Applying Human Centered Design Process for Designing Air Traffic Control Interfaces

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Abstract. In this research, we focused on task analysis of air traffic controllers in actual en-route Air Traffic Control (ATC) in an experimental activity based on a Human-Centered Design (HCD) approach. We discuss the method of design to develop a system of human consciousness, and created prototype design along with HCD process. In this paper, firstly, we propose an observation survey technique that can obtain survey results of high effectiveness, with a process of HCD that can be executed simply compared with current available techniques. In this analysis, we conducted a simulation at one of the air traffic sectors of the Tokyo Area Control Center. After analyzing the current ATC work, we developed a prototype design of the future ATC interface for Air Traffic Controllers based on our findings.

1 Introduction

The importance of User-Oriented design process such as Human Centered Design: HCD are recognized under the process of designing systems. The idea of HCD process is important to design the specialized systems or user-interfaces for experts as well as consumer products. However, HCD is not practical processes but philosophical concepts. Some ideas of general HCD processes or User Experience: UX Design approaches are defined as framework to carry out practical design process. However, such kinds of current available techniques cannot be used efficiently as those are. Key approaches for applying HCD process to specialized systems are customized methods for fitting each special systems/works to capture the functions and roles correctly. In the process of developing complex systems, the user-oriented design such as HCD or UX is one of the important ideas to develop specialized complex systems which operators can use their special knowledge and skills. However, practically, normal HCD methods cannot be applied for capturing these highly specialized functions. An important key technique is how to embody the concept of HCD or modify the process for developing actual systems. Especially, it is very important to consider the practical points of view for understanding users focus and working context in highly specialized operation, because actual special expert work is hard to understand essentially.

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Therefore, in this study, we try to develop a method which including the analysis from users' cognitive perspective based on HCD concept. We attempt to apply our method to interface design for ATC systems as our case study. ATC system is designed for fitting to ATC controllers' work. Thus, we design the ATC system interfaces after understanding the role of user's systems and system functions well correctly for making higher usability systems for specific ATC systems and work. However, technically, it is difficult to fully appreciated users roles and mechanisms of the target system for designers in highly specialized system design, as compared with designing general consumer products. Therefore, in this study, we propose an observation survey technique that can obtain results of high effectiveness, with a process of human-centered design that can be simply executed compared with conventional techniques. Additionally, we will show practical techniques for carrying out analysis of well understanding roles and function of ATC systems as a target. In addition, we propose the actual case study for taking users in design process which is feature of HCD. Then, finally, we show our concept design model as a prototype model and result of user test. Then, we consider the method of task analysis, to find the issues related to the human factors for supporting ATC systems in the future.

2 Approach for HCD Process

Human Centered Design: HCD is one of effective method to understand the user's 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 an engineer in considering the features in the control system operations and the intentions of the controller in ATC Systems. HCD is defined as "an approach to design and develop a system that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" in ISO 9241-210: Human-centered design for interactive systems [1]. One of Characteristics of HCD is defined as following 4 main iterative processes for design.

1. Understand and specify the context of use.
2. Specify the target user and organizational requirements.
3. Creating and considering design solutions.
4. Design Evaluation (User test).

In this research, we focus on following point of view for fitting practical design process iteratively for ATC interfaces based on HCD.

3 User Research

3.1 Understanding and Finding ATC Work

Main purpose of our user survey is to understand the meaning of work, the functions of the target system, and discover the improving points under the current systems condition. Task analysis is important process to understand the functions and the role of the systems and point out the drawbacks within the current system condition. As a first step, we observed ATC systems and controllers' work by using a training simulator. And surveyed how to use systems interface, and understanding roles of ATC work by carrying out ethnographically way. In this study, we recorded several video data as video ethnography.

3.2 Characteristics of ATC Controller's Work as a Result of User

As characteristics controllers from task analysis, the Radar controller and Coordination controller, who take charge of the 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 sequence of controllers' tasks is 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 a controller communication mainly based on the time-line data of action and protocol. The context of each segmented situation is analyzed based on the action and protocol data as well as based on an explanation of the situation made by a supervisor.

