding three components in a mirror image of A’s TSA.

Beliefs in A’s mind does not always coincide with B’s real SA, and vise versa. TSA of a dyad is represented as follows:

\[
\text{TSAn}(g, P) = \text{SAn}(A, Pa) \sqcap \text{BEL}(A, \text{BEL}(B, \text{hold}(Pb, t))) \sqcap \text{BEL}(A, \text{BEL}(B, \text{BEL}(A, \text{hold}(Pa, t)))) \sqcap \text{SAn}(B, Pb) \sqcap \text{BEL}(B, \text{BEL}(A, \text{hold}(Pa, t))) \sqcap \text{BEL}(B, \text{BEL}(A, \text{BEL}(B, \text{hold}(Pb, t)))).
\]
Every appearance of $Pa$ or $Pb$ in the above formula does not necessarily the same. As for $Pa$, it appears three times and each of which can be distinguished as follows:

$$Pa = \{ p | \text{SAN}(A, p) \}$$
$$Pa' = \{ p | \text{BEL}(B, \text{BEL}(A, \text{hold}(p, t))) \}$$
$$Pa'' = \{ p | \text{BEL}(A, \text{BEL}(B, \text{BEL}(A, \text{hold}(p, t)))) \}$$

If and only if the above three versions of $Pa$ coincide each other, the team has complete and sound TSA for A. If $Pa'$ or $Pa''$ do not include some elements of $Pa$, TSA is incomplete. If $Pa$ does not include some elements of $Pa'$ or $Pa''$, TSA contains wrong beliefs. TSA can be assessed by comparing $Pa$, $Pa'$, and $Pa''$. The same argument is applicable to $Pb$.

In order to assess TSA quantitatively, we will introduce two measures of similarity or difference between ISA and corresponding mutual beliefs: soundness and completeness. Soundness represents the degree of match of beliefs on other’s SA to the real SA. The soundness of B’s beliefs on A’s SA is defined as follows:

$$\text{Soundness of } Pa' = \frac{\text{count}(Pa \cap Pa')}{\text{count}(Pa')}$$

where count($X$) is the number of elements in $X$. Completeness is the degree of coverage of beliefs on other’s SA over the real SA. The completeness of $Pa'$ is defined as follows:

$$\text{Completeness of } Pa' = \frac{\text{count}(Pa \cap Pa')}{\text{count}(Pa)}$$

Similar assessment can be done for A’s beliefs on B’s SA, $Pb'$, which is in a mirror image of $Pa'$.

If the conventional definition of TSA is adopted that TSA is the intersection of SA shared by every group member, just completeness of TSA can be assessed as follows, and soundness makes no sense.

$$\text{Completeness of } Pa = \frac{\text{count}(Pa \cap Pb)}{\text{count}(Pa)}$$
$$\text{Completeness of } Pb = \frac{\text{count}(Pa \cap Pb)}{\text{count}(Pb)}$$

In this study, TSA is also assessed following the above definition, and the results will be compared to discuss which definition is more appropriate to represent the reality of group cognitive process.

**RESULT OF SIMULATION**

The TSA simulator was applied to two-man operation of DURESS (Vicente and Rasmussen, 1990) and ISA and mutual beliefs of the both operators were inferred. SA of the first and the second level and their mutual beliefs generated for various simulation scenarios were compared each other to assess completeness of TSA. Difference between mutual beliefs and the real SA reflects the limitation of team cognitive process imposed by situation of group cooperative activity. Since this simulation considered no wrong knowledge and no error mechanisms, the simulator made no erroneous inference results. Hence just completeness makes sense, and soundness was not evaluated.
Simulation scenarios were generated by varying the initiating abnormal event, task allocation between two operators, condition of verbal communication, operators’ mental models (knowledge), design of operation panels, and condition of action observation. Various combinations of the following conditions were made for each initiation event and task allocation.

1. The operators can / cannot observe colleague’s action.
2. The operators use the common operation panel / separate operation panels.
3. The operators communicate / does not communicate vocally.
4. The operators have the same / different mental models.

How verbal communication and control room setting affect TSA was examined first. As for verbal communication it is assumed that the operators report their state of mind in a think-aloud manner when they acquire new information from the environment. The control room setting here means whether or not the operators can observe colleague’s action.

Fig. 3 shows the completeness of Operator B’s beliefs on Operator A’s SA of the first level for Scenario 1 to 5. Complete TSA is obtained for Scenario 1 and 3, because verbal communication is conducted in these scenarios. While the operators can observe action each other in Scenario 3, cannot in Scenario 1. It shows that good TSA is achievable through verbal communication even though operators cannot observe other’s action at all.

The operators can observe action but do not communicate each other in Scenario 2. The result of Scenario 2 is apparently inferior to Scenario 3. Even if the operators have the same mental models, use the common operation panel, and observe action, complete TSA cannot be attained without verbal communication. It is impossible to know the complete image of other’s mind without verbal communication.
communication, and mutual beliefs obtained from action observation is no more than prediction. It is, however, possible to assess quantitatively how close TSA can get to the complete level. The operators infer other’s SA from their own SA and action observation in Scenario 2.

Neither communication nor action observation was done in Scenario 4 and 5; no mutual beliefs were established though the operators had the same mental models and used the same operation panel. Verbal communication and action observation are essential for inferring other’s SA.

Fig. 4 compares the results of TSA assessment between the two TSA definitions: intersection of individual SA (XSA) and combination of individual SA and mutual beliefs (MSA). It is assumed here that the both operators have the same mental models, use the same operation panel, but they do not communicate each other. Since the operators use the same mental models and the same information to establish SA, XSA is complete. This result is, however, dubious, because team cooperation can never be complete without communication. This result indicates that the TSA definition proposed in this study is more realistic than the conventional definition.

![Fig. 4 TSA assessment by different definitions.](image)

In addition to the above results, it was demonstrated that TSA simulation is effective to assess impacts of sharing the same mental models or the same operation panel onto TSA.

**CONCLUSIONS**

We proposed a new definition, formulation, and an inference method of TSA following the idea that TSA is reducible to individual SA and mutual beliefs. In addition, a method of TSA assessment by computer simulation was developed. Test simulation using team operation of DURESS showed
that the new TSA definition reflects the reality of team cognitive process better than the conventional definition.

REFERENCES


