Developing a Concept Interface Design of ATM Systems Based on Human-Centred Design Processes

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Abstract. To accomplish our mission smoothly, we need to have good cooperation between human partners and artefacts in complex systems. In particular, it is a critical factor to establish good relationships between human partners and artefact systems. This type of system is also the work of Air Traffic Management (ATM). This research aims to make an interface design concept of the future ATM systems based on a Human-Centred Design approach. First, we discuss the method of design process to develop user interfaces of human consciousness. And then, we attempt to suggest methods of good understanding of Air traffic controllers' knowledge and behaviour based on the perspective of users. After that, we examine to make a prototype interface design concept of the future ATM systems which derived from the results of the task analysis.

Keywords: Design Method, Air Traffic Management, Human-Machine Interface Design.

1 Introduction

Air traffic controllers are expected to maintain the safety of air space and smooth air traffic flow. As the work and tasks of controllers become more complex and the volume and types of information required to carry out these tasks become increasingly greater and more complex, the need for systems that are designed to support controllers becomes greater (Banks, 2002). One of the promising strategies for systems to assist in task performance is the concept of cognitive systems that try to enable systems to interact with humans in a knowing manner that is similar to the way in which humans interact with one another (Forsythe et al., 2006). Such systems require being equipped with a user model that explains the user behaviour from a variety of aspects of cognitive processes such as awareness, memory, user knowledge and experience, context recognition, planning, intention formation, and even consciousness in order to assist in the user's work process by estimating them (Forsythe et al, 2006; Haikonen, 2003). Human Centred Design: HCD is one effective method to understand the user's

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requirements. In order to design a system that can assure system safety, enhance usability, and support human reliability in the future, the idea of HCD processes can help a developing engineer in considering the features in the control system operations and the intentions of the controller. First, in this paper, we propose an observation survey technique that can obtain survey results of high effectiveness, with a process of human-centred design that can be simply executed compared with conventional techniques. Then, we consider the method of task analysis, to find the issues related to the human factors for supporting ATC systems in the future. Then, finally, we show our concept design model as a prototype model.

2 Analysis Method for Understanding Controllers' Behaviour

2.1 ATC Systems from a Cognitive Systems Perspective

From a cognitive process perspective in particular, it is essential that trainees and systems developers understand the complex processes that are involved in the cooperative work among multiple controllers. Since air traffic controller skills are acquired through specialized training, their cooperative work processes are very complex and temporal constraints are also very restrictive and severe. In order to design and develop more reliable systems or training programs for ATC controllers, we need to understand the details of the basic system (including controller) functions.

Distributed cognition is a methodological framework by which cognitive processes that span multiple actors mediated by technology can be analysed (Hollan et al, 2000). Distributed cognition can be effective in analysing cooperative work from a cognitive process perspective. Distributed cognition analysis makes explicit the dependencies between human actors and artefacts by examining the transformation and propagation of information through various forms of representations. As such, this 'knowledge' can be represented in terms of interactions in context, which lend themselves to further analysis. The management of knowledge, and hence the retention of knowledge, is through changes in distributed cognition induced by the introduction of new systems, personnel, and norms.

2.2 Distributed Cognition

In this research, we attempt to analyse interactions between humans and artefacts that take place in current en-route ATC work based on distributed cognition. We have taken the activities of a cooperative team of en-route controllers as the unit of analysis. We discuss the application of analysis based on field observation in en-route controllers' work as a team, and report on the findings from an ethnographical analysis.

Distributed cognitive approach can be effectively applied when the problem involves the analysis of what knowledge and experience people use in the context of cooperative work. Distributed cognition is one of the analysis methods that serves as a framework for understanding interactions between people and technology so as to inform the design of interactive systems (Hollan et al., 2000). Distributed cognition can be effective in analysing cooperative work from a cognitive process perspective.

A central tenet of distributed cognition is that cognition should be regarded as a property of a system of individuals and external representational artefacts carrying out cooperative activities (Fields, 1998). In this paper, we focus on the features of controllers' activities and behaviour. As the first step in analyzing how air traffic controllers work, we collect data through the observation and recording of the en-route simulator.