From the analysis, air traffic controllers are expected to maintain the safety of air space and smooth air traffic flow. One of the most 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 [2]. Such systems require being equipped with a user model that explains the user behavior 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 [3].

3.3 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 and aircraft pilots. 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 analyzed [4]. It can be effective in analyzing cooperative work from a cognitive process perspective. Distributed cognition analysis makes explicit the dependencies between human actors and artifacts 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.

4 Practical Process for Modelling ATC Work

4.1 Micro-Task Analysis

Air Traffic controller (Radar controller and Coordination controller) tasks in ATC work were subdivided and set on a micro-task basis. The contents of the tasks are briefly described by the micro-task of 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 behavior”, 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.

4.2 User Modeling

We analyzed the simulator experiment as Micro-task analysis including task process and cause of actions with ATC controller. Furthermore, we marshaled data about design subjects based on results of analysis. In the next step the supervisor who has a license of an Air Traffic Controller prioritized the order of design subjects, and selected main targets from the list of subjects. In this study, we tried to develop 2 methods for analysis to analyze design subjects. As a first method, it focuses on visualization of physical task. The other one focuses on visualization of the task related to mental workload. There are 3 main problems for visualization of physical tasks: (1) one situation which is needed to provide an instruction immediately, (2) on the other hands standing by to judge the timing of situation for providing instruction, (3) increment of instruction quantity by providing an instruction for navigation. Furthermore, as a visualization of mental workload, we focus on the situation of a route crossing and spacing between aircraft.

4.2.1 View Point of Physical Task Problem

We tried to survey the controller's mouse cursor trajectories which we expected to discover drawbacks of the current control interface by visualizing the process of a mouse cursor.

As the practical process of visualization of physical tasks, Radar screen shots were extracted on the sheet with control tasks, mouse trajectories and interview contents. We selected the situation for 26 min of recorded video data.

The result of our analysis is listed regarding to the situation per minute. The main drawbacks derived from the analysis of visualization of physical tasks are shown in following list. As the result of analysis, we could found 24 issues regarding with current ATC interfaces by using simulator experiment from physical tasks perspective. We divided into following 7 types of work conditions.

< Types of conditions based on practical analysis>

1. Instruction which providing immediately or standing by the timing.
2. Increment physical workload by providing instructions.
3. Affecting aircraft spacing by reducing speed instruction.
4. Common type of tasks.
5. Limited instruction by air space restriction.
6. Need to consider the wind factor to provide instruction.
7. Instruction without using map information.

4.2.2 Cognitive Point of View

In the analysis which took into account mental workload, we conducted a survey for pointing out interface drawbacks, by categorizing controllers' mental workload. In the practical process of visualization of mental workload analysis, we observed the working process, condition and situation by using video data, and selected situation is lined up visual situation temporally. Then, we divided into 4 types of mental workload as follows. Figure 1 shows an example process to categorize the mental workload along with temporal process in the analysis.

- [Exiting]: This workload is each aircraft which from handed over control to own sector until handing off to the next adjacent sector.
- [Crossing]: This type of workload is occurring when more than 2 aircraft which are flying to a different destination or route would cross.
- [Spacing]: This type of workload is occurring, in case the more than 2 aircraft which are flying to the same destination would be merging their route.
- [Catching up]: This type of workload is occurring, in case the aircraft multiple identical destinations flies in tandem, it takes the case behind the aircraft speed is faster than before the aircraft.

