Situation Comprehension for UGV Based on Domain Knowledge

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Abstract. Battlefield situation comprehension (SC) plays an important role in the operation observation-orientation-decision-action (OODA) circle of UGV as the results of SC are the input of the UGV mission planning. A situation comprehension method for UGV based on domain knowledge is proposed to overcome the problems of heterogeneous situation data, various relations and plan to be comprehended. Firstly, an ontology based situation comprehension architecture is given. Then, core ontology for situation comprehension is established, based on which a detailed ontology include the opposing sides classes and environment classes is constructed and steps for building situation inferring rules are listed. Finally, in a frontline defence scenario, different situation types are defined with SWRL and three scenario snapshots are depicted to demonstrate the method proposed in this paper.

1. Introduction

With the development of the technology, unmanned combat systems take important roles in the military confrontations around the world. Unmanned ground vehicle (UGV) is becoming the major equipment in the ground operation as its environmental adaptability, fearlessness and persistence in operation, and flexibility in application. Mission planning methods of UGV have been explored[1-2], however, as an important section in the operation observation-orientation-decision-action (OODA) circle of UGV, situation comprehension (SC) is the premise of effective decision-making as the results of SC are the input of the UGV mission planning. Specifically, one of the aims of SC is early-warning which help the controllers to take actions in advance. Meanwhile, for a certain mission type, results of SC can be transferred to a specific format as part of a problem input of planner. It also can be integrated in the methodology of knowledge based mission planning.

According to situation assessment model proposed by Endsley[3], SC include the representation of situation essentials and inference based on the established representation model. Methods based Bayes network and representation formula has been used for the situation knowledge representation[4]. As the problems of heterogeneous situation data to be integrated, various relations and plans to be comprehended, and the different mission types to be supported, formerly mentioned methods may not be satisfying. The ontology based method can be an appropriate choice as it has been widely used in the situation awareness field. Matheus et al. proposed the ontology-based situation awareness model and rule derivation method, based on which an ontology based situation modeling and referencing system SAWA was developed[6-7]. Mieczyslaw and his group members continuously improve the ontology based situation awareness model in several papers[8-9]. Norbert et al. took advantage the ontology based method to overcome the information overload problem in the traffic management situation awareness field[10].
Web Ontology Language (OWL) is chosen for the definition of domain ontologies with a GUI-based modelling tool Protégé, as it can process OWL-based files and includes editors, consistency checkers and built-ins reasoners. However, OWL cannot express some complex relations and implications, parts of the UGV operation domain knowledge need to be represented by means of rules with Semantic Web Rule Language (SWRL).

The following sections of the paper are structured as follows. The overall SC process is illustrated in section 2. The situation essentials and ontology used in the operation of UGV are introduced and analysed in section 3. The situation comprehension knowledge model established with Protégé and rules in SWRL are shown in section 4. An example under a frontline defence scenario of UGV to demonstrate the proposed method is shown in section 5. Finally, a conclusion is conducted in section 6.

2. Situation Comprehension Process

The flow chart of the situation comprehension process is illustrated as below.

![Situation comprehension process for UGV operation](image)

**Figure 1.** Situation comprehension process for UGV operation

The schema level of the SC knowledge graph is designed, in which a SC domain ontology for UGV is developed by combining the SC core ontology and domain knowledge under the help of military experts. Then initializing data such as environment data, deployments of both sides, shared information from neighboring forces and real-time field event are introduced to form SA instances which varying with the perception on the battlefield. SA instances are proceeded to the reasoner and inferred situation are sent to the unit commander or UGV controller. Confirmed situation are represented according to the need of mission planner as the input of the decision making. In the next SC cycle information updates are collected and used to instantiate the situation. Steps in gray blocks are not included in this paper.

3. Situation Comprehension Ontology

In the construction of knowledge graph of a specific domain, the order is as firstly the schema layer, then the data layer (instance layer). Firstly, the situation essentials of UGV operation battlefield are analysed.

3.1. Essentials and Core Ontology of UGV Situation Comprehension

Essentials in the operation battlefield for UGV are shown below.

Battlefield environment essentials, which include the geographic objects, the climate factors, transportation system and electromagnetic factors. The geographic objects include the topographical features, river systems, major landmarks and so on which are considered in the operation of UGV. The climate factors include the current weather, historical climate data and relevant statistical results. The transportation system involves the road distribution in the battlefield which influence the accessibility of UGV. The electromagnetic factors include the frequency and channel arrangement, potential jam source and anti-jamming measurements et al.

Military essentials, which include the battlefield infrastructure, composition, equipment, deployment and logistics factors of both sides in the battlefield. Battlefield infrastructure includes observation post, obstacle and so on. Equipments include manned/unmanned vehicle, tank, armored vehicle which are used to take reconnaissance, surveillance, combat actions.
The structure of the situation comprehension ontology is shown in figure 2, and only part of the classes are illustrate our ideology.

3.2. Mission Types of UGV
The goal of situation comprehension may vary when UGV implements different missions as the key point for operator of UGV is different.

