Strip'TIC: Exploring Augmented Paper Strips For Air Traffic Controllers

Christophe Hurter[1,3], Rémi Lesbordes[2], Catherine Letondal[2], Jean-Luc Vinot[1,3], Stéphane Conversy[1,3]

[1] ENAC
7, Avenue Edouard Belin
31055, Toulouse, France

[2] DGAC DSNA DTI R&D
7, Avenue Edouard Belin
31055, Toulouse, France

[3] IRIT, Université de Toulouse
118 Route de Narbonne,
Toulouse cedex, France

{christophe.hurter, remi.lesbordes, jean-luc.vinot}@aviation-civile.gouv.fr, {catherine.letondal, stephane.conversy}@enac.fr

ABSTRACT
The current environment used by French air traffic controllers mixes digital visualization such as radar screens and tangible artifacts such as paper strips. Tangible artifacts do not allow controllers to update the system with the instructions they give to pilots. Previous attempts at replacing them in France failed to prove efficient. This paper is an engineering paper that describes Strip'TIC, a novel system for ATC that mixes augmented paper and digital pen, vision-based tracking and augmented rear and front projection. The system is now working and has enabled us to run workshops with actual controllers to study the role of writing and tangibility in ATC. We describe the system and solutions to technical challenges due to mixing competing technologies.

Categories and Subject Descriptors
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Keywords
Paper computing, augmented paper, digital pen, interactive paper, tangible interfaces, visualization, air traffic control.

1. INTRODUCTION
As with any other activity, air traffic controllers' efficiency depends on the quality of the instrumental support to the activity. In French control centers, current systems mix computer-based visualization (e.g. radar image) and tangible artifacts (paper strips): controllers monitor the aircraft position on the radar, devise and give instructions, by radio, to aircraft pilots to avoid conflicts, and write down the instructions onto paper strips in order to remember them.

Though instructions are hand-written on the strips, the underlying technology (regular paper and pen) is not able to update the computers with the instructions the controllers give to the pilots. This prevents the potential use of automation to help controllers regulate the traffic more efficiently and in a safer way. Thus, airspace authorities have decided to replace paper with digital devices (dubbed "electronic stripping" or stripless environment) in the hope that the instructions could be fed to the system. The recent rise of multi-touch or stylus-based screens seems to support this choice and many hope that such technologies can replace paper [6].

AVI '12, May 21-25, 2012, Capri Island, Italy Copyright © 2012 ACM 978-1-4503-1287-5/12/05... $10.00

Although electronic stripping has been constantly improving during recent years, there is still reluctance to its adoption. We suspect that such reluctance is partly due to the fact that screens do not offer the level of interaction qualities that paper offers. In fact, the designers of electronic systems have spent considerable effort in order to replicate interactions on the paper, be they prospective (DigiStrips [21] or ASTER [4]), or operational (Frequentis SmartStrips or NAVCANStrips).

Figure 1: two controllers using the Strip'TIC prototype (digital pens, augmented radar, stripboard, and paper strips).

In the meantime, paper itself has evolved into "augmented paper", which, together with a digital pen, offers new ways of interacting with digital systems while keeping its interaction qualities. In other words, the future has changed: paper, once considered an outdated technology, may very well be part of the set of techniques that support the air traffic control of the future. As researchers on interactive systems, and especially on tangible artifacts and paper computing, we wanted to take advantage of this new trend to design a system based on augmented paper for ATC understand better whether and how tangibility and writing contribute to ATC controllers' efficiency. This context is particularly worth exploiting, since it heavily relies on the use of paper *and* digital devices. The work presented here focuses on the system.

This paper is an engineering paper that describes Strip'TIC (Stripping Tangible Interface for Controllers), a system that mixes several technologies to support a number of requirements for ATC. Strip'TIC relies on augmented paper and digital pen, vision-based tracking and augmented rear and front projection. We have designed and evaluated Strip'TIC together with actual controllers and following an iterative, participatory process. The contributions of the paper are: (1) a novel, effective working system relying on digital pen and mixed-reality (2) a novel system for ATC preserving traditional working methods (3) replicable solutions to technical challenges due to mixing competing technologies.

2. FRENCH EN-ROUTE ATC ACTIVITY

In this section, we briefly describe the tasks of french *en-route* (and not *tower*) controllers, and focus on the evolution of the supporting technologies. The activity of en-route air traffic controllers consists of maintaining a safe distance between aircraft. To do so the airspace is divided into sectors, each sector being the responsibility of a team of controllers. When a flight flies through a sector, the controllers guide the pilot by giving instructions (heading, speed, or altitude orders).

In a typical setting, two controllers sit at a Control Position, which is especially designed to support their activities. A traditional Control Position (in France and some other countries in Europe) includes a set of vertical screens (the main one being a radar-type visualization), and a horizontal board on which paper flight strips lie [19]. There are two radar screens, one for each controller, often with different settings (e.g. pan and zoom), and a single horizontal strip board, shared by both controllers. Paper strips are printed shortly before a flight enters the sector. Each strip corresponds to a flight, and displays information such as the level of entry, the route and a timed sequence of beacons the flight is supposed to overfly while crossing the sector (Figure 2). One of the controllers is the planning controller, who receives newly printed strips, annotates them if necessary, and places them on the strip board. The other controller is the tactical controller, who solves separation conflicts, gives orders to pilots by radio, writes down the orders on the paper strips, and "shoots" exiting flights to other sectors.