3 Case Study of Observation

3.1 Method of Observational Survey

In an observational survey, the "1) Behavior (task) of the target person", "2) Space and environment", and "3) Related artefacts" are recorded in pictures. Next, referring to the recorded pictures, each item is structured as a matrix (time series). These are the result of the output from the observational survey.

The recorded pictures have also been made public in a conventional observational survey. However, the recording work based on the investigator's timing takes up the majority of this type of survey. This can be large depending on the specialist's tacit knowledge and heuristics. Moreover, the method of recording images has not been precisely decided. The technique of photo diaries is a conventional observation technique. The photo diary is arranged in a time series, taking pictures and adding comments, etc. However, the technique that we propose increases the visual volume of information by displaying the pictures of some items recorded according to prior decision in a matrix state, arranged by structure and by visualizing the user's actions (Fig.1). The photo diary tends to be a biased recording method and tends to vary by the recorder. However, our suggested technique can decrease the amount of bias and blur with preliminary definitions of the recorded items.

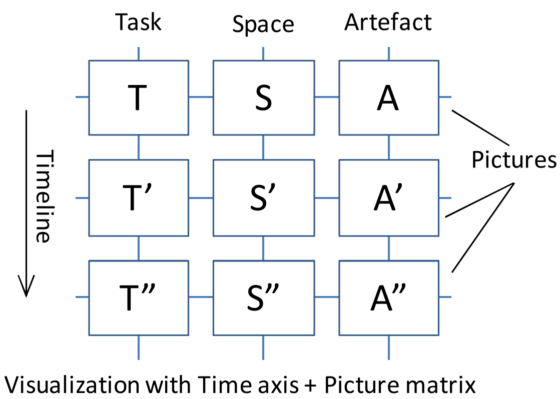


Fig. 1. Task analysis pictures data format

This refers to five models of work provided for contextual design（Beyer and Holtzblatt, 1997） for the three recorded items of "1) Behavior (task) of the target person", "2) Space and environment", and "3) Related artifacts". In contextual design, to make a user model, the contents of the investigation describes five models, the “sequence”, “workflow”, “physical”, “artificial material” and “culture”. The sequence model is for describing user tasks, and the flow model is for describing communication records as pictures of the "Behavior (task) of the target person", and pictures of "Space and environment". The artefacts model records "Related artefacts". The cultural model describes information on the cultural background of the object, the task, and the space. However, it is necessary to execute an interview for interpolating, because it is impossible to record pictures. The "Behaviour (task) of the target person", "Space and environment", and "Related artefacts" are recorded in one point on the axis of time when an observational survey is executed. The recording of regular intervals or on an arbitrary timing is repeated. The recording date is automatically stored in the data by the digital camera, and it is possible to confirm it later on a PC. However, if this cannot be done, the date and time are recorded so that the observed pictures can be confirmed.

3.2 Overview of Observation of ATC Work

We observed the working process of a team of controllers (Fig.2). We carried out observations during a time period of relatively heavy traffic that imposed a certain level of workload on the ATC controllers. We observed that there are some specific features in the work of the ATC; in particular, the basis of that work is prediction and instruction, to secure and maintain safe traffic conditions. Air traffic controllers control air traffic separated into many distinct areas called sectors and more than two controllers are allocated to and take charge of each sector as a team. Usually one controller takes the role of “Radar controller”, and the other takes that of “Coordination controller”. As a team, a Radar controller and a Coordination controller frequently monitor the display of the radar control interface and flight-strips and carry out controlling tasks while exchanging information.

The controllers then input the contents of instructions into the RDP (Rader data processing) system, and the flight-strip. At the same time, the Coordination controller also projects the situation from the radar monitor and the flight-strip (which contains the flight plan) in the same way as the Radar controller. However, the roles and tasks of the Coordination controller are different from those of the Radar controller.

