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Research Article

A Conceptual Architecture for Adaptive Human-Computer Interface of a PT Operation Platform Based on Context-Awareness

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We present a conceptual architecture for adaptive human-computer interface of a PT operation platform based on context-awareness. This architecture will form the basis of design for such an interface. This paper describes components, key technologies, and working principles of the architecture. The critical contents covered context information modeling, processing, relationship establishing between contexts and interface design knowledge by use of adaptive knowledge reasoning, and visualization implementing of adaptive interface with the aid of interface tools technology.

1. Introduction to AHCI of PT Operation Platform Based on Context-Awareness

Adaptive systems are usually embedded in larger human-machine systems such as the autopilot, warning, or navigation systems which could enhance human-machine system performance [1]. Context-awareness is critical for military agencies to benefit operational effectiveness by facilitating the planning process, improving the quality and timeliness of decisions, and providing better feedback regarding the strategic consequences of military actions based on knowledge technologies and visualization components [2]. But the HCI (human-computer interface) for military combat vehicles now lacks adaptability, and its intelligent implementation mechanisms cannot be suitable for all kinds of special transportation vehicles.

As humans and computers generally undertake their respective part in intelligent transportation vehicle, human is in charge of the supervision of the overall task at the higher level [3]. But as the tasks allocated to the computer increase, the heavy cognitive load and defective context-awareness caused inevitable errors and tedious work during operation process. Adaptive interface is useful to support the operators in complex dynamic task controls [4]. AHCI (adaptive human-computer interface) is an interface which is supposed to adapt its interaction contents, information processing modes, and behavior patterns automatically to meet changing task requirements and user characteristics at any time considering operator abilities, workload variations, and skill levels [5].

PT operation platform is a real-time interactive platform on military intelligent transportation vehicle, whose interface directs impacts on huge amounts of information transmission and combat efficiency in the information warfare. PT's interface is influenced by tasks, devices, environments, and other contextual factors that determine the modes of task execution and the patterns of interaction. The current situation is that the HCI of PT is limited by mobility, computing ability, input/output modes, and some other factors; although it can support the task execution, it still lacks user friendliness and autonomy. To address these challenging HCI demands, it is possible to understand the requests of states and users well enough to adapt the interface components, content, structure, and form, in terms of the dynamic changed situation, as well as to provide the operator with the necessary data and information [4, 6]. Therefore, studying new human-computer interaction modes and designing AHCI based on PT's characteristics become a new important subject which would be capable of detecting and responding to changing contexts of the user and the task in the PT operation platform.

In order to design and develop AHCI of the PT operation platform on the basis of mission analysis and reasonable human-computer function assignation, a conceptual architecture was established on general AHCI theory in this paper. Technologies of context-awareness were used in adaptive mechanism in response to dynamic context changes. The favorable context-modeling technology for the context types and the methods of adaptive knowledge reasoning were discussed according to the practical application of PT, by which a mapping relationship between context information and interface visualization could be generated. And an AHCI of the PT can be realized based on the visualization modes and interface design tools, which is supposed to provide information and operation services appropriately for different users, stages, and tasks automatically in time.

The ultimate goal is to achieve visualization of battlefield contexts and customization of user needs and the tools of interface development to enhance the operational efficiency of the PT operation platform.

2. A Conceptual Architecture for AHCI of the PT Operation Platform Based on Context-Awareness

Context-awareness is the concept of describing the performance of a system and getting a task-specific understanding during the complex operation [7]. It was first presented in connection with pilot performance in air-to-air combat and the ability of commercial airline pilots to fly in difficult air traffic condition [8]. Similarly, PT is also a complex dynamic control system in which context variables change over time.

For the PT operation platform, the main goals and functions of AHCI are shown in Table 1.

According to the specific application environment of the PT operation platform, the AHCI conceptual architecture based on context-awareness is shown in Figure 1, which is mainly constituted of the device layer, the adaptive control layer, the interface configuration layer, and the user interface layer.

