An Assessment Method of Pilot Situation Awareness in Manned/Unmanned-Aerial-Vehicles Team

Jun Chen(✉), Qilin Zhang, Xunjie Qiu, and Bo Hou

School of Electronics and Information,
Northwestern Polytechnical University, Xi'an 710129, China
junchen@nwpu.edu.cn

Abstract. In manned/unmanned-aerial-vehicles team, the situation awareness level of manned-aerial-vehicle (MAV) pilot affects the pilot's cognitive state. Evaluating the pilot's situation awareness level will enhance the cognitive and interactive capabilities of unmanned-aerial-vehicle (UAV) and MAV. This paper proposes an assessment method of pilot's situation awareness, which is based on attention resource allocation theory and conditional probability cognitive process. Using the presented method, the situation awareness level of pilot could be quantified and evaluated reasonably. Finally the paper simulated the model at different levels of autonomy (LOA) to demonstrate the rationality of the model.

Keywords: Manned/unmanned-aerial-vehicles team (MAV/UAVs team) Situation awareness (SA) · MAV pilot · Human – robotics interaction

1 Introduction

Facing the increasingly complex battlefield environment in the future, making up for the lack of unmanned-aerial-vehicles (UAV) intelligence and fully use the role of the human intelligence at critical moments. Manned/unmanned-aerial-vehicles team as a new combat mode has been highly concerned by research institutions and scholars at home and abroad [1–3].

The process of Situation awareness (SA) includes perception of environmental elements, elements comprehension, and complete the projection of its future status [4] in a certain time and space.

The three processes of SA are indispensable, only after the becoming of projection information, the operator completed a SA process [5, 6].

2 MAV/UAVs Team Cooperative Combat System

In the process of MAV/UAVs team cooperative combat, in order to use pilot's wisdom and comprehensive judgment ability, at the same time maximize the UAV's independent combat capability. The function assignment between man and machine must be clarified. Specific structure as shown below.

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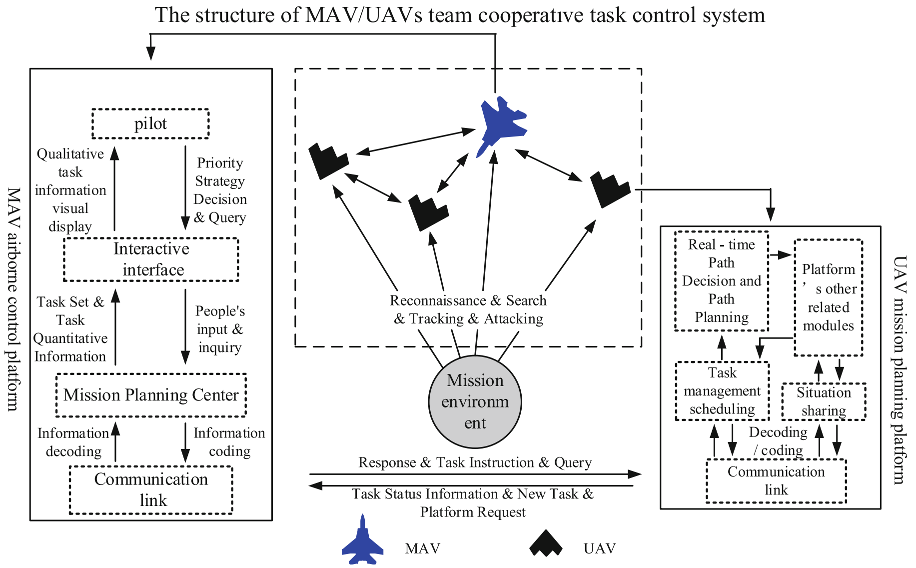

Fig. 1. The structure of MAV/UAVs team cooperative task control system

As shown in Fig. 1, manned-aerial-vehicles (MAV) as the leader of the team. It mainly acts as a manager and is responsible for the entire team of the supervision and control tasks. It also assign a task to UAV, query status, response to the request, and can directly control the UAV. UAV as a wing plane in the team, mainly as a managed or dominated role, to accept MAVs control commands, return status, tasks, threats and assistance requests and other information. In the air–and–space integration combat command system, the two together to complete the combat mission.