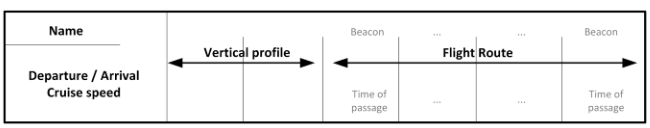

Figure 2: Paper strip with its corresponding areas.

3. RELATED WORK

Controllers log their clearances in order to be able to recall what they did with a flight. They log it on the paper strips, not on the radar image. The reasons are historical: paper strips used to be the only supporting artifacts until the 50's and the advent of radar. Controllers could only use those artifacts to log and read back their clearances. But the reasons are also pragmatic: for designers of a new system, it is easier not to cope with the problem of information entry on an electronic system and to rely on a proven system instead, namely paper and pen. Since paper strips were the only item updated with log, there have been multiple attempts to replace paper strips with a computer-based system, in the hope that elements logged could be used by computer system. These attempts have led to both studies on the role of paper strips and studies on new digital systems to supplement paper.

3.1 Paper strips in ATC

A number of research projects have underlined the importance of paper strips in ATC [23] [18]. The combination paper/stylus offers pliancy and efficiency, be they for workspace organization (strip board), data writing format (on strip alone) or procedure. This flexibility allows controllers to sometimes bypass the constraint rule to fill the strip. What seems to be dangerous behavior is actually required for the sake of interaction fluidity and efficiency, and therefore safety and capacity [10].

Paper also supports collaboration. It can be read, transmitted, and even written by different people at the same time. The tangibility of strips helps communicate and structure collaboration through gestures: the transmission of a physical strip from a controller to his or her teammate represents the transmission of flight responsibility. It is the freedom of movement of tangible properties that makes this collaboration fluid. Freedom of movement also allows users to adapt the spatial organization of strips on the board, even if such an organization is defined precisely by written procedures or the culture of the control center [19]. Paper is also more reliable than computer-based tools since it is not susceptible to fail (an argument often cited by opponents to electronic stripping).

3.2 Electronic stripping for ATC

One of the first attempts to go beyond regular strips was the Caméléon project [18]. The goal of Caméléon was to leverage the existing interactions with paper while augmenting them with computational capabilities. Caméléon explored various technological alternatives: transparent strip holders onto a touch-screen whose position could be tracked, a pen-based tablet with no screen but with regular paper. However, these early prototypes were built with the technology of the mid-nineties and not all possibilities could be explored, especially those based on augmented paper.

Following Caméléon, DigiStrips used an LCD touch screen to display a virtual stripboard of electronic strips. The interaction relied on touch, gesture recognition, animation and finely-tuned interactions based on the tangible paper strip paradigm: unique (i.e not duplicated) virtual strip, free layout on the stripboard, entry of orders to pilots through specialized interactors, support for cooperative work, etc [21]. Aster [4] builds on DigiStrips design but relies on a pen-based LCD tablet instead of the touch screen. Aster also relies on a physical model of virtual strips which makes interactions map closer to those of the real world.

Electronic stripping has been constantly improved during recent years. Some systems became operational, e.g. NAVCANstrips in Canada, and some have been progressively introduced e.g. Frequentis SmartStrips (a follow-up to DigiStrips). However, there is still reluctance to their adoption. A controller said after the installation of an electronic system: *"I genuinely didn't realise how much multitasking I used to move traffic when it's busy until I got my hands on this system and was unable to do just that. An ATCo (Air Traffic Controller) who is unable to multitask cannot shift a lot of traffic. The electronic system is a system that requires the user to be heads down dealing with one strip at a time."* Furthermore, electronic stripping is operational only in areas where traffic is less dense than the traffic over France, which is at Europe's crossroads.

How is it that after all these years, electronic systems seem to be no better than a paper-based system? What are the exact features or properties of the paper that make it so special? Can't they really be replicated with an electronic system? Now that the digital pen is a mature, reliable technology that enables written traces to be communicated to computers reliably and instantaneously thanks to streaming, we were able to experiment with augmented paper strips in order to find the exact expectation from users of those systems and extend the work started in the Caméléon project [18].

3.3 Paper computing

Several approaches (referred to as paper computing) address the gap between paper and computer use, focusing on various tasks [24]. PADD [7] or Musink [26] address the integration of paper input into electronic documents, while other work rather aims at combining information. Adding dynamic digital information to static paper content is a common way to integrate paper and electronic documents. Other approaches, such as PapierCraft [13] aim at enabling paper-based commands to edit electronic documents, e.g. through paper-based copy-and-paste actions. In Paper Remote [5], paper does not act as information but as a remote user interface for a television. In approaches using pen-based interaction, technologies such as Anoto enable direct manipulation of digital content though a pen and interactive surfaces equipped with the pattern [8].

These different types of tasks are supported by a set of different input and output devices. Getting input requires techniques to transform physical documents or interactions: Anoto pen technology relies on a printed pattern analysis by a pen-camera [1]; in the same manner, EnhancedDesk [13] needs bidimensional codes. paper++ [17] uses conductive ink ; a-book [20] has a graphical tablet under the paper ; in Caméléon [18], a physical paper-strip is detected through its holder that is connected to an electrical circuit. Some systems such as digisketch [11] enable pen input from the screen equipped with the Anoto pattern.

