MAMMI Phase1- Collaborative workspaces for en-route air traffic controllers

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I. Introduction

En route control positions put into operation in the last few years are all based on the WIMP (Windows, Icons, Menus, and Pointers) interaction paradigm. Each controller has only one designation mean (a mouse or a trackball) and his/her own screen(s). This technology has a lot of advantages compared to older environments that often relied on paper strips. Nevertheless, this technology has not been able to improve teamwork for ATCOs, because it implies some rigidity compared to interaction and collaboration flexibility enabled by previous systems.

To explore new possibilities of collaboration based on modern en route control tools, EEC proposes the concept of Multi-Actor Man Machine Interface (MAMMI) based on single equipment where ATCOs would share not only the information, but also the mean to manage this information. The idea is to design a unique horizontal large interactive table where several (from two to four) controllers could interact, exchange objects, and overall adjust their task repartition in real-time. This concept could optimise the collaboration between ATCOs, and could also end up to a lesser specialisation of each team member. Its ultimate aim is to improve the ATCO operation efficiency, which would provide more capacity to the air transport system.

The MAMMI project started in July 2006 for at least one year. This paper presents, in its first part, an overview of collaboration means and usages for En Route controllers on systems that are either in operation or in advanced experimental stage. In a second part, written in collaboration with the *DIGITABLE* project (http://www.digitable.fr), are presented the results of a State of the Art and experiments on interactive tabletops displays and associated interaction techniques. These two points lead to the identification of high level requirements which will create the bases for the design of demonstrators exploring the MAMMI concept.

II. Research approach and situation of the problem

The proposed research approach for this project is an innovation-driven approach: proceed with the goal of designing a demonstrator application, and organise all the research axes around that goal. Research results inform the design, contribute to the development of prototypes, or provide means for evaluating the productions. The main flow of the project is managed through a participatory design method, in order to maximize the probability of producing a result in a given time that will be usable for obtaining user feedback.

This main flow is alimented by two work directions: ATC and HMI (Human Machine Interaction).

The ATC axis aims at extracting relevant elements in the dynamic organization and collaboration of En Route ATCOs in order to propose an appropriate environment corresponding to their needs. This concerns particularly high workload situations linked for example to weather problems, during which controllers change their habits and may asks for the presence of more than two controllers on a given position.

On the HMI side, this new collaborative environment will rely on tools based on interactive tabletop displays for which efficient interaction techniques need to be defined and implemented. These aspects raise both a technical frontier and Human Machine Interface design challenges. The technological frontier deals with the interaction peripherals that need to support the actions of several users at the same time on the same support. The HMI design challenges consist in the reproduction of mutual awareness and coordination created by physical objects of the control position that are compulsory for a shared interaction on the same workspace.

III. Collaboration between en route controllers

Our analysis of the collaboration on En Route control positions relies on interviews of controllers working in operations, ATC researchers and ATC experts, together with the organization of workshops to create exchanges between all these profiles. We have chosen three systems to support the different discussions on collaboration aspects. The first one is ODS and aims at providing a reference for an operational system. The two others are ERATO and CPDLC. These two systems are still in advanced experimental stage. This status confers them an interesting position to observe and include future concepts in our global approach.

As indicated before, the MAMMI project is focused on the collaboration between en route controllers around these three principles:

- Several ATCOs to interact collaboratively on a single en route position
- Real time tasks and workload repartition
- Lesser specialization for the ATCOs

We linked these three principles with two directions for the design of the future illustrators and prototypes:

- Flexibility of the organization
- Sharing of information

This paragraph presents the results of our analysis related to the association of these two axes with the activities of the En Route controllers and the opportunities and requirements to improve the collaboration in the scope of MAMMI.

A. ODS, a modern operational system

Several en route control positions are available for observation in operational use. We have selected the ODS control position currently in operation in French En Route control centres as best known by the participants to our study.

This control position is clearly designed for two controllers with specific activities and roles. The tactic controller (on the left), is in charge of contacting aircrafts, attributing clearances, managing guidance and separations, resolving conflicts and transferring aircrafts to other sectors. His/her main tools are the paper strip board, the radar display and the radio. The planner controller (on the right) is in charge of inter-sector coordinations, integration of new strips and pre-analysis to help the tactic controller. His/her tools are the strip board, the telephone and the radar display.