2.1. Device Layer. The function of this layer is to perceive atomic context information from external and internal sources. The first kind of context information is external context which includes postures, target parameters, working conditions, battlefield environment data, and external task commands that were obtained from physical sensors or peripheral devices, such as GPS, radar, electrooptical device, and command and control systems. Sensor data is simply sampled and packaged into a digital signal that can be transferred to a computer for further processing [9]. The second kind of context comes from internal equipment by recording the system output, device current states, and interface display situation. The last kind of context information is interaction history which contains user input to the system and the feedback from the system.

Data collected via various sources can be used to make assessments of the system state, the environment, the task, and the user. Adaptive decisions will be generated by use of these assessments to decide which adaptations to select [1].

2.2. Adaptive Control Layer. There are two functions in this layer.

The first function is context information processing. A rough knowledge representation can be established by classified atomic contexts acquired from device layer. Atomic contexts can be refined into composite contexts after consistency test and fusion, which will be imported to reasoning engine consisting of rules and learning methods.

The second function is to make adaptive decisions by reasoning. The reasoning process may contain more inference activities that are triggered by degrees, after which mapping relationships between the context space and the user interface space can be established. Finally, adaptive decision-making that is suitable for the current situation will be put forward and request the interface rendering engine to generate the interface.

In the AHCI knowledge base, the context base stores context knowledge. Former cases and inference rules are stored in rule base.

2.3. Interface Configuration Layer. According to adaptive decisions, interface rendering engine extracts the interface elements and templates from the interface elements base to assemble a user interface which is suitable for the current users, tasks, and environment. Main interface attributes involve the interactive patterns, contents, display styles, and so forth. This layer contains an important mechanism to realize the adaptive conversion of interface configuration.

2.4. User Interface Layer. The interface in this layer was assembled by interface configuration layer which realized adaptive information visualization and adaptive task operation. As the new context, the interaction log between user and the system will be sent back to device layer in supporting next adaptive process.

3. AHCI Working Principle of the PT Operation Platform Based on Context-Awareness

3.1. Context Information Processing

3.1.1. Contexts of the PT Operation Platform. Context is any instantaneous, detectable, and relevant property related to future device actions that describes the current situation on an abstract level [9, 10]. It usually comes from the end users of the interactive system, the hardware and software computing platforms with which their interactive tasks are carried out, and the physical environment where they are working [11].

Context information modeling is an important step when designing AHCI based on context-awareness. After the rough refining, the high level composite contexts can be generated for the further adaptive decision-making. The contexts of PT are divided into the following categories as shown in Table 2.

Table 1: Goals and functions of AHCI for the PT operation platform.

Main goals	Description	Examples	Description of function
Improve usability	Make system convenient and efficient	Default setting	Improve the understanding ability of the system, avoid repeated execution (default based on the highest operation frequency or latest operation record)
Simplify the operation process	Combine process steps, omit redundant operations	Simplifying tasks	Simplify the task steps by batch processing and macro command, execute tasks automatically without user's confirmation
Reduce operation complexity	Reduce operation process and cognitive load	Simplifying the interfaces	Hide the function components which are not in need
Display information appropriately	Provide needed information timely and properly	Guiding	Help operators to accomplish mission tasks
		Error correction	Indicate errors and correct them in time
		Information push server	Provide information autonomously according to the requirements
		Status tracking	Reflect situation in real time
Support user needs diversification	Meet the demands of different users	Customizing interface	Transform component configurations according to user characteristics