Output, besides direct visualization of ink on paper, may be provided through projection [15], on the pen [16] or on a wall-sized display [9]. Caméléon highlights the screen-selected flight strip by projecting colors on the physical strip holders to draw the user's attention. Audio or tactile feedback is also provided in some systems [16]. For moving display surfaces, some tracking is required, as in MouseLight[25], where the position of the display surface is detected by using two Anoto pens mounted on the projector, or by using the ARToolkit [8], to detect AR codes printed on paper.

4. DESIGN STUDY

We performed a design study of the controller's activity using standard ethnographic and participatory design methods. Our approach relates to two types of processes: 1) designing prototypes through observations and participatory workshops, 2) instrumenting observations through the development of one or more prototypes.

4.1 Requirements

In this section, we summarize the requirements that guided our study and the design of the Strip'TIC prototype:

System input (input): The IT system must be aware of the user's interactions with physical artifacts; users can move strips on the board, draw marks (e.g. draw information on paper strips), write text (e.g. write aircraft heading), and point to objects (e.g. point to aircraft on the radar screen) and feed this information into the IT system. For instance, when writing a new heading on the paper strip, the system must later monitor whether the aircraft complies with this instruction (i.e. the pilot followed controller's clearance).

Provide feedback (feedback): Since the system is aware of users' actions, this suggests that the system can also use tangible artifacts to provide additional feedback and improve usability.

The next requirements are constraints we imposed on ourselves:

Maintain current working methods (methods): we want to improve controllers' efficiency to fulfill their tasks with a new system, but not revolutionize their activity: changes of working methods are costly in terms of training and safety validation. Therefore, our system must, as far as possible, maintain current working methods.

Support collaboration (collaboration): Since controllers work in a minimum of pair in front of a control position, we needed to develop a collaborative system. Information must be shared and the prototype must support multi-user manipulations.

Use of paper strip: as previously detailed, paper has many qualities that electronic stripping lacks (tangibility, flexibility, etc.). Our goal is to develop a new system that leverages paper qualities.

We believe that a digital pen and augmented paper are an appropriate answer to these requirements. Other technologies could have been used (e.g. LCD Tablet). However, the goal of the project is also to explore writing and tangible artifacts. Hence we forced ourselves to respect the last requirement:

Use of digital pen technology: Our goal is to track controllers' actions and to allow them to use the digital pen as a mouse pointer all over the working position (strip, radar screen, stripboard).

4.2 Method

The project unfolded in 3 phases (figure 3). 3 prototypes were developed, focusing on different aspects.

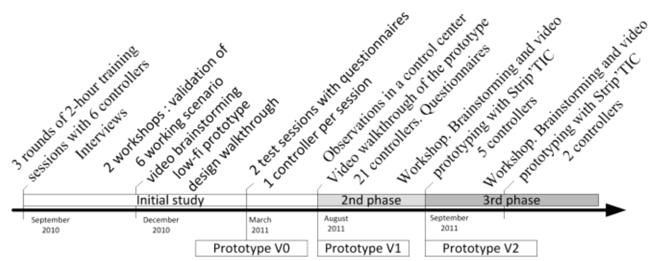

Figure 3: project timeline.

Initial study. During the initial phase, we observed 3 rounds of 2-hour training sessions with 6 experienced ATCo (2 expert instructors and 4 controllers undergoing continuous training, all of them having more than 5 years' experience) using simulated traffic in a training center. After each session, we asked questions in order to clarify technical points, such as the difference we observed between training books and the actions the controllers performed. We also picked up recurrent or difficult tasks. We tried to identify actions that demand a high cognitive workload and that have a high safety concern, such as conflict detection between aircraft. The initial observation phase focused on the controller's activity when interacting with the radar screen and the strip board. We identified actions such as linking (connection between duplicated information), and homing (when switching between the mouse pointer and the pen).

After these initial observations, we conducted two workshops with confirmed controllers and HCI experts. During the first workshop, we detailed the technical qualities of augmented paper strip, and we defined 6 working scenarios with 3 experienced controllers. We then conducted a brainstorming session to invent new interactions that could improve existing tasks. Together with the participants, we built low fidelity sketches of the interactions. Based on these results, we built a prototype that we presented during a second workshop. This workshop involved 3 controllers and 1 HCI expert: we discussed and improved 8 functions through the prototype (Figure 4).

This led to a refined version of the prototype (V0) with a simple radar screen displaying simulated aircraft, and paper strips with digital pen patterns. Controllers could draw information on the paper strip and see the system display the strip name and the location of the written information on an auxiliary screen, and highlight the corresponding aircraft on the radar screen. Several features were available: selection of an aircraft, filtering, distance computation. We organized 2 usability test sessions of the prototype, each with one controller who had to perform 6 predefined tasks; they were also asked to fill in a questionnaire. In the questionnaire, the controllers were asked to rank the proposed features of the prototype V0. This helped us to design he next prototype.