Given such a complex flow and representations of information involved, we considered analysis based on distributed cognition to be an effective method to understand the behaviour of the actors, the work-place environment, as well as the information flow, including interactions in collaborative work from a cognitive systems perspective.

Fig. 2. The situation of real en-route ATC work

3.3 Settings for Analysis and Micro-tasks

Air Traffic controller (Radar controller and Coordination controller) tasks in ATC work were subdivided and set on a micro-task basis. The contents of tasks are briefly described by the micro-task by replacing the ground-to-air communication and the contents of the operation of control systems, etc. which were transcribed. All the descriptions of the tasks concerning the operation of ground-to-air communication and the control console (the input switch and the screen display of control information, etc.) and the flight-strips are described as "The tester's behaviour", and the name is given individually as a micro-task.

The following items have been summarized in the table of micro-tasks.

1) Classification - describing the classification of the micro-task.
2) Situation - describing situations in which the micro-task can be generated.
3) Task name - describing the name of the micro-task.
4) Action - describing the contents of the micro-task based on the actions of the air traffic controller.
5) Ground-to-air communication - describing the contents of the ground-to-air communication separately between the air traffic controllers as instructed (out), and received (in).
6) Operation - describing the operation of the systems control console in detail.
7) Flight-strips - describing the operation of flight-strips which are printed in flight plans.

3.4 Method of Task Analysis

The Radar controller and Coordination controller, who take charge of en-route ATC, frequently monitor the display of the radar control interface and the data of flight-strips, and carry out controlling tasks while exchanging information. For instance, when the Radar controller projects the existence of a related aircraft from the radar monitor, a series of instructions from the Radar controller are directed to the pilot through communication with the aircraft to avoid conflict. The controllers then input the contents of these instructions into the RDP (Radar Data Processing) system, and input the flight-strip.

The seqpuence of controllers' tasks are described in time-line data that consists of action logs and protocol logs based on the data from videos and flight-strips. The situation is then segmented following the contents of controllers communication mainly based on the time-line data of action and protocol. The context of each segmented situation is analysed based on the action and protocol data as well as based on an explanation of the situation made by a supervisor.

4 Data Analysis and Findings

In this analysis, we observed one of the sectors of the Tokyo Area Control Centre as a simulation. The target sector has various types of traffic such as climbing after taking off, descending for landing, over-flight, etc., which are characteristic tasks of this sector. We categorised how these working processes are formed in actual activities based on observations. Fig.3 is an example of the analytical process of work observation. We describe below examples of task flow and work observed.

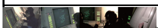
Pictures	State annotation	Time	Radar Controller					Communication (Talking)	Coordination Controller				
			Callsign	Micro-task		Radio Communication	Operation		Callsign	Micro-task		Coordination with adjacent sectore	Operation
		5:21:52											
		5:21:53											
		5:21:54											
		5:21:55											
		5:21:56	ANA62	Instruction (for vertical separation)		ANA62, Descend and maintain FL250 and report speed							
		5:21:57											
		5:21:58											
		5:21:59											
		5:22:00			Request reporting speed		AS ALT 270						
		5:22:01											
		5:22:02								STP: Input			
		5:22:03											
		5:22:04				(Read-back and report speed) Descend and maintain FL270 now speed 275 knots, ANA62							
		5:22:05											
		5:22:06											
		5:22:07											
		5:22:08											
		5:22:09	ANA62	Instruction (for lateral separation)		ANA62, Reduce speed 270 knots							
		5:22:10											
		5:22:11											
		5:22:12											
		5:22:13								STP: Input			
		5:22:14	ANA62	Checking read-back		Roger, reduce speed 270 knots, ANA62							
		…											

Fig. 3. Partial example of task analysis process

As a finding from the observation, The Radar controller sometimes confirmed with the pilot to get information on current speed due to control the separation between related aircraft. In such a case, radio communication occurred twice with 2 aircraft to get speed information from each aircraft. In a similar case, when the controller attempted to adjust an aircraft heading, the controller requested to the pilot to report the current state of the aircraft heading direction for confirmation. In that case also occurred once they needed to communicate to get an aircraft state information. Controllers consumed time for carrying out that work process. We focus on these work processes to improve the process from a design perspective. This is because we realised that Mode-S technology can be used to improve this time-consuming process. Mode-S technology is a new technology for the future ATC systems. Mode-S can provide the actual heading and speed data of aircraft which down-link from each aircraft to the ATC systems. But, it is still not defined how to use that information in ATC work. So, we tried to develop the prototype design of ATC interface as a future concept including Mode-S systems.

