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A Support Vector Machine Model for the Situation Awareness System

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Abstract

Situation awareness (SA) is to describe the challenges faced by us when interacting with controlled systems or work environments through technological interfaces. This paper first gives a mathematical description for SA. It then classifies all the possibilities of SA functions into classification and regression problems which can be readily resolved by some machine learning tools. Based on the results, this paper constructs a support vector machine model to deal with the two types of issues of SA.

Keywords: Situation Awareness; Machine Learning; Support Vector Machine, Information Systems.

1. Introduction

The enhancement of operators' situation awareness (SA) [1] has been becoming a major design goal for those developing operator interfaces, automation concepts and training programs in a wide variety of fields, including aircraft, air traffic control, power plants, and advanced manufacturing systems. This dramatic growth in interest in SA, beginning in the middle of 1980's and accelerating through the 1990's, was spurred on by many factors, chief among them the challenges of a new class of technologies.

Although there are many dimensions to SA, and its functional role depends on the specifics of the environments and tasks, continued advances into understanding and supporting SA are almost sure to depend on advances in measurements. Salas [2] summed up the situation well: "a central problem in understanding situation awareness is the lack of well-developed measurement tools". In human factors, one of the most influential perspectives on SA has been put forth by Endsley, who has studied the phenomenon within the contexts of automation [3], air traffic control [4], and naturalistic decision making [5], among others. Informally, Endsley notes that SA concerns "knowing what is going on". More precisely, SA is defined as "the perception of the elements of 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's definition describes SA as a three-level model involving elements of perception, comprehension, and projection. In this model, Endsley describes, at Level one, SA as knowledge that results from the perception of disjointed "elements'' in the environment, in which an element is equated with environmental objects and attributes. At Level two, SA typified as a mental picture or model, is described as comprehension of the situation, or an understanding of its current significance. At Level three SA is described as the ability to predict future states of Level one's elements. Other researchers in this area have also presented qualitative, cognitive models for SA, defining it as a mental picture or an internal product. For example, in the context of land navigation, Wesler [6] equated SA to the contents of short-term memory. In aviation, Gibson and Garrett [7] described SA as a Gestalt-like appreciation of a situation, and Taylor [8] described SA as a "veridical model of reality".

In order to assess and control SA more expediently, this study first gives a description of SA mathematical. It then classifies all the possibilities of SA functions and elements into two typical problems: classification and regression problems. Obviously the two types of problems can be readily resolved by existing machine learning tools. Support vector machine (SVMs) model [10] has been introduced for solving pattern recognition problems and function approximations because of their superior performance [10, 11]. SVMs are developed based on the idea of structural risk minimizations (SRM) [12, 13] which shows that generalization errors are bounded by the sum of training errors and a term depending on the Vapnik-Chervonenkis (VC) dimension of the learning systems. In the SVMs, the original input space is mapped into a high dimensional feature space via a certain kernel function to avoid the highly and costly computation of the inner product of two vectors. In

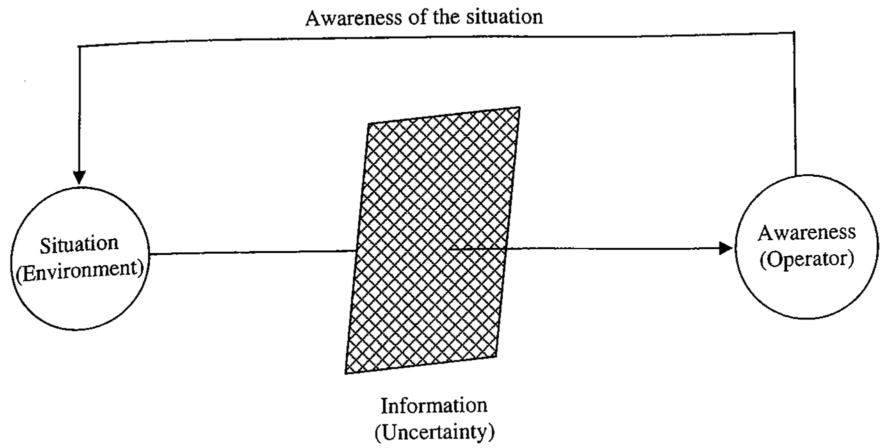


Fig. 1 A system and ecological framework for modeling the judgment or mediated SA

this feature space the optimal separating hyperplane with maximal margin will be determined to maximize the generalization performance of the tool [14]. SVMs can be used to solve both classification and regression problems for us.