Second phase. In order to work on a new version of our prototype, we visited controllers in an en-route control center in Bordeaux. During our 1-day visit, we first observed 2 positions during 2 hours each, then some controllers watched our demo during their break. We used the V0 prototype to explain digital pen technology to 21 controllers, gather their feedback and discuss possible features and new interactions. We also had prepared 2 video-prototypes showing features based on projecting additional information on the augmented strips. Among the 21 controllers who saw our demo, 13 filled our questionnaire. 8 controllers provided their email to be contacted for a forthcoming participatory workshop. Based on the two first phases, and with additional requirements such as feedback, we developed the Strip'TIC prototype V1 (Stripping Tangible Interface for Controllers),

Third phase. We developed the Strip'TIC prototype V2 (detailed in section 5) with improved design requirements. Thanks to this prototype, we were able to run an additional participatory phase involving professional controllers during two one-day workshops. A first workshop was organized with five controllers both from Bordeaux and Reims en route centers; one of them was an instructor, another was still under training, the others were qualified and well-trained controllers: we conducted a brainstorming and a video prototyping session. The second workshop, which came one week later, was composed of two qualified controllers again from Bordeaux. After a brief demonstration of the prototype features, the controllers were asked to run scenarios in pairs with think-aloud procedure instructions, using the system. They selected scenarios from a set that we had prepared (see section 7). They were encouraged to divert freely from the given scenarios as well as use low-fi prototyping material that we had put next to the system, in order to sketch alternatives. These interviews were videotaped and transcribed. During the first workshop, we organized a brainstorming and video prototyping session. In addition to the video prototyping session, we invited the controllers to try an electronic strips system, Aster [4], by performing some interactions, such as moving electronic strips and inputting handwritten notes with a stylus. Then we informally questioned them about their thoughts and feelings regarding the electronic and the Anoto systems.

5. PROTOTYPE DESCRIPTION

In this section, we describe in detail the Strip'TIC prototype. This prototype is composed of seven parts (Figure 4): a top projector (1), a bottom projector (7), a radar screen (2), a stripboard (3), digital pens (4), a webcam (5), and an infrared lighting system (6).

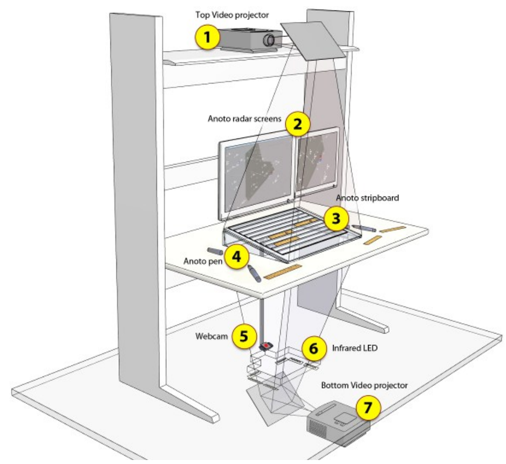

Figure 4: Strip'TIC prototype schema.

In the following we use this specific vocabulary:

- Digital pen: a pen that streams its location (x, y, identification of the sheet). Streaming is in real-time and wireless. The digital pen is also a regular pen that writes on paper (Figure 7).
- Pen pattern: (almost invisible) small printed dots that cover a surface (be it paper or a screen), and are acquired by an infrared camera within the digital pen to detect the location of the pen.
- Augmented Reality (AR) Pattern: visible printed shapes (Figure 6) acquired by a webcam to track their 3D location [2].
- Regular pen: pen used by controllers to write on paper strips.

5.1 Hardware

In this section, we detail Strip'TIC hardware implementation. We added the corresponding requirements for each implemented feature between brackets.

Paper Strip with pen pattern (input, methods): We overlaid unique digital pen pattern on regular paper strips (Figure 6, top). When users write on this modified strip, the digital pen sends its location to the system. Since the system has a list of every pen pattern and their corresponding strip, the system retrieves the ID of the strip and the areas the user is writing on (Figure 2). Current working methods are not changed since controllers keep on writing with a pen on paper strips.

Radar screen with digital pen pattern (input): We developed a simplified version of the radar screen that shows past, current, and extrapolated aircraft positions, with the main interactions (pan, zoom, distance tool etc.). We added a translucent pen pattern onto the radar screen, in order to enable controllers to interact with it using a digital pen (Figure 7). We also added a thin glass layer to prevent the user from leaving ink on the radar screen. This set of layers lowers the screen luminosity, but contrast remains suitable to display information.

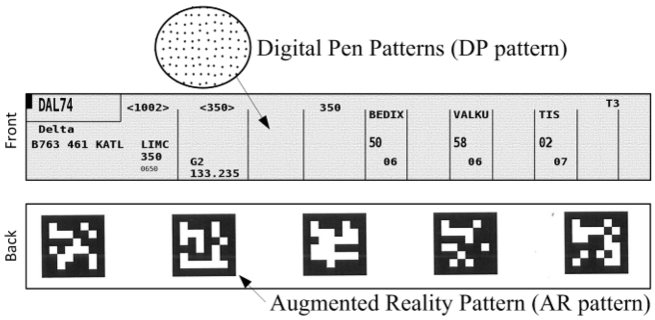

Figure 5: Front and rear of paper Strip.