Fig. 4. Example design including Mode-S design

We carried out interviews with 3 examinees who have experience in Air Traffic Control work. As a result of the interviews, all examinees prefer the 3-line data-block to the 4-line data-block which is just added Mode-S information on the bottom line. One example idea which examinees preferred is shown in Fig.4. If the controller can use the Mode-S data from the data-block symbol as in Fig.4, they expect to reduce time consumption for instructing to change speed or heading status.

5 Development of Prototype Design

5.1 Proposing a New Concept Design

We tried to develop a prototype design of the future ATC interface for Air Traffic Controllers based on our findings. Our new concept design is based on the idea that the interface can be used intuitively, and controllers can work more efficiently and maintain safety by using it. Therefore, we suggested that the interface system be controlled via a touch panel display.

An advantage of a touch panel interface is that the system can provide integrated command control functions which were distributed as console buttons on the display in the current system. Fig.5 is our proposal for prototype design of radar target symbols. In this design (Fig.5), we expect that controllers can get all information of aircraft state including from the data-block symbol quickly.

Fig. 5. Comparison of Data-block Picture (left: Conventional, Right: Our prototype)

In addition, Fig.6 shows a concept idea of control and function processes to change the aircraft heading in our prototype interface design. When controllers want to change the aircraft heading as their instructions, they can first tap the vector bar on the screen. The vector bar can be controlled by dragging a finger over the target symbol on the display. And as an additional function, if the vectoring action is over 90 degrees, the colour of half of the symbol will change as an over-action warning.

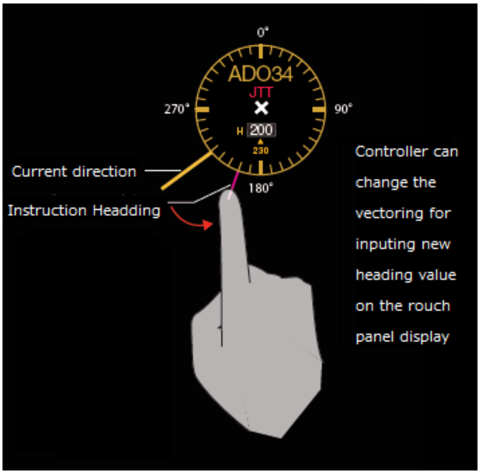


Fig. 6. An example of interface usage in prototype systems

We also carried out interviews with 3 examinees to evaluate our concept. From the interview, the examinees accepted the idea of the design concept that controllers can control intuitively. When controllers input data for their instructions, they don't need to look for the button on the console in this concept. Controllers can control and input data with the integrated interface by using the touch panel display intuitively. On the other hand, they indicated a disadvantageous point in this concept. In the case that several aircraft symbols are overlapped in the display, they feel that it is difficult to identify each target. We will try to improve this visibility problem from a design perspective, in the case of overlapping aircraft symbols.

6 Conclusion

In this research, we proposed a technique for analysing the tasks of ATC by using the idea of the HCD method, and also based on Distributed Cognition as an approach to study system designs. We suggested one idea for analysing the field data to improve conventional analysis. Moreover, Distributed Cognition is a useful perspective to adopt when studying systems such as Air Traffic Control. It is expected that the analysis technique proposed in this study will be able to contribute to improving field data analysis in real en-route ATC work. Moreover, we will develop a new concept prototype design for the future ATC interface based on the result of the analysis. As a future study we are going to evaluate our prototype design in more detail. Then, we will assess and improve the design process model along with HCD for designing ATC interfaces.

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