3 Pilot SA Assessment Model

3.1 The SA Assessment Model Based on Attention Resource Allocation

Operator's attention resource ratio

Typically, the pilot through the aircraft cockpit display interface to monitor n visual information, assuming n visual information obtained by the attention resources are as follows:

$$A = (A_1, A_2, \cdots A_i, \cdots, A_n) \tag{1}$$

The information i obtained attention resource A_i is:

$$A_i = B_i V_i S_{ai} E_i^{-1} \tag{2}$$

B_i is occurrence probability of information i, V_i is related to information i, S_{ai} is the prominence of information. Indicates the impact of the display information on attention due to the difference in color, size, and character type. $E_i^{-1}$is the effort by the pilot eye movement or head to get information [7].

In the above formula, V_i is related to information i, which is determined by the following equation:

$$V_i = p_i \mu_i \tag{3}$$

p_i is potential cognitive state of information i, μ_i is important membership of information.

Fraction attention indicates the proportion of the displayed resources in all information. And the pilot assigned to the attention of each monitor resources need to meet the following equation:

$$\sum_{i=1}^{n} f_i = 1, f_i \geq 0 \tag{4}$$

In Eq. 4, f_i is the attention resource of the pilot obtained from the information displayed by the interface.

If the pilot is treated as an idealized monitor, in order to achieve the optimal allocation of resources, the pilots should allocate their own attention resources according to the importance of each interface, so attention resource ratio f_i can be derived from the following formula:

$$f_i = \frac{\mu_i}{\sum_{i=1}^{n} \mu_i}, i = (1, 2, \cdots n) \tag{5}$$

In the actual situation, the person's attention distribution is random. Pilot uses the potential cognitive state p_i of information i indicating that the operator can correctly assess the importance of the display probability:

$$p = (p_1, p_2, \cdots p_i, \cdots, p_n) \tag{6}$$

Combined Subjective Expected Utility Theory (SEU), The pilot's attention resource ratio can be modified to the following equation:

$$f_i^* = \frac{p_i \mu_i}{\sum_{i=1}^{n} p_i \mu_i}, i = (1, 2, \cdots n) \tag{7}$$

f_i^* is modified attention resource ratio.

Introduced fuzzy entropy attention resource ratio
"Ambiguity" and "randomness" are two uncertainties in the human attention distribution mechanism. They can influence each other, but cannot replace each other. Thus, hybrid entropy [8] can be used to measure the impact of these two uncertainties. With the increase of mixed entropy, people's desire to obtain information and anxiety caused by lack of information and other psychological activities will be strengthened, and it is helpful to attract people's attention. This is consistent with the general knowledge of people. Thus, the mixed entropy can be defined by simulating the pilot's mental cognitive process. Assuming that D is a fuzzy subset of the information utility set U, the mixed entropy can be defined as:

$$H_{tot}(D,P) = m(D,P) + H(P) \tag{8}$$

In Eq. 8, $m(D, P)$ is fuzzy entropy, $H(P)$ is probability entropy, $H_{avg}(D, P)$ is hybrid entropy, hybrid entropy and probability entropy can be obtained by the following formulas:

$$\begin{aligned} m(D,P) &= \sum_{i=1}^{n} p_i S(\mu_i) \\ H(P) &= -\sum_{i=1}^{n} p_i \ln p_i \end{aligned} \tag{9}$$

In Eq. 9, $S(\mu_i)$ is the binary fuzzy entropy of μ_i:

$$S(\mu_i) = -\mu_i \ln \mu_i - (1-\mu_i)\ln(1-\mu_i) \tag{10}$$

According to Shannon's information additive principle, the average hybrid entropy of n interfaces $H_{avg}(D, P)$ is:

$$H_{avg}(D,P) = \frac{1}{n}\sum_{i=1}^{n} H_{tot}(D,P) = \frac{1}{n}\sum_{i=1}^{n} p_i S(\mu_i) - p_i \ln p_i \tag{11}$$