Stripboard (input, feedback, collaboration): The stripboard is a board made of plexiglass, slightly inclined towards the controllers. Controllers can place strips freely on it horizontally, but not vertically: there are 9 horizontal rows that prevent strips from falling, and that enable controllers to align strips horizontally and stack them vertically. Similarly to the radar screen, the stripboard is covered with the translucent digital pen pattern to enable controllers interaction using the digital pen. Finally, we used a frosted glass instead of standard glass on top of the stripboard. When writing on frosted glass, the pen behaves and feels the same way as when writing on paper (same roughness, same haptic feeling).

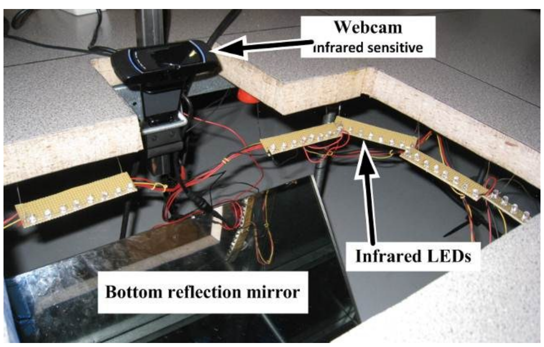

Figure 6: Infrared LEDs with the webcam to track strips.

Rear and front projection (feedback): We used two projectors to display information on the stripboard and the strips. The semi-translucent sheet for the digital pen pattern on the strip board serves as a screen for rear-projection. The front projector projects information onto the paper strips. Figure 9 and 10 shows both projected images: bluish rectangle virtual strips (rear-projected on the strip board), and orange circles to highlight parts on paper strips.

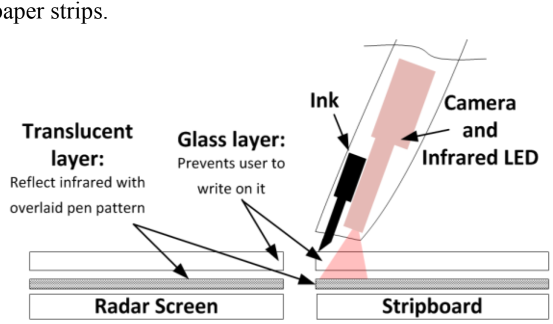

Figure 7: Digital pen with glass and translucent layer.

Strip tracking (input, feedback): We printed 5 AR patterns on the back of each strip (Figure 6, bottom), and used AR toolkit [2] to detect the location of the strips (Figure 8). A webcam films the back of each strip through the rear of the stripboard. Since the system knows the location of strips, it can project appropriate feedback with the front projector.

Hot box areas (input): we defined hot areas on the strip board so that commands are executed when a strip is laid down on it. We simply use the strip tracking system to detect when a strip is laid down on one of the hotbox areas.

5.2 Software

The following list details the implemented software features we have developed to improve controllers' activity.

Radar visualization: Controllers point on an aircraft on the radar image to select it (Figure 8). They can also draw whatever they want on the radar screen with the digital pen. This feature helps to customize controllers' environment by adding temporary information (i.e. meteorological phenomenon by drawing a shape on the radar screen that corresponds to the turbulence area). Since the pen leaves no ink because of the material used, the drawings are displayed on the screen.

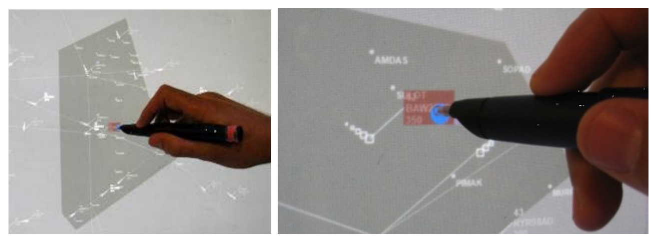

Figure 8: controllers can use the digital pen on the radar screen to select an aircraft.

View linking**:** The textual callsigns of aircraft are duplicated in the radar screen and the stripboard to let controllers link aircraft representations. However, it is still difficult to find a strip on a stripboard from the corresponding representation of an aircraft on the radar (and vice-versa). Therefore, we developed a bi-directional linking interaction: pointing with the pen to an aircraft on the screen highlights the corresponding strip on the stripboard (bright frame with a top protected image), and pointing to the aircraft name on a strip highlights it on the radar screen. If a paper strip is missing on the stripboard (e.g. because the aircraft is not yet monitored), the system projects a virtual strip at the bottom of the stripboard (Figure 10).

Projected Virtual Strips: Virtual strips are displayed with the rear projected images on the stripboard. (Figure 9). These images are not affected by user occlusion (hands and arms shadows). Our prototype also creates a virtual strip for each paper strip laying on the stripboard. Even if this rear projected image is not visible when the paper strip lies on the stripboard, it is very useful when a controller picks up the paper strip to show it to a coworker: the strip information remains visible on the stripboard thanks to the virtual strip.

Missing paper strip**:** When a controller lays down a paper strip on the stripboard, the system detects the ID of the strip (thanks to the AR pattern). The controller becomes in charge of this aircraft since he or she owns the corresponding paper strip. The radar screen displays this aircraft in a brighter color (compared to a darker color for aircraft that are not managed by the controller).