In a patrolling and surveillance mission, the key points lie in the patency of the path, visibility of UGV. In a combat mission, the key points lie in that whether the target is in the attack range, the readiness and usability of weapon. In a reconnaissance mission, the key points lie in the status of sensors and self safety of UGV.

So in an UGV operation situation comprehension context, different situation types need to be defined according to the types of mission and UGV. Meanwhile, in the commander control interface, corresponding warning levels are set to assist the commander to make decisions.

3.3. Detailed Situation Comprehension Ontology
Detailed ontologies with properties and relations are modelled with Protégé, in which classes, properties and relations in the ontologies are expanded. UGV and armored vehicle are classified by the supported task types, tank by the weight. The ontology graph is show as below.
Figure 3. Situation comprehension ontology for UGV
Object properties and data properties of UGV are shown in table 1.

Table 1. Major properties of UGV

| Property types   | Property name      | Domain | Range   |
|------------------|--------------------|--------|---------|
| Object Property  | Moveon             | UGV    | Road    |
|                  | hasArmament        | UGV    | armament|
|                  | canAttack          | UGV    | Military_factors |
|                  | takeWarningShoot   | UGV    | Military_factors |
| Data Property    | attackRange        | UGV    | int     |
|                  | scoutRange         | UGV    | int     |
|                  | length             | UGV    | double  |
|                  | width              | UGV    | double  |
|                  | speed              | UGV    | double  |

After the construction of SC ontology, steps for building the rule library and reasoning are summarized as follows.

Step 1: knowledge and rules described with natural language for defining situation types are drawn from books, documentations and military guidelines of unmanned operation domain.

Step 2: situation elements including classes, object properties and data properties are extracted from the rules in step 1, formalized situation types are depicted with SWRL.

Step 3: objects in the rules are instantiated by comparing individuals in intelligence and ontology classes in SWRL rules.

Step 4: appropriate reasoner is selected and started to get a situation type.
4. Scenario and Demonstration

The battlefield scenario used in this paper cover an entire process of frontline defence. An ISR UGV ug1 and a combat UGV ug2 are deployed along the frontline to prevent enemy force from crossing the line, with manned command vehicle far from the UGVs. Once the enemy force appears on the other side of the line, different situation types, based on which further decisions and actions would be made, can be defined according the position and composition of the enemy force.

![Figure 4. Initial scenario of UGV operation](image)

Under this scenario, rules can be formulated as below.

**Rule 1**: When superior command centre notifies that unknown enemy force appears and the distance to front line is no less than 8 km, early warning situation can be defined.

\[
situation(?s)^\text{EnemyForce(?ene)^hasObj(?s,?ene)^distance2frontline(?ene,?dis)^swrlb:greaterThanOrEqual(?dis,8)} \rightarrow \text{EarlyWarningSituation(?s)}
\]

For the UGVs and controllers, this means that the ISR UGV need to patrol along a assigned route and combat UGV will enter a standby status.

**Rule 2**: If enemy force further advances to the reconnaissance range of ISR UGV, UGV1 continuously watch the target, and the combat UGV goes to the attack position, ready to fight situation can be defined.

\[
situation(?s)^\text{EnemyForce(?ene)^hasObj(?s,?ene)^distance2frontline(?ene,?dis)^IRS_UGV(?ugv1)^scoutRange(?ugv1,?sr)^swrlb:lessThanOrEqual(?dis,?sr)} \rightarrow \text{ReadytoFightSituation(?s)}
\]

**Rule 3**: if enemy force advances to a position 1 km from the frontline, combat UGV can take a warning strike, invasion warning situation can be defined.

\[
situation(?s)^\text{EnemyForce(?ene)^hasObj(?s,?ene)^distance2frontline(?ene,?dis)^Combat_UGV(?ugv2)^attackRange(?ugv2,?ar)^swrlb:lessThanOrEqual(?dis,?ar)} \rightarrow \text{InvasionWarningSituation(?s)}
\]

If enemy force crosses the frontline, combat UGV can take direct shoot, meanwhile the ISR UGV takes photos of enemy force and delivers to the command vehicle. whether the combat UGV is capable to resist or needs assistance are decided by the head commander.

Three different battlefield scenario snapshots are shown in figure 5-7 to demonstrate the SC ontology and the situation types definition.

Assume that the scout range of ug1 is 8 km and the attack range of ug2 is 6 km. Individuals in three snapshots are instantiated and a Pellet reasoner is utilized. The results show that scenario of figure 5 corresponds to EarlyWarningSituation, figure 6 to ReadytoFightSituation and figure 7 to InvasionWarningSituation.
5. Conclusions
This work proposed a ontology based situation comprehension method for UGV operation. Core ontology and steps for defining rules are established and demonstrated under a defence scenario. In an actual UGV operation, individuals and relations are more complicated, which may generate more situation types. Further more, situation comprehension and mission planning can be integrated to the speed up the OODA cycle by expanding the ontology with planning-based properties.

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7. References
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