The rest of the paper is organized as follows: in Section II, we will describe SA modelling and related measurement method, Machine Learning Tools for SA will be presented in Section III. The fundamental concepts of SVC and how SVC can solve classification and regression problems in SA will be discussed in Section IV. Section V summaries the study.

2. Situation Awareness Modelling and Measurement

In this section, we will introduce the notion of SA at first. Brunswik's [15] perspective on judgment under uncertainty is the initial basis for a model of the judgmental components of situation awareness. Let us focus on the Fig. 1 which describes the basic idea of both Brunswik's theory of judgment and interface-mediated situation awareness.

The left side of Fig. 1 denotes a situation or an environment, and the right side of the figure depicts awareness, or what Brunswik referred to as the organism. Mediating the situation-awareness relationship, or generally the environment-organism relationship, is both information and the uncertainty that accompanies it. In the practical applications, one of the most important issues is how to analyze the situation around us and how to utilize an efficient mathematic model to measure them, and then make the corresponding decision making to deal with the possibly alterative situations. It must be noted that the usual methods adopted are to measure the quality of a judgement in terms of a correspondence between the judged situation and the actual, environmental situation, measured by linear association, or establish some mathematics models, however, in generally, we don't exactly know what relationship between the situation and the judged situation; therefore, the suitable mathematics models are usually hard to be established.

3. Constructing Machine Learning Tools for Situation Awareness

In recent years, the machine learning tools including support vector machine have been developed aiming at resolving little samples problems. In these tools, the process has been split into a training step and a testing step, among the training step the machine learning tools are trained by the training samples, as a result, the parameters in the tools are obtained and the corresponding simulating function is formed. The testing course is to verify the performance of the tools so that which can be utilized future applications. In the following paragraph, we will describe the proposed approach to deal with the SA system.

First of all, let us focus on the situation or environment around us, it is well known that the ingredients which affect the final making-decision consist of many factors, and all the factors involved in the situation should be considered, otherwise the final awareness results will reflect on the warp. In order to