This simple principle helps controllers to detect a missing paper strip (i.e. dark colored aircraft on the radar screen in the supervised area) or when a strip is still on the strip board though the aircraft is not in the supervised controller's area anymore (i.e. bright aircraft outside the supervised area).

Figure 9: A controller points on a paper strip, then the corresponding beacon is highlighted on paper strips.

Conflict analysis**:** The controllers can select a beacon by pointing with the digital pen on the radar screen. The system will automatically highlight this beacon on every paper strip with a top projection. The same applies when controllers select a beacon on a paper strip. This feature helps controllers detect conflicting aircraft that will be at the same location (close to a specific beacon) in the same time (Figure 10). Controllers can also use a tool that measures distance on the radar screen: they have to click twice on the radar screen to display a connecting line showing its length.

Figure 10: Virtual strip are projected on the stripboard. A controller points on a paper strip: the corresponding beacon is highlighted on the virtual strip.

Report ATC orders**:** Controllers report instructions to aircraft (i.e. change of heading, speed or altitude) by writing them on paper. The system will then try to interpret these orders with text recognition and feed other software layers with interpreted information. This feature is useful to detect if an aircraft does not comply with a previous instruction.

Define aircraft clusters**:** Controllers can define pairs of aircraft by holding two partly-overlapping strips and then drawing a stroke that goes from one strip to the other. The system will display a line that connects the two strips on the stripboard and highlights, in blue, the first line of each aircraft label on the radar screen. To remove the link, controllers must draw a stroke that cuts this link on the stripboard. The defined pairs help controllers to create clusters of conflicting aircraft.

Free handwriting communication: Controllers can use free handwriting to send messages to other controllers, or to write information on the radar screen and on the stripboard. Controllers can add temporary information like "the frequency 123.5 is not operational", or request an altitude to a distant controller by writing "AF123 FL?". This may reduce the number of phone calls.

Hot box areas: Controllers can duplicate a strip by laying it on the printer icon. Another area is used to indicate that the strip has to be archived when the controller has completed monitoring.

Written commands on the stripboard: Since the user can write on the strip board, we added some simple commands. The user can perform a quick search by writing "AF" to highlight only Air France flights, or write "280" to highlight aircraft at altitude 280.

6. IMPLEMENTATION CHALLENGES

The stripboard enables the system to provide feedback, to track users' pen strokes and to track the position of the strips. The stripboard was by far the most difficult hardware to create. The challenge comes from the fact that all these technologies interfere with each other: AR tracking competes with rear- projection; pen pattern detection competes with translucent material; pen pattern competes with AR tracking; any layer between a screen and the eyes competes with contrast; and pointing with the pen should leave no ink on non-paper surface. In this section, we list the technical challenges that we faced to develop Strip'TIC and detail our solutions.

6.1 Digital pen pattern

Pen pattern is printed on paper strips. The pen pattern is provided with PostScript files one file per A4 page. We are able to print pen pattern with a laser printer without rescaling. We manage to overlay strip information with pen pattern by merging two PostScript files: one that contains the pen pattern and one with the strip information. Our only remaining concern is that currently no laser printer is able to print paper with a strip size (5cm x 20cm). Therefore, we printed 20 strips per A4 format page, and manually cut them. We are currently investigating a prototype printer to overcome this issue.

The main challenge was to use pen pattern on the radar screen and on the stripboard. Pen pattern detection is made with infrared light: a small infrared light inside the pen illuminates the paper while the camera films the paper (Figure 7). In order to use pen pattern on translucent material (the radar screen and the stripboard), we performed many trials. One attempt was to print pen pattern on tracing paper. This paper is translucent and reflects infrared. Unfortunately, sticking tracing paper on the radar screen and on stripboard is difficult: tracing paper does not create homogeneous areas (some are brighter, and some are darker), which hinders the quality of display. Therefore we used the Kimoto 100 SXE [12] plastic sheet that also reflects infrared. As opposed to Digisketch [22], we managed to print pen pattern directly on this plastic layer with a standard laser printer. The resulting visualization is brighter and more homogenous compared to tracing paper.

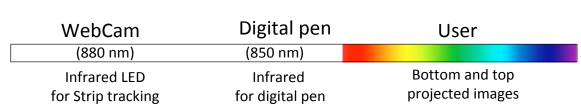

Figure 11: light spectrums

6.2 Strip tracking

In order to track paper strips with the AR pattern, we used the AR Toolkit. However, the toolkit couldn't correctly detect AR pattern because the pen pattern creates a gray layer that alters the detection process.

To address this, we spread the range of spectrum of the lighting used by each technology along the whole spectrum (Figure 11). Since AR pattern is not to be seen by users, we could shift the spectrum to infrared. We thus used an infrared light source and a modified webcam. Infrared light source is provided by 30 infrared LEDs positioned under the strip board (Figure 6). Standard webcams are rendered infrared blind by their manufacturer with a filtering lens. We removed the infrared filter in front of the lens and replaced it with an infrared sensitive filter. The modified webcam only detects infrared light from the LEDs. The infrared spectrum of the AR processing is different from the infrared spectrum used by the digital pen, thus they do not compete with each other.