Figure 1: ODS control position

A first look at this organization shows:

- The strip board as a potential collaborative space between the two controllers
- A radar display available for each controller with different configurations
- External communication means clearly separated: the radio for the tactic controller and the telephone for the planner controller

In usual practices a given strip is managed sequentially by the two controllers and is not properly speaking a support for real time collaboration. However, in high workload situations, the tactic controller may sometimes delegate the writing on the strips to the planner as it is often done on approach control positions. In non usual situations, when the aircrafts routes are very changing with a low level of predictability, e.g. when cumulonimbi lay in the sector, the tactic controller barely uses the strip board and concentrate on the radar display. The planner controller helps him/her by checking the clearances, the global traffic situation and the acknowledgements of the pilots through the radio.

This mutual monitoring between the two controllers is part of their collaboration. They build a mutual awareness on one side by listening the other's vocal communications (radio or telephone) and on the other side by perceiving the other's actions. This improves their ability to detect inconsistencies or errors. Moreover, both controllers use their idle time to compare the data on the strip board and the data on the radar display to detect discrepancies.

In extreme situations, a third controller may come in support to the tactic and planner controllers. During the first minutes of his/her intervention, the third controller builds his/her own representation of the traffic and manages simple and punctual tasks such as pointing aircrafts that can be transferred or calling another sector on the phone for a specific purpose. These tasks may be realized on his/her own initiative or on demand of the two other controllers. Then, he/she will assume longer activities based on a strategy built in collaboration between the three controllers such as:

- Building solutions to conflicts or managing separations in a specific area of the sector
- Transferring outgoing aircrafts
- Managing the coordinations with other sectors

In this organization with three controllers, the strip board may be separated in two parts, one for the planner and the other for the third controller. We can also notice an increase of the vocal communication between controllers as a consequence of the increased synchronization needs between three users instead of two.

In the scope of MAMMI, these observations indicate that the organization on a position is changing according to dynamic parameters. These parameters also have implications on the use of the tools. For instance the radar display and the strip board are not managed in the same way in nominal traffic or in extreme situations. This puts important requirements on the *access to tools* that need to be shared by several users for different purposes, sometimes at the same moment. Beyond the concurrency on the access to tools, the question of transfer of responsibilities has to be considered also with the *delegation of activities* to a third controller.

Another fact is that in high workload situations with ODS, controllers minimize their use of the system and rely mainly on their memory to schedule and ordinate actions and on the radar display to build the conscience of the situation. This raises the question of the workflow and sequencing of actions, explored in the paragraph.

B. ERATO, a tool to help solving problems

ERATO proposes a workflow to the En Route controllers through the reification of events (mainly potential conflicts) and their integration on a timeline called the *agenda*. Both tactic and planner controllers have access to their own agenda with a different visibility: the planner controller will anticipate more and access a wider time range than the tactic controller.

The agenda becomes a planning tool for controllers, which indicates the events to come. It also provides a more explicit workflow between the two controllers with a pre-analysis by the planner and an execution by the tactic controller. Note that the events are first under the responsibility of the planner controller and then go under the responsibility of the tactic controller.

The collaboration around ERATO first comes from the pre-analysis by the planner controller which requires vocal exchanges or implicit communication with the tactic controller. Then the planner controller can pinpoint events once they are under the responsibility of the tactic controller. These actions act as reminders. Finally, in extreme situations, the planner controller may directly manipulate the tactic's agenda, which constitutes a good example of the limits of a unique mouse pointer in collaboration activities.

In the scope of MAMMI, ERATO shows the difficulties of providing an explicit *workflow* that fits with all possible situations. Interviewed controllers pointed a risk with this kind of tools to be too rigid or not efficient enough compared to the current ODS system. The challenge is to provide a support for the workflow between controllers that has the capacity to adapt to and to be tailored by the controllers themselves. Moreover, if a workflow is supported by a time representation, this representation has to be built to enable maximum *anticipation* for the controllers.

C. CPDLC, an asynchronous non vocal system

Our panorama could not be complete without considering the link with the aircrafts. In ODS, this link is achieved through the radio and is supported by the radar display. This fits well in an aircraft-centred system. However, the observation of the possibilities and limits of CPDLC (Controller Pilot Datalink Communication) brings new elements to take into account.

First, the non-vocal aspect of CPDLC may create some conflicts due to unsynchronized actions between tactic and planner controllers. For example, the planner controller may accept a coordination request through OLDI/SYSCO for an aircraft to FL300 and whereas the tactic controller sends a CLIMB TO 300 message to another aircraft. This could create a conflict between these two aircrafts. As all these actions were non-vocal, the two controllers could not prevent this conflict before it is created.

In the same way, the asynchronous aspect of CPDLC does not necessarily fit well with a workflow and a transfer of responsibilities between tactic and planner controllers on a given aircraft. In case of errors either by a pilot or by a controller, the time of detection is longer and may require the controllers to make an effort in remembering the context of a situation that is no more under their responsibility.