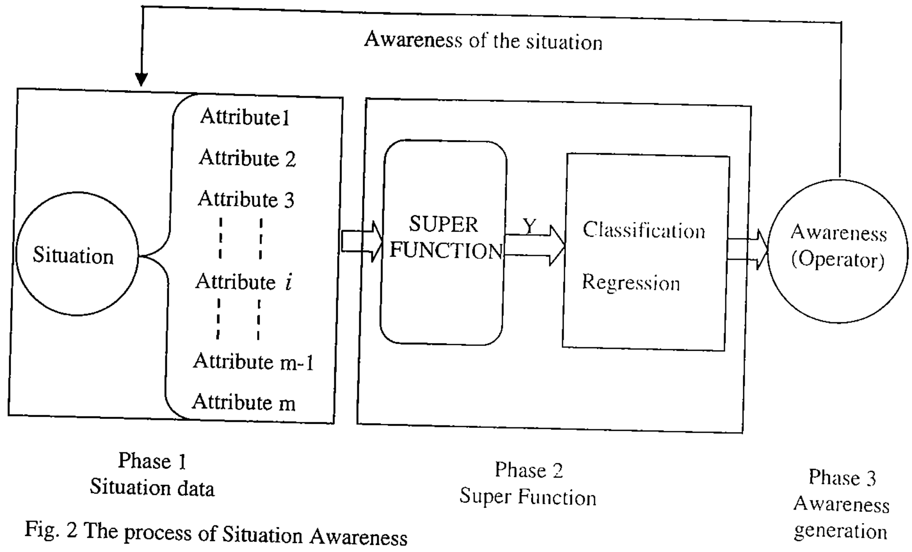


Fig. 2 The process of Situation Awareness

depict the situation more reasonably and roundly so that they can be implemented into the future machine learning tools, the mathematic language will be utilized to present them. We know the situation may consist of thousands of factors, however only parts of which affect the final awareness, in the following analyses we just need to focus on these factors. Assume there are m factors in the situation affecting our final making decision; in mathematic method the m factors can be regarded as m variables. However, the data type of the m variables can be integer, decimal fraction, continuous-valued or natural language description. In order to apply the machine learning tool to resolve the problem, the data type of the m variables should be numerical value, for the variable such as integer and decimal fraction type, which can be utilized directly and for other data type of the variables, they should be transformed into the numerical value as pre-processing. As for the methods for pre-processing, they should be different for various data types.

After transforming all the variables into numerical value, we can obtain a input set including all the variables $X = \{x_1, x_2, x_3, \cdots, x_m\}$.

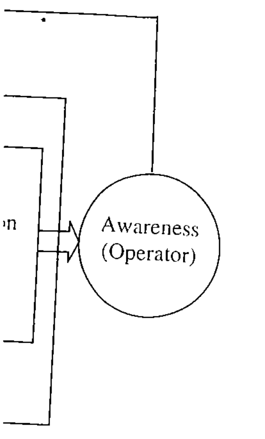
Through this expression, we can depict the situation using a mathematic method, and the different values of these variables correspond to one instance in the environment. We know there are too many instances in the situation and have different effect on us. We make a decision based on the cognitive perspective to these instances. Therefore, we can consider there exists one super function which brings different effect corresponding to the instances, and this effect can be evaluated by the numerical value "Y". According to different value of "Y", the making-decision is determined, furthermore, we can classify the problem into two types based on the different meanings of the value of "Y" as follows:

1. Regression Problems: if we need to deal with a forecasting problem such as stock forecasting, rainfall forecasting and so on, the value of "Y" should be continuous, and then they can be regarded as a function regression problem.
2. Classification Problems: if we want to detach the result into several levels and generate awareness and decision based on the different levels, we can consider the problem as the classification problems. The detail idea is shown in Fig. 2.

In this process, we do not rely on many constructs that are frequently used by other SA theorists: comprehension, attention, memory, projection, schemas, and mental models to name just a few. We focus instead on describing and then decomposing the functional, statistical relationship between directly observable variables. In particular, we view all instances of SA to be one of species of judgment judge uncertainty, and use a combination of available judgments analysis techniques as the basis for modeling and measurement.

4. Support Vector Machines Model

The SVMs technique has been introduced for solving pattern recognition problems and function approximations because of their superior performance. In the SVMs, the original dataset is mapped into a



Phase 3
Awareness
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Machines Model

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higher dimensional feature space and an optimal separating hyper-plane is constructed in this feature space. The basic essence of support vector machine is presented as follows:

Let $S = \{(\mathbf{x}_1, y_1), (\mathbf{x}_2, y_2), \ldots, (\mathbf{x}_l, y_l)\}$ be a training set, where $\mathbf{x}_i$ are m-dimensional attribute vectors, $y_i \in \{+1, -1\}$, $y_i = 1$ and $y_i = -1$ for Classes 1 and 2, respectively. According to Vapnik's original theory, the SVM classifier is:

$$D(\mathbf{x}) = w^T \Phi(\mathbf{x}) + b. \tag{1}$$

where $\Phi(\mathbf{x})$ is a mapping function which maps input space $\mathbf{x}$ into a high-dimensional space, w^T is an m-dimensional vector and b is a scalar.