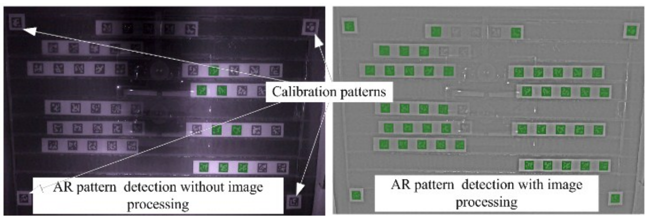

Figure 12: Strip tracking without (left) and with (right) image processing. Green squares represent detected AR pattern.

We used image processing to improve the AR toolkit recognition efficiency. We used a full-HD image (1920x1080) of 30 frames per second. The image processing computation is divided into the following steps:

- 4 times image down-sampling to speed up computation,
- 5 image mean to remove white noise,
- a strong Gaussian blur with a 10x10 kernel size and 5 iterations, and…
- subtraction of the blurred image from the original one to provide an image with a uniform gray background (this step removes the non-uniform lighting provided by the LED light source),
- conversion of the image to binary with a 0.5 threshold value for luminosity (normalized to 1.0).

We finally send these images to the AR toolkit recognizer, and get back detected pattern locations. The detection rate of individual markers is roughly 10% without image processing, and 95% with image processing (Figure 12). Since we use five markers per strip (Figure 12), the strip tracking rate is 100%. With all these improvements, we managed to track AR patterns with a frame rate of 30 images per seconds (Core i5 3.33 Ghz processor).

6.3 Projected images and calibration

Another technical challenge was to project images under the stripboard to make them visible from above. To do so, we only had to rely on the semi-translucent plastic layer for digital pen pattern. This layer diffuses bottom projected images, so that the image is also visible from the top of the stripboard. This layer also reflects top projected images to the user.

In order to improve the projected image quality we used a surface mirror that removes reflection ghosts. Then the calibration of the projected images was done with a homography computation of a deformed square planar object. We developed a direct manipulation interaction to adjust the four corners of the projected image with the four corners of the stripboard. We used the graphic card to compute this homography (texture mapping on a deformed quad). Finally, the calibration of the strip tracking system was done with the four AR patterns at each corner of the stripboard.

7. USAGE SCENARIO

After the last development of the Strip'TIC prototype, we invited controllers to participate in two workshops during which we conducted brainstorming sessions, video prototyping and exploratory design sessions. We used scenarios as concrete situations from which controllers could experiment with our prototype and explore new interactions. In the following session, we present the results of one of these scenarios played during these evaluation sessions.

7.1 Splitting en-route sector

En-route control centers are divided into several small areas called sectors, which are vertically stratified into 2 to 4 levels from low-altitudes to high-altitudes. For safety reason, controllers manage a limited number of aircraft per sector. If the number of monitored aircraft significantly increases, the current sector must be split: a subset of the monitored aircraft is transferred to another pair of controllers. Hence, each paper strip is either transferred to the new sector stripboard or left on the current one. In a preparatory phase, controllers orally share information such as detected conflicts, specific weather conditions, etc., and select aircraft/strips to be transferred. Then the controllers of the new position pick up those strips physically and place them on their stripboard. A transition phase begins with a significant amount of cooperation between the two positions. This allows the effective transfer of aircraft responsibility (radio frequency transferring).

We decided to instrument a sector split, since this situation is complex and error-prone, and because it relies heavily on the tangible aspect of the artifacts. The scenario that we devised involved the following steps: the controller in the position to be split starts the procedure by pointing to the "SPL" (split) projected button (on the stripboard); the system suggests a set of strips to transfer to the controllers (using the current aircraft altitude as a criterion), by highlighting them with the top projector. The receiving controller is then able to move these strips to the receiving position. The corresponding virtual strip remains displayed on the first stripboard: the giving controller is thus still able to interact with them. Finally, sector split is completed by pointing again on the "SPL" projected button, when controllers of both giving and receiving positions agree on the new configuration. This last action removes the virtual version of the transferred strips from the giving position stripboard. On the receiving sector, the controllers use the transferred paper strips to transfer responsibility for the aircraft (flight integration). They can print a new paper strip if needed with new sector information. Thanks to the recording of past traces with the digital pen, some previous hand-written information (e.g. radio or transponder malfunction, specific flight route) can be automatically displayed (virtual strip) or printed (paper strip).

7.2 Users' feedback

During debriefings, controllers stressed the usefulness of the Strip'TIC prototype regarding the sector split event. Strip'TIC displays relevant information (strip selection) and is a valuable help to speed-up the strip transfer process while reducing potential errors (thanks to feedback and virtual strips).

Virtual strip: The duality of virtual or paper strip reflects the level of responsibility when transferring flights: an aircraft is supervised only if controllers have its corresponding paper strip. Virtual strips only help keep information regarding an aircraft. Virtual strips also help discover transfer errors when a virtual strip is displayed for a supervised aircraft but the physical strip is missing.

New interactions: Controllers found the aircraft selection with the digital pen, on the radar screen or from strips, very efficient. This allows controllers to have fast access to features such as links between flight representations, strip transfer, strip reprint, and thus speed-up their tasks. Controllers suggested new features such as adjusting the list of strips suggested for transfer (add or remove), selecting the hand-written information to be reprinted, etc. Finally, controllers suggested to synchronize interactions during the short transition phase where strips are both displayed on the giving and receiving positions (e.g. by highlighting the last hand-written information).