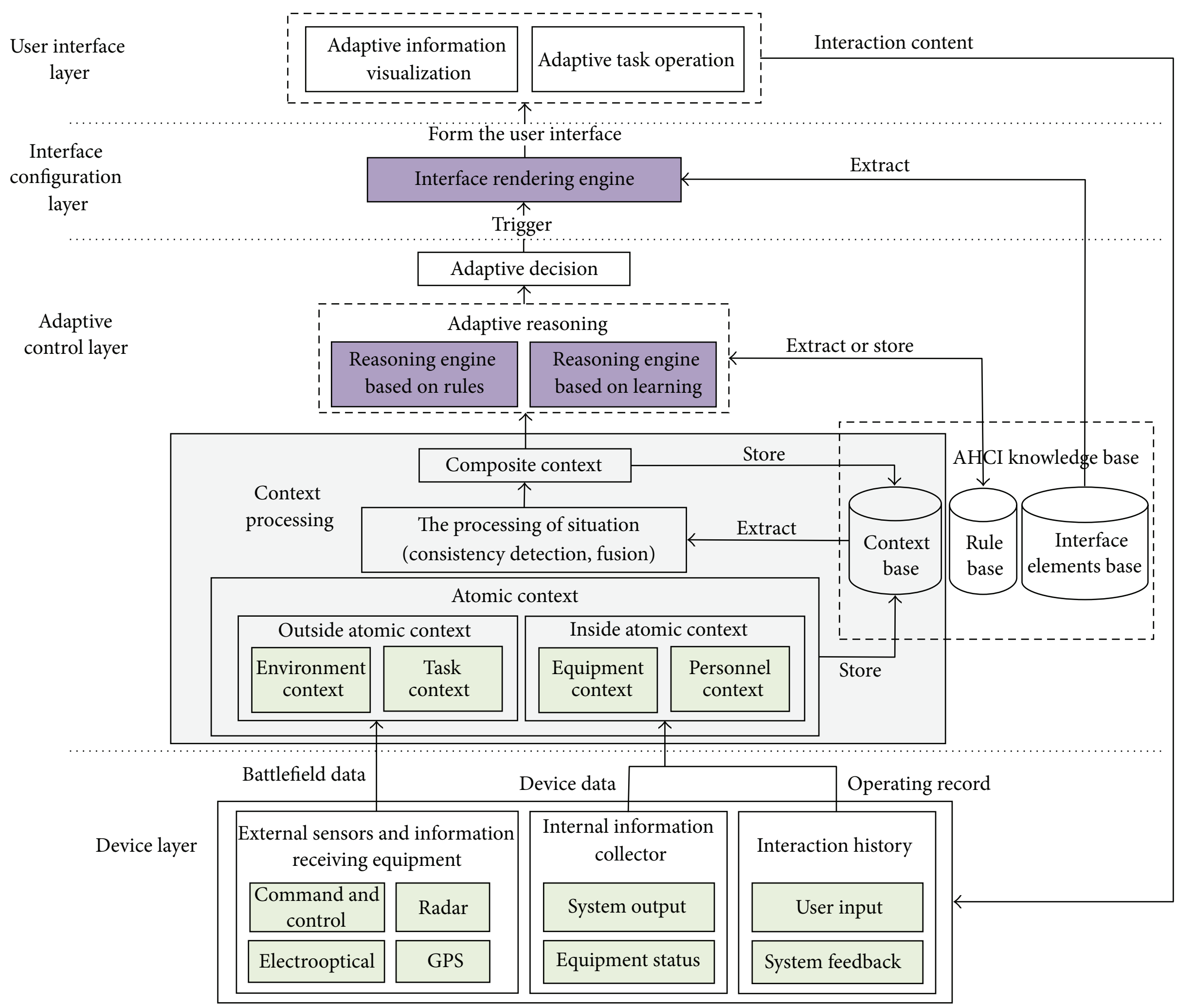

Figure 1: Conceptual architecture for AHCI of the PT operation platform based on context-awareness.

Table 2: Categories of the PT's contexts.

Context categories	Explanation
User context	Describe the different users such as the conductor and the driver
Equipment context	Describe the equipment states, both hardware and software
Environment context	Describe the physical environment, such as temperature, humidity, and visibility
Time and space context	Describe the time, location, and so forth
Social context	Describe the external information communication between collaborations
Task context	Describe the target, task processing, and operation flow
Display and control context	Describe the current layout, color, operation mode, and so forth

Table 3: Characteristics of PT's contexts.

Characteristics	Explanation
Concurrency	There are concurrent features among internal and external tasks.
Wide distribution	In the battlefield, context sources are widely distributed.
Dynamic nature	Context varies in terms of time, space, and interactive mode that affect the operation behavior.
Sociality	External communication during the task execution will have an impact on other contexts.