The constraint condition that p_i needs to satisfy is:

$$p_i \geq 0, \sum_{i=1}^{n} p_i = 1 \tag{12}$$

In order to evaluate p_i, according to the maximum entropy theory [9], p_i should take the maximum value of $H_{avg}(D, P)$. By solving the extreme value of the Lagrangian function L under the constraint condition, p_i^* can be obtained to achieve the maximum probability of $H_{avg}(D, P)$:

$$L = \frac{1}{n}\sum_{i=1}^{n}(p_i S(\mu_i) - p_i \ln p_i) - \lambda(\sum_{i=1}^{n} p_i - 1)$$
$$p_i^* = \frac{e^{S(\mu_i)}}{\sum_{i=1}^{n} e^{S(\mu_i)}} \tag{13}$$

On the basis of Eqs. (2), (3) and combining Eqs. (7), (13), the pilot's assigned resource allocation for information i is:

$$f_i^* = \frac{A_i}{\sum_{i=1}^{n} A_i} = \frac{B_i p_i^* \mu_i S_{ai} E_i^{-1}}{\sum_{i=1}^{n} B_i p_i^* \mu_i S_{ai} E_i^{-1}} \tag{14}$$

3.2 Cognitive Process Based on Conditional Probability

In this paper, according to Endsley's SA theory model, the cognition process of information displayed in the cockpit is defined as four parts: not perceived, perceived but not understood, understood but not predicted and can predict. Based on this, we defined the following events.

Definition 3.1: Event a_i is the behavior of the pilot to pay attention to the information component i at some point.

Definition 3.2: Event b_i is the behavior of the pilot to comprehend the information component i at some point.

Definition 3.3: Event c_i is the behavior of the pilot to project the information component i at some point.

The probability of occurrence of event a_i is given by the operator's attention resources rate, available from Eq. 14,

$$p(a_i) = f_i^* \tag{15}$$

The probability of comprehension the information on the basis of the perceive information i is:

$$p(b_i|a_i) = n_i \tag{16}$$

The probability of projecting the information on the basis of the comprehension information i is:

$$p(c_i|a_i b_i) = k_i \tag{17}$$

On the basis of the above definition and combine Endsley's SA theory model. Through the division of the cognitive state of the information component by the operator, using the conditional probability formula, we can get the following Table 1:

Table 1. Conditional probability of four kinds of SA state

SA state	Cognitive state	Conditional probability (P)
Not perceived	C_u	$1 - p(a_i) = 1 - f_i^*$
Perceived but not understood	C_d	$p(a_i)(1 - p(b_i \mid a_i)) = f_i^*(1 - n_i)$
Understood but not predicted	C_c	$p(a_i b_i)(1 - p(c_i \mid a_i b_i)) = f_i^* n_i(1 - k_i)$
Predict	C_p	$p(a_i b_i)p(c_i \mid a_i b_i) = f_i^* n_i k_i$

We can obtain the expected value of the cognitive level of the information component i by Bayesian conditional probability formula.

$$\overline{p_i} = C_u(1 - f_i^*) + C_d(1 - n_i) + C_c f_i^* n_i(1 - k_i) + C_p f_i^* n_i k_i \tag{18}$$

The pilot's awareness level $\overline{SA}$ is obtained by accumulating the cognitive level expectation $\overline{p_i}$ of each information.

$$\overline{SA} = \sum_{i=1}^{n} \overline{p_i} \tag{19}$$

4 Simulation and Result Analysis

In the simulation section, we select the fighter parameters, battlefield environment, decision results and task execution results as the information received by the operation. Calculate SA levels at different LOAs of MAV/UAVs team.

As shown in Table 2, the initial value of B_i, E_i^{-1} S_{ai} μ_i is given, Maximum probability P_i^* can be calculated by the Formula 13.