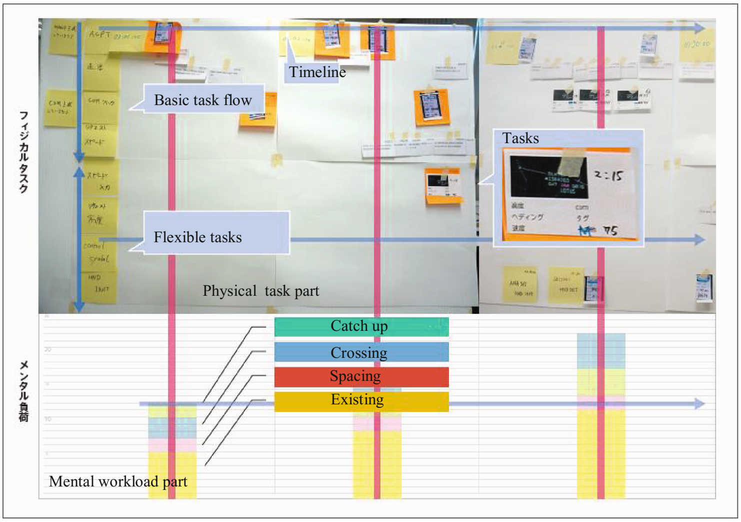

Fig. 1. An example process to visualization of the mental workload

In our visualization method of mental workload, the result of analysis is divided into 6 types by air traffic controllers who are supervisor of this analysis. Our group is consisted with following types, (1): issues of both cross and spacing, (2): issues of both catch-up and spacing, (3): common issues, (4): of catch-up issues, (5): intersection of issues, (6): spacing issues.

4.3 Creating Concept Design

4.3.1 Development Basic Design Ideas

In the verification of the validity of the visualization method of physical tasks, we utilized scenario-based acceptability technique. Because we cannot evaluate the ATC work accurately without explaining to designers any the scenario-based ideas of ATC work. In order to carry out the scenario-based evaluation, we develop an idea sheet which has 4 main sections as “Background of the issues in ATC work”, “Ideas of using image”, “flow of the use case ideas” and “Scenario of ATC operations for using the data”, “topics of ideas” By utilizing ideas sheet shown in the following Fig. 1, we tried to develop effective ideas for the problem which is our higher priority in ATC work.

As the results, we developed 7 types of user interface and function idea. And, we could summarize those functions clearly based on the scenario for each situation.

We developed a prototype design for next generation ATC system console interface based on HCD design process shown in Fig. 2. Characteristics of our concept design are supporting functions such as future state prediction and indicate information along with time-line. In this study, we created 6 functions as a total. First 4 functions as named “Cross Point”, Screen Capture”, “Reservation”, “Touch Input” are derived from the analysis based on visualization of physical task. And our second group of function named as “Predict Fix”, “Focus Input” based on the analysis of visualization of mental workload.

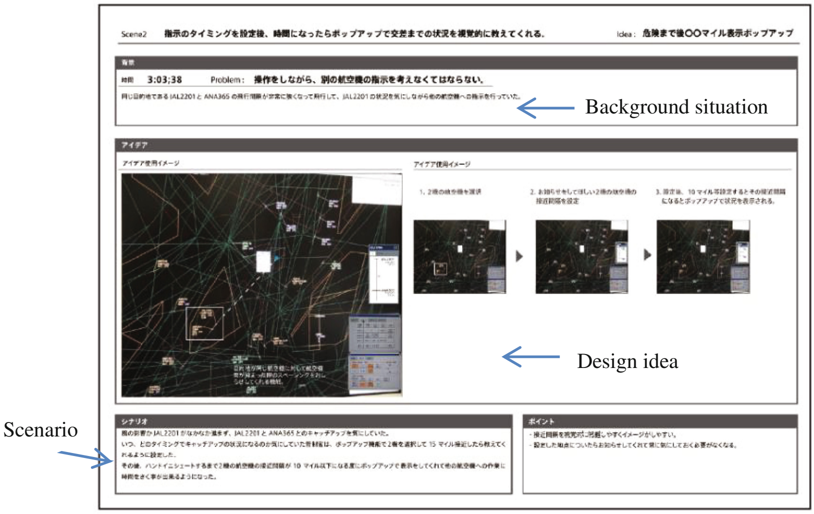

Fig. 2. An example of design process sheet

Screen Capture. A controller can see the future situation on the radar screen which selected area and set several minutes ahead. The controller also can confirm the crossing situation of future with using “Screen Capture” function together.

Focus Input. If a controller wants to zoom up specialized area to see the more precise situation, “Focus Input” can zoom up a situation in the special window.

Touch Input. This interface provides an alternative data input function by using our touch panel effectively instead of keyboard typing for inputting a value of speed altitude and heading.

Reservation. This function provides a reminder to notify the timing of instruction and helps to indicate which are critical or important.