In the scope of MAMMI, CPDLC establishes the need of managing the evolution of actions, especially the ones that are long to achieve and vulnerable to errors. This should enable a good *mutual & synchronized situation consciousness*. To be efficient, this function shall be integrated in the different tools that are successively used by the controllers in order to provide *a global feedback & continuity for the monitoring of actions*.

D. Opening to other sectors

The last aspect we considered for the collaboration between controllers is the inter-sector coordination. Even if it is not a part of the collaboration between controllers on the same position, inter-sector coordinations rapidly appeared as key elements for the mutual awareness, having consequences on the planner/tactic collaboration. For example planner controllers sometimes use inter-sector coordinations to transmit clearances to aircrafts that are not on the frequency at the time, in anticipation to the entry in the sector.

There is also an important part of mutual awareness and monitoring between two adjacent sectors. This enables to conclude non-vocal or implicit coordinations between two planner controllers of two different sectors. In the case of implicit coordinations, the tactic controller may also indicate to the planner controller that he/she is aware of the coordination and integrates it in his/her global analysis. This can be defined as an awareness validation implying three controllers.

In the scope of MAMMI, inter-sector coordinations may find a place in collaborative spaces, considering that the collaboration between two planner controllers of adjacent sectors can be managed in the same way as the collaboration on a single position. Moreover, there is clearly a requirement to provide to a given sector, context from other sectors.

E. Summary of the overview

In this overview of collaboration, ODS showed the importance of the access to the information for the *analysis and the resolution of conflicts*. ODS also pointed that the situations where *transfer of responsibilities* become crucial with two or more controllers. The *inter-sector coordinations* also have an important role in the global collaboration and decision process. These three activities can be considered as good candidates for the experimentations on collaboration in the scope of MAMMI.

In the beginning of this section, we exhibited two directions for the design that can be linked now with more precise elements:

- The problematic of the flexibility of the organization was reflected here by the concepts of workflow, access to tools and delegation of activities.
- The sharing of information was related to anticipation, mutual & synchronized situation consciousness, and, finally, global feedback & continuity for the monitoring of actions.

All these elements need now to be analysed to determine which tools may support them and how they can be instantiated in the global activity of En Route control.

A pre-requisite to this phase is the analysis on the HMI side to determine potential solutions and techniques for the design of a collaborative En Route control position on tabletop devices.

IV. State of the Art of Technologies and Interaction Techniques

Traditional tables are an intuitive and common tool for co-located collaboration. Tables' horizontal surfaces afford the placement and organisation of physical objects, and collaboration amongst a group of co-located persons. That's why interactive tabletop displays have been the focus of a great deal of recent researches and manufacturers.

These devices offer a compelling platform for shared display groupware, allowing multiple users to simultaneously interact with an application using a direct touch/interaction paradigm. This paradigm although very rich, remains difficult to use in a domain like ATC, which brings significant constraints such as efficiency and safety.

To create the connection between the tabletop hardware and the interaction techniques, an appropriate toolkit is required which supports direct manipulation, animation and other advanced techniques, together with the management of multi-inputs on different technologies.

A. *Tabletop hardware*

Recent technological advances in user input tracking have enabled the construction of interactive tables that can now be commercialized. They enable the detection and tracking of multiple points of input, including complex shapes such as hand profiles, from multiple users simultaneously.

Figure 2: Philips Entertaible

The following recent hardware platforms are explored in the scope of MAMMI:

- The DiamondTouch (Mitsubishi Electric Research Laboratories) is a top-projected interactive tabletop with a multi-touch technology providing user-identification. Compared to other multi-touch systems, it can uniquely identify each user by electrically coupling users to the table.
- The Entertaible (Philips Research Homelab) is a research prototype employing a proprietary technology to support multi-user, multi-touch interaction while uniquely identifying inputs from multiple users. The benefit of the EnterTaible is that it supports user interaction on a LCD display preventing undesirable shadows caused by top-projection.

Both have interesting input resolutions that enable to test realistic solutions and can be plugged to display devices supporting rich graphics and visual effects.

Each one provides its own technique to capture multi-inputs. The DiamondTouch enables to distinguish between up to four users and is based on enclosing rectangles to define the geometry of the inputs which limit each user to two one input area only, defined by two points. The EnterTaible detects an indefinite number of inputs represented by sets of points but do not allow to distinguish between users.