Equipment, environment, time, and space contexts can be obtained directly from sensors. User context is obtained directly from user's input or interaction records. Social context and task context are acquired during the process of the mission. According to the mission analysis and functional assignation including object, goal, logical function, and task scheduling, contexts above at a certain moment would be combined with the current display and control context to be reasoned adaptively to generate causal relationships between context and display control interface.

Due to the particularity application environment, these contexts have the characteristics shown in Table 3.

Because of the particularity and limitations, real-time context knowledge acquisition, storage, modeling, integration, and reasoning for the PT operation platform are very important and complex.

3.1.2. Context-Modeling Method for AHCI of the PT. Context information both accurate and fuzzy should be used for adaptive decision-making latterly in implementation of AHCI. The first step is to establish a context model. Ontology and logical modeling were presented to establish the context model in this paper.

(1) Context-Modeling Based on Ontology. Ontology provides a foundation for semantic interpretation and information fusion processes, while facilitating information search and retrieval, knowledge elicitation, knowledge modeling, and knowledge representation [2].

Ontology modeling presents semantic concepts and attributes of context entities, as well as the relationships among them by using ontology theory. Ontology modeling tool *Protégé* can test consistency of context information with inner adaptive reasoning method. But the context interpretation based on ontology requires correct and complete information, so it is hard to express inaccurate contexts with this approach.

Building ontology model for accurate and complete context information of PT's interface, the ontology is the specification of all conceptual elements in every combat phase that affect PT's display and control. The application is mainly involved in domain ontology and task ontology. The former describes the static specified domain knowledge and gives the concepts, relationships, activities, characteristics, and laws of domain entities; the latter describes hierarchical and interdependent relationships of task status concepts which reflect the dynamic behaviors in task changes.

Taking the fighting task as an example, the domain ontology model was built according to task analysis as shown in Figure 2. Context ontology and its relationships in combat implementation stage were set up in domain model.

(2) Context-Modeling Based on Logic. Most context information of PT is naturally uncertain and fuzzy because of sensor data missing or semantics confusion; context model should be designed in a way that allows the representation of uncertainty [12].

Based on logical method, context can be defined by a series of facts, expressions, and rules to support contexts' reasoning processing. Logical rules mainly define constraints conditions so that new facts or expressions could be deduced and inferred from existing facts or expressions. The lists of facts and expressions could be added, deleted, and updated. With solid mathematical foundation, the modeling based on logic has obvious advantages on formalization and representation of uncertainty context.

For PT, context-modeling based on logic also can be used in subsequent adaptive reasoning to generate mapping relationships between contexts and interface mode.

3.2. Adaptive Interface Knowledge Reasoning. The AHCI must be decision centric which is able to advise the user when to take over control of the system and when to supervise control tasks [4].