In order to separate the data linearly in the feature space, the decision function satisfies the following condition:

$$y_i(w^T \Phi(\mathbf{x}_i) + b) \geq 1 \qquad for \quad i = 1, \cdots, l. \tag{2}$$

In order to determine the optimal separating hyper-plane which has the maximal margin between two classes, we can formulate the following optimization problem:

$$\min_{w,b} J(w,b) = \frac{1}{2} w^T w. \tag{3}$$

subject to (2). If the training data are non-linearly separable, slack variables ξ_i can be introduced into (2) to relax the hard margin constraints as follows:

$$y_i(w^T \Phi(\mathbf{x}_i) + b) \geq 1 - \xi_i \qquad for \quad i = 1, \cdots, l. \tag{4}$$

$$\xi_i \geq 0 \qquad for \quad i = 1, \cdots, l. \tag{5}$$

According to the structural risk minimization inductive principle, the SVMs which minimize the guaranteed risk bound can be represented as follows:

$$\min_{w,b,\xi} J(w,b,\xi_i) = \frac{1}{2} w^T w + \gamma \frac{1}{2} \sum_{i=1}^{l} \xi_i \,. \tag{6}$$

subject to (4) and (5), where γ is a parameter which determines the tradeoff between the maximum margin and the minimum classification error.

The optimization problem of (6) can be solved by using the well-known Lagrange multiplier method. By introducing Lagrange multipliers α_i and $\beta_i (i = 1, 2, \cdots, l)$, one can construct the Lagrangian function

$$L(w,b,\xi_i,\alpha_i,\beta_i) = J(w,b,\xi_i) - \sum_{i=1}^{l} \alpha_i \{ y_i [w^T \Phi(\mathbf{x}_i) + b] - 1 + \xi_i \} - \sum_{i=1}^{l} \beta_i \xi_i \tag{7}$$

According to the Kuhn-Tucker theorem in optimization theory, the solution of the optimization problem is given by the saddle point of the Lagrangian function and can be shown to have an expansion

$$w = \sum_{i=1}^{l} \alpha_i y_i \Phi(\mathbf{x}_i) \tag{8}$$

where the examples $(\mathbf{x}_i, y_i)$ with nonzero coefficients α_i are called support vectors. Accordingly, the coefficients α_i can be found by solving the following convex quadratic programming problem:

$$\max_{\alpha_i} -\frac{1}{2} \sum_{i=1}^{l} \sum_{j=1}^{l} y_i y_j (\Phi(\mathbf{x}_i)^T \cdot \Phi(\mathbf{x}_j)) \alpha_i \alpha_j + \sum_{i=1}^{l} \alpha_i \tag{1}$$

subject to

$$\sum_{i=1}^{l} \alpha_i y_i = 0, \qquad i = 1, 2, \cdots, l. \tag{2}$$

$$0 \leq \alpha_i \leq \gamma, \qquad i = 1, 2, \cdots, l. \tag{3}$$

By substituting (8) into (1), the decision boundary function of the classifier can be obtained. Given a new input $\mathbf{x}$, the corresponding value $y(\mathbf{x})$ can be estimated by using (12) and if $y(\mathbf{x}) > 0$, classify it to Class 1, on the contrary, it belongs to Class 2.

$$f(\mathbf{x}) = sign\{ \sum_{i=1}^{l} \alpha_i y_i \cdot (\Phi(\mathbf{x}_i)^T \cdot \Phi(\mathbf{x}_j) + b \}. \tag{4}$$

5. Conclusion

Situation awareness is commonly used to describe the challenges faced by human operators when interacting with controlled systems or work environments through technological interfaces. The notion of SA has been successfully applied into plenty of practical applications and presents the sharp developing tide. In order to describe the SA control it more expediently, this paper first gives the description of SA a mathematical analysis. It then classifies all the possibilities of SA into classification and regression problems which can be readily resolved by the machine learning tools. A support vector machine model to deal with SA is establishes based above results. Our future study will include a software development to implement the proposed model.

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