These two technologies enable a richer exploration of the interaction techniques by testing different approaches:

- with and without user identification
- with and without multi-fingers/multi-hands interaction

B. *Interaction techniques*

Regardless of the hardware, a wide variety of researches have been done into ways that users can interact with data and with each other through interactive tabletop surfaces. This includes user interface design, multi-finger and two-handed gesture interactions, and computer supported collaborative work.

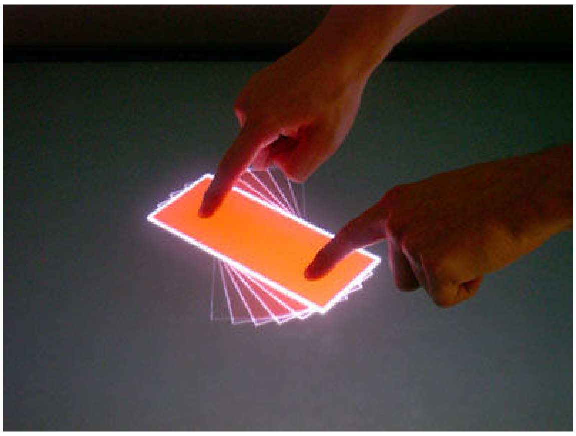

Figure 3: Tangent two fingers interaction

Here are some representative elements on the collaborative and tactile aspects:

- *Direct interaction paradigm*: tabletop systems combine a direct multi-input surface with an output display such that the input and visual space are overlaid. This affords a user interface where graphical objects can be manipulated directly
- *Group/Mutual awareness*: the use of a direct input device allows partners to more easily perceive what action the other is taking or is about to take
- *Collaborative coupling*: people are located around the table, and their positions may influence their activity with other people
- *Territoriality*: they also may have different ability or incentive to work on different parts of the table
- *Role of orientation*: people are located around the table, and have different views on objects displayed on the table. The orientation of objects not only eases reading, but also has a meaning with respect to collaboration.
- *Multi-finger and whole hand interaction*: tabletop systems are designed to be used by multiple persons at

the same time, but they also permit bi-manual and multi-finger interactions.

Moreover, researches on tabletop devices tend to show that collaboration around a table has different properties than collaboration around vertical displays and thus requires deeper investigations than just relying on traditional results for vertical desktop or collaborative spaces.

Tabletop user interfaces must by the way address specific issues:

- *Conflicts and coordination policies*: since people interact with the same artefacts, they can run into conflicts. Specially designed coordination policies can help them resolve conflicts.
- *Occlusion*: when interacting with a direct-touch interface, occlusion of the display device is unavoidable but it can be greatly reduced by using a LCD display rather than top-projection
- *Orientation*: due to the possible lack of a predefined viewing angle, displaying and manipulating information on an interactive tabletop displays may require specific techniques,
- *Remote reaching*: with a very large surface, drag-and-drop is not always appropriate because it could require to walk some meters or tense the arm
- *Visualization*: the shared nature of tables results in the need to display large quantities of information in a limited space (i.e., enough information to be of interest to several users and controls to manipulate it).

In the scope of MAMMI, the interaction techniques used in the demonstrators will thus require a specific attention to transpose existing ATC tools but also to find new solutions to fully benefit of the tabletop possibilities. These solutions will need to be explored with the implication of ATC experts but also HMI experts around the participatory design process foreseen in our methodology.

C. *Software tools and experiments on multiple inputs*

Exploring the design and consequences of shared working surfaces requires the ability to build realistic prototypes, at least in terms of interaction: too many subtle interaction and communication effects are involved which cannot be satisfied with low fidelity simulations. Therefore the MAMMI project includes the availability of software tools that allow the rapid development of functional prototypes and provide an existing background in ATC, rich graphics and animation.

As for software, IntuiLab and ENAC have used extensions to the IntuiKit environment that are being developed in the DigiTable project (http://www.digitable.fr) to manage multiple event sources. By its very nature, IntuiKit allows multi-threaded interaction; the extensions deal more with addressing devices and associating them. With those extensions, IntuiKit allows the programmer to address all devices plugged on the computer, and detect device plugging during execution. It also allows to subscribe to events emitted by any device in a group, thus ensuring handling of multiple pointers. Finally, IntuiKit incorporates a model of input sources that allows to replace equivalent sources, thus enabling substitution of a given device by an equivalent one, even at run time. Those features have been used to handle multiple mice, multiple pointers on Wacom tablets, and Mitsubishi's DiamondTouch.