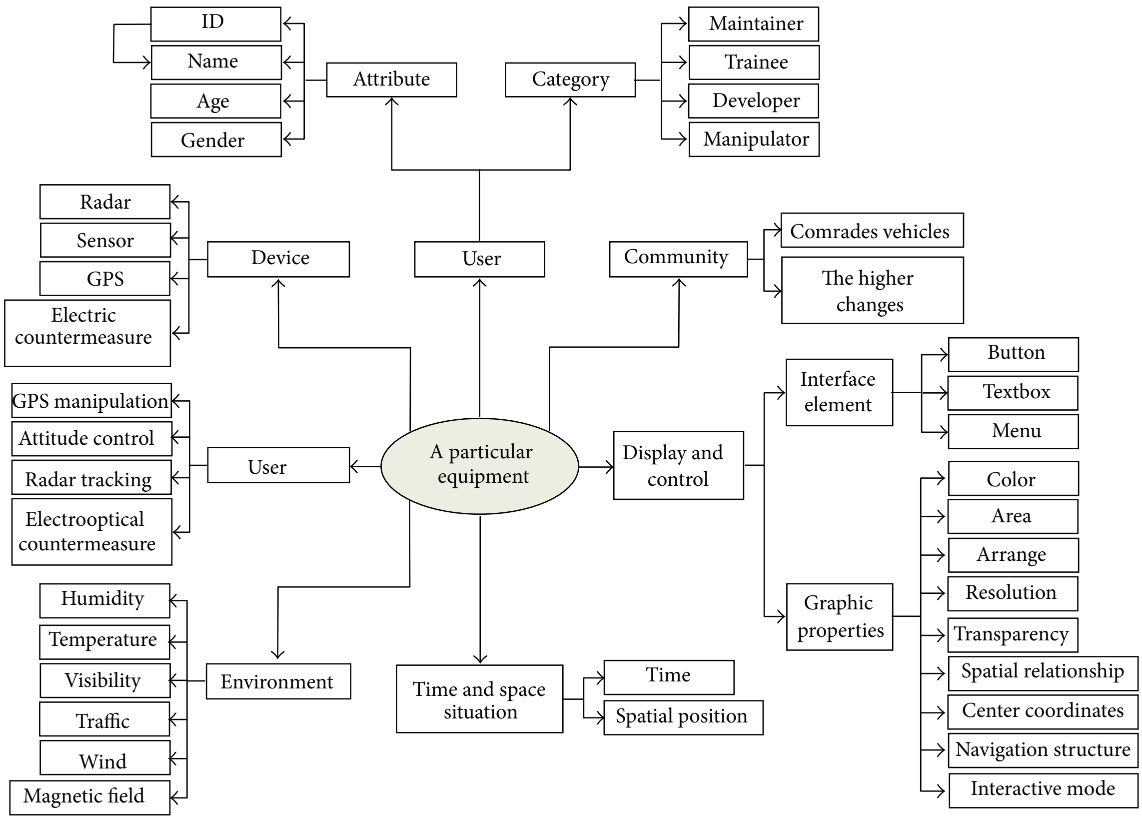

Figure 2: PT's domain ontology.

Adaptive context reasoning is to provide new and relevant information which is derived from context data sources to be used by the given application or the user [13, 14]. It is to identify composite contexts and then match adaptive responses to the current situation through the reasoning engine according to certain logical rules. Adaptive reasoning should give user effective responses, maximum accuracy, and efficiency task completion, as well as the most optimal display mode to minimize the cognitive and operation fatigue.

There are two main adaptive aspects for the AHCI of the PT operation platform: adaptive for information visualization and adaptive for user task operation. With regard to different categories of PT's contexts and different adaptive goals, adaptive reasoning technology should be carried out not only for display related knowledge but also for task operation related knowledge. In this paper, Ontology-Based Reasoning and Case-Based Reasoning were proposed to be used respectively or together according to their advantages in decision-making.

(1) Ontology-Based Reasoning. Ontology-Based Reasoning uses ontology axiom to realize the collision detection, express optimization, ontology integration, and validation by limitation of ontology model and its own description language. So Ontology-Based Reasoning would be used to complete preliminary reasoning of composite context. As Ontology-Based Reasoning requires custom logical rules, all domain ontology knowledge and training models have been defined before; in high level reasoning, other methods would be used on the basis of Ontology-Based Reasoning's preliminary result.

(2) Case-Based Reasoning. CBR (Case-Based Reasoning) is a method that uses previous cases as reference to infer possible cases. The procedure is matching the current context with history context to predict possible decisions and to optimize rules and inference mechanism through the summary and analysis of cases. As CBR can deal with complex and uncertain knowledge, it would be used on focused of extracting and analyzing cases automatically. For PT's contexts which are incomplete and indistinguishable, it is hard to build exact relationships one by one between context and interface mode. Rough sets are a kind of CBR method that can realize adaptive knowledge simplification and reasoning on PT's task operation adaptation to get a mapping from the context space (CONS) to user interface space (UIS), represented as IF CONS, THEN UIS.

Adaptive knowledge reasoning for information visualization on PT is to realize the optimal interface mode by matching the most appropriate interface elements to compose an interface adaptively. The interface property is a tuple of the form UIS = $\langle L, N, S, A\rangle$, in which L is the layout arrangement, N is the hierarchy structure of navigation, hyperlinks, and menu, S is the interactive style, and A is the set of display attributes that includes color and size [15].

3.3. The Working Mode of Adaptive Interface Visualization. Interface visualization is an expression technology by which information data is converted to intuitive understanding image and graphics shown on the interface in order to provide commander a clear understanding of the current state during mission accomplishment [16]. It is a mapping process from data form to the visual form.