Predict Fix. When a controller receives an aircraft from adjacent control areas, the planned time and route is shown on the radar screen and on the display of “Predict FIX”.

Focus Input. If a planned route of aircraft will cross with another aircraft route, our system shows the time of crossing at the intersection point in the window of “Predicted Time”.

This prototype design is set on a 36-inches-display which will be standardized as the next ATC display in Japan. Display interface structure is defined 6 panels shown in Fig. 3 and as following a list.

Fig. 3. Our suggested prototype interface design

Radar Display. The controller can check the position and flight information of aircraft on this panel. Controller mainly uses this panel to input flight information for revising the state of aircraft. This panel has a relationship to all other suggested functions.

Display Control Panel. Display Control Panel has functions for changing display information. The controller also can input information for revising instruction information to aircraft. Suggested functions as "Screen Capture" and "Cross Point" can be used from this console.

Quick Action. This window can be input information related with instruction to aircraft. The functions of "Reservation", "Touch Input", "Focus Input" can be used from this panel.

Predict Area. For using "Screen Capture", this panel shows a future state as a projection which a controller set a preferred time when they want to see.

Predict FIX. In order to use "Predict FIX" function, this system calculates a time of passing at the FIX. And the panel shows "Passing time", "name of FIX" and "Flight call sign" as a "list" on the display.

Predict Time. This panel shows the time-line information of "Predict FIX", "Cross Point" and "Reservation". This display is a kind of memorandum record along with time-line.

4.4 Evaluation

4.4.1 User Test

We carried out user test that focused on effectivity, interaction process and willingness to use suggested functions (Fig. 4). Test subjects are consisted with 6 interface ideas. 2 examiners have an air traffic controller license and worked as a real controller.

Fig. 4. A situation of user test for concept design

Table 1 shows our user test result of the suggested 6 interface ideas. As for "Predict Time" and "Screen Capture", both evaluators gave almost positive scores to "Effectivity", "Interaction Process" and "Willingness to use". An evaluator commented that a controller can give to an instruction at an appropriate time.

As for "Predict Time" and "Screen Capture", both evaluators gave positive scores to "Effectivity", "Interaction Process" and "Willingness to use". One of the evaluators commented that a controller can give an instruction in appropriate timing by using the function of "Screen Capture".

Table 1. User test result for suggested design

	Effectivity		Interaction Process		Willingness to use	
	Evaluator 1	Evaluator 2	Evaluator 1	Evaluator 2	Evaluator 1	Evaluator 2
Predict fix	4	3	4	3	4	3
Cross Point	4	4	4	3	3	4
Screen Capture	3	4	4	3	4	4
Reservation	3	2	3	3	3	2
Touch Input	2	3	4	4	3	3
Focus Input	3	2	2	4	3	2

As for “Cross Point”, both users gave high scores for all criteria. However, a controller indicated some of information tags might be overlapped on the radar screen and it might case issues.

Regarding with “Reservation” function, Evaluators scored to “Easy to understand” in “Interaction process”, however, one evaluator marked “Don’t want to use” in “Willingness to use” section. This idea should be improved and reconstructed in our future work. “Touch Input” got a high score to “Interaction Process” and “Willingness to use”. As for “Focus Input”, One of the controllers commented that she thought it isn’t a necessary function in the current air traffic situation.

- Effectivity: “1” is “Not effective interface for ATC work”, “4” is “Very effective interface for ATC work”
- Interaction Process: “1” is “Difficult to understand”, “4” is “Easy to understand”
- Willingness to use: “1” is “Don’t want to use anymore”, “4” is “Want to use in the future”

From the result of user test, “Cross Point” which derived from focusing of visualization of mental workload, and “Screen Capture” which from visualization of physical task got higher scores and these two functions have possibility to be effective and willing to use in the future.

5 Summary

In this study, we discussed about how we introduced HCD process to specialized and complicated process. After that we showed the concrete analysis process and technique for fitting specialized systems, in this time, ATC work was a case study. Furthermore, we proposed some prototype design along with our analysis result. And then, we also carried out user test and evaluation. However, user test was still really primitive. Therefore, we need to brush up design ideas iteratively along with HCD process to provide a more sophisticated design.

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