Table 2. The initial values of factors under different LOAs and information

Factors	LOA	Information			
		Fighter parameters	Battlefield environment	Decision results	Task execution result
Information probability B_i	Manual control	0.85	0.15	0	0
	Command control	0.5	0.4	0.1	0
	Consent management	0.3	0.3	0.4	0
	Exception management	0	0.2	0.4	0.4
	Completely independent	0	0	0	0

(*continued*)

Table 2. (*continued*)

Factors	LOA	Information			
		Fighter parameters	Battlefield environment	Decision results	Task execution result
Highlighting information S_{ai}	Manual control	0.5	0.5	0	0
	Command control	0.4	0.4	0.2	0
	Consent management	0.2	0.4	0.4	0
	Exception management	0	0.3	0.4	0.3
	Completely independent	0	0	0	0
Make efforts E_i^{-1}	Manual control	0.1	0.2	0	0
	Command control	0.1	0.5	0.4	0
	Consent management	0.1	0.4	0.4	0
	Exception management	0	0.2	0.4	0.4
	Completely independent	0	0	0	0
Fuzzy membership μ_i	Manual control	0.8	0.2	0	0
	Command control	0.4	0.4	0.2	0
	Consent management	0.2	0.4	0.4	0
	Exception management	0	0.2	0.4	0.4
	Completely independent	0	0	0	0
Maximum probability P_i^*	Manual control	0.27	0.4	0.16	0.17
	Command control	0.26	0.26	0.53	0.14
	Consent management	0.33	0.27	0.27	0.14
	Exception management	0.14	0.27	0.27	0.33
	Completely independent	0.2	0.2	0.2	0.2

Table 3. Under different LOAs f_i^*, n_i, k_i and $\overline{p_i}$

	Manual control	Command control	Consent management	Exception management	Completely independent
f_1^*	0.918	0.185	0.032	0	0
f_2^*	0.082	0.74	0.416	0.047	0
f_3^*	0	0.075	0.552	0.5	0
f_4^*	0	0	0	0.453	0
n_1	0.3	0.3	0.4	0	0
n_2	0.3	0.4	0.5	0.4	0
n_3	0	0.2	0.5	0.5	0
n_4	0	0	0	0.4	0
k_1	0.2	0.2	0.4	0	0
k_2	0.2	0.3	0.5	0.3	0
k_3	0	0.1	0.5	0.4	0
k_4	0	0	0	0.3	0
$\overline{p_1}$	0.294	0.059	0.0128	0	0
$\overline{p_2}$	0.026	0.296	0.198	0.0178	0
$\overline{p_3}$	0	0.02	0.2622	0.205	0
$\overline{p_4}$	0	0	0	0.172	0
$\overline{SA}$	0.32	0.375	0.473	0.395	0

As shown in Table 3, f_i^* can be calculated by the Formula 14, n_i and k_i is given. Cognitive level expectation $\overline{p_i}$ can be calculated by the Formula 18.

Finally, $\overline{SA}$ at different LOAs can be calculated by the Formula 19.

It can be seen from Fig. 2, pilot's SA level at consent management mode is highest, followed by exception management mode. Manual control mode and command control mode is smaller and completely independent mode is minimum. Therefore, when the pilot needs to maintain a high level of SA, can switch to consent management mode or exception management mode.

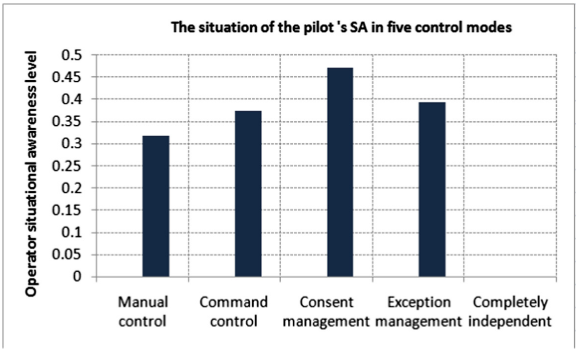

Fig. 2. The situation of the pilot's SA in five control modes

5 Conclusion

In MAV/UAVs team, the situation awareness level of MAV pilot will affects the pilot's cognitive state. Evaluating the pilot's situation awareness level will enhance the cognitive and interactive capabilities of UAV and MAV. Attention resources are the key factors that constrain the operator to perceive, understand and predict the situation. This paper presents a situational awareness assessment method based on attention resource allocation and conditional probability cognitive process. Finally we simulated the model at different LOAs, proving the rationality of the model.

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