AHCI visualization of the PT is the working process that interface rendering engine is triggered by adaptive decisions to present the visualization mapping results using the interface elements extracted from interface elements base. The visualization procedure includes data transformation, view transformation, content adaptation, dialog adaptation, task allocation, and decision support as well as the transformation between interfaces [3].

There are two interface variant ways in visualization modes which are dynamic interface behaviors by "changing" the original interface [17]. For static variation, the different interface templates that were designed in advance are waiting to be called and selected by user to display on the interface. For dynamic variation, the system judges the situation automatically by analyzing the contexts and matches the most appropriate interface elements and features to generate specific alternative mode.

The antecedents of visualization mapping are adaptive decision rules, while the consequents are corresponding interface mode, whose element attributes can be represented in set of $\text{Icon} = \langle \text{tag}, \text{graphic attributes} \rangle$, in which tag is the abstract symbol of visual objects, such as spot, line, and face, while graphic attributes include tag's center coordinates (x, y), area S, arrangement, resolution, transparency (0–100%), and the spatial relations among multi-icons. The attribute configurations and values will be assigned under various contexts' triggers.

4. Interface Tools Technology of the PT's AHCI

In order to implement adaptive interface and to transplant the interface into other similar vehicles easily, it is necessary to explore the adaptive interface tools technology.

4.1. The Model-Based User Interface Technology. Interface model is an important part in AHCI knowledge base. It describes different aspects of the interface by declaration. It consists of some typical models, such as task model, data model, display model, and layout model. In fact, the development of the model-based user interface means how to describe the whole interface in a better way by these models. Departing from users' perspective, the interface is divided into two parts, visibility and usability, while PT's display-control system is also divided into two parts, interface and logic, which guarantees the appearance of the adaptive interface.

4.2. The XML-Based Interface Management. The XML-based interface management gives the solution of converting the display and the layout model into the specific interface.

The model-based user interface technology obtains partial and integral descriptions of the interface display modes which are established by the interface description language XML. The interface is obtained after analyzing the XML documents by use of interface elements and interface templates. Interface templates are about the overall description of interface, which include the overall interface style and layout on a given type of PT platform. By invoking the templates, the decision result could be displayed on the interface under the adaptive interface architecture.

4.3. The Development of PT's Interface Elements Base. The PT's interface elements base is important in the embedded graphics system whose development is a necessary way to bring out the interface tools technology. After generalizing and arranging common interface elements related to PT operating, the interface elements base will be created by development tool Wind ML (Wind Media Library). Actually WINDOW is a basic component of Wind ML. Departing from the WINDOW, researching on *Display* and *Event*, the needed elements will be extracted from the PT's interface applying the object-oriented idea and then the element classes will be established. Moreover, the common property and the operation object will also be extracted to be packaged into the element classes. Based on the above, the elements base that has better portability and conformity will be guaranteed.

5. Conclusion

Nowadays, we are concerned with dynamic contexts management in interface design knowledge for real-time human-computer interaction in the military intelligent transportation vehicle.

This paper put forward the idea of AHCI aiming to improve task execution efficiency and reduce the cognitive load and the operation complexity of operators on PT. An AHCI conceptual architecture for the PT operation platform based on context-awareness was presented whose working mode was divided into three steps. Firstly, PT's context model was built based on ontology and logical method. Secondly, preliminary test and fusion of the context data would be implemented with the ontology reasoning method, while mapping relationship between context space and interface space could be established based on the CBR reasoning. Finally, adaptive interface visualization was supposed to be realized with help of interface design tools according to the adaptive decision. The structure proposed in this paper makes it possible to quantize all the information and thus enables using adaptive analyzing and visualization mechanisms in the PT military combat vehicle.

As context-awareness is critical on the modern battlefield, a large amount of intelligence information should be collected for decision-making process. In many cases, because of the lack of reasonable tools and methods to process context information, analysis and decision-making may be decelerated [18]. On the basis of the existing research, we will continue to study the analytical and visualization methods in depth to improve the decision-making process of AHCI on such special transportation vehicle and to expand its generality.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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