As for hardware, IntuiLab has started working with several USB mice connected on a computer, and developed demonstrator applications with them. Wacom has kindly provided IntuiLab with a tablet and two styli supporting two-handed interaction. IntuiLab has then procured a Mitsubishi DiamondTouch that supports interaction from four different persons. Finally, Philips Research has given ENAC access to their Entertaible prototype, which is demonstrated at the INO workshop in Brétigny.

V. High level requirements for the design of demonstrators

The analysis of the collaboration between En Route controllers enabled to define the different concepts attached to the flexibility of the organization and the sharing of information. It also enabled to detect good candidates for the writing of ATC scenarios to explore the MAMMI concepts. In parallel we drew the frame of the technologies and techniques available on tabletop devices, showing the opportunities they create for the HMI design but also the limits they require to investigate.

The main stake now is to merge the selected ATC concepts with the potential HMI solutions. To progress in this direction and adjust the constraints on the design, we define in this section a set of high level requirements based on an abstraction of the previously established elements.

In this abstract scope, the controllers can be characterized as decision makers in an uncertain environment. The elements to make these decisions come from the pilots, the aircrafts, the team-mate(s) and the other sectors, all this passing through the tools constituting the En Route control position. The decisions are the result of the analysis based on a mental representation of the situation, balanced by the management of risks and constraints. In this uncertain environment, the workflow is assumed by the controllers and is not linear. The organization reflects the workflow at a given time and thus explains its dynamicity. All this raises the questions of:

- the quality of the information provided by the system to the controller to make decisions in a collaborative context
- the global complexity and adaptability of the tools that support the information

A. *Quality of information*

The quality of information provided by current ATC systems does not always enable a good predictability of the events to come for the ATCO. This forces him/her to revise frequently his/her judgement and may imply substantial efforts to look for appropriate information, thus consuming a large part of the collaboration resources which cannot be used for more value-added actions such as analysis and resolution of conflicts.

Efforts to improve the quality of information are often separated from the objective of collaboration around activities based on this information. Or, if the two objectives are conducted together, it may be into a fixed workflow which may introduce rigidity in the organization, particularly on a control position that is built for two separated persons.

Some information are always available and updated continuously (e.g. tracks on the radar display) while others appear in an unpredictable manner (e.g. safety nets or phone calls). The firsts take their place in the regular activity of the controller and the seconds are more intrusive and require reactions and adaptations from the controller.

While managing situations, controllers need both immediate and permanent information. They assemble them to build an analysis and may need to exchange this analysis with other controllers in a collaborative context. To enable this efficiently, some requirements need to be fulfilled on the tools that support the information.

Good information shall by the way have the following qualities:

- being as reliable as possible
- supporting the tasks of the controllers in a timely manner, including anticipation needs
- being flexible enough to be used in collaboration phases

B. Complexity and adaptability of tools

Recent electronic tools on control positions bring a significant number of new features. This implies a new complexity in the way to access these features but also to combine different information and finally to share them. These tools will create difficulties to be used in collaborative context and thus need to be adapted to the following needs:

- Giving an access to information compatible with the interaction constraints
- Being usable by several users concurrently
- Enabling support for information exchange and combination to facilitate analysis

The adaptability of tools involves the support of workflows and sequencing, together with the monitoring of actions until they are completed and validated. In a shared environment, the more the information can be mixed the better the quality of the analysis. This leads to the following requirements for the tools:

- Providing feedback of user's actions adapted to a multi-users context
- Giving information about the sequencing, progression and completion of actions
- Proposing interactions between tools to be robust to extreme situations and improve quality of information
- Proposing integration with workflows or timers

VI. CONCLUSION

To progress toward the objectives of the MAMMI project, three paths have been followed in parallel. The first path consisted in breaking technical frontiers for the implementation of applications on tabletop devices. On this point, the consortium of the project can now rely on solid software tools to build demonstrators that will be supported on several tabletop devices. Thanks to the results of the second path, these demonstrators will explore the possible interaction techniques, paving the way to the definition of components really adapted to the users needs and proposing solutions to the HMI challenges imposed by horizontal collaborative workspaces.

The participatory design approach chosen for the next phase will also enable to take into account the results of the third path with the reality of the ATC constraints as they have been defined in our high level requirements. They will be supported by scenarios around the analysis and the resolution of conflicts, transfer of responsibilities, and inter-sector coordinations, in order to propose innovative tools to increase the flexibility of the organization and the sharing of information.

The long-term target is now the construction of a real collaborative environment to help the controllers build their goals and decide how to achieve them. Through this, we should be able to fulfil the initial objective of the MAMMI project, which is to improve ATCO operation efficiency by enabling controllers to explore the opportunities of a flexible and extensible control position.

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