8. CONCLUSION AND FUTURE WORK

We have described Strip'TIC, a system that instruments air trafic controllers' activity. As opposed to prototyping for the sake of technology exploration, we tried hard not only to make the system actually work, but also to make it useful and usable. This is a prerequisite for the second goal of the project, studying writing and tangibility. We think that details and precision matter when trying to understand the true unique benefits of tangible artifacts and paper. During the workshops we observed that discussions benefit heavily from having up-to-date techniques, such as strip tracking, projection (both above and below) and digital online paper in a working prototype that still looked open and modifiable when the controllers used it.

Future work encompasses studying control tower activity, which is more collaborative and which involves more strip manipulations. We also started to analyze in which dimensions competing technologies (e.g electronic, mini LCD or paper strips) actually differ and seek to build a comparative framework.

9. ACKNOWLEDGMENTS

Our thanks to François-Regis Collin for his technical support, and to Paul Edouard, Vincent Gaits, Hasna Nadfaoui, Jérome Pailler, the students who worked on early stage of this project.

10. REFERENCES

[1] Anoto, digital pen technology http://www.anoto.com

[2] ARToolkit, http://www.hitl.washington.edu/artoolkit

[3] Baldonado, M.Q.W., Woodruff, A., Kuchinsky, A. Guidelines for using multiple views in information visualization. In Proc of ACM AVI '00, 110-119.

[4] Benhacene, R., Hurter, C., Marion, A., Merlin,B., Rousselle, M.P., Ribet, P., ASTER, tackling the problem of flight integration. 7th ATM seminar Barcelone 2007.

[5] Berglund, A., Berglund, E., Larsson, A., Bang, M. Paper remote: an augmented television guide and remote control. Univers. Access Inf. Soc. 4, 4 (May 2006).

[6] Conversy, S., Gaspard-Boulinc, H., Chatty, S., Valès, S., Dupré, C., Ollagnon, C. Supporting Air Traffic Control Collaboration with a TableTop System. In Proc of CSCW'11.

[7] Guimbretière, F. Paper augmented digital documents. In Proc of UIST '03. ACM, 51-60.

[8] Haller, M. Pen-based interaction. In ACM SIGGRAPH 2007 courses, 75-98.

[9] Haller, M., Leitner, J., Seifried, T., Wallace, J. R., Scott, S. D., Richter, C., Brandl, P., Gokcezade, A., Hunter, S. The NiCE Discussion Room: Integrating Paper and Digital Media to Support Co-Located Group Meetings. In of CHI 2010.

[10] Harris, J., Henderson, A. A better mythology for system design. In Proc of CHI '99. ACM, 88-95.

[11] Hofer, R.L. Kunz, A. Digisketch: taming Anoto technology on LCDs. In Proc of EICS '10. ACM, 103-108.

[12] Kimoto 100 SXE http://www.kimoto.co.jp/english/products/light.html

[13] Koike, H., Kobayashi, M. EnhancedDesk: Integrating Paper Documents and Digital Documents. In Proc of APCHI '98. IEEE Computer Society, W., DC, USA, 57.

[14] Liao, C., Guimbretière, F., Hinckley, K. PapierCraft: a command system for interactive paper. In Proc of UIST '05. ACM, 241-244.

[15] Liao, C., Guimbretière, F., Loeckenhoff, C. Pen-top feedback for paper-based interfaces. In Proc of UIST'06, pp. 291 - 220.

[16] Livescribe, http://www.livescribe.com

[17] Luff, P., Adams, G., Bock, W., Drazin, A., Frohlich, D., Heath, C., Herdman,P., King, H., Linketscher, N., Murphy, R., Norrie, M., Sellen A., Signer, B., Tallyn, E., Zeller, E. Augmented paper: developing relationships between digital content and paper. In Computer Science, Vol. 4500. Springer.

[18] Mackay, W.E., Fayard, A.L., Frobert, L., Médini, L., Reinventing the familiar: exploring an augmented reality design space for air traffic control. In Proc of the CHI '98. ACM Press, 558-565.

[19] MacKay, W.E., Is paper safer? The role of paper flight strips in air traffic control. In CHI 99, 311-340.

[20] Mackay, W.E., Pothier, G., Letondal, C., Boegh, K., Sorensen, H.E., The missing link: augmenting biology laboratory notebooks. In Proc of UIST '02. ACM, 41-50.

[21] Mertz, C., Chatty, S. and Vinot, JL. The influence of design techniques on user interfaces: the DigiStrips experiment for air traffic control. HCI-Aero 2000.

[22] Hofer, L., Kunz, A. 2010. Digisketch: taming anoto technology on LCDs. In ACM EICS '10. ACM, 103-108.

[23] Sellen A.J., Harper R.H.R. The Myth of the Paperless Office. MIT press, Cambridge, MA. 2001.

[24] Signer B., Norrie M., Interactive Paper: Past, Present and Future, In proc of UbiComp '10, Sep 26-Sep 29, 2010.

[25] Song, H., Guimbretiere, F., Grossman, T., Fitzmaurice, G., MouseLight: bimanual interactions on digital paper using a pen and a spatially-aware mobile projector. In CHI '10.

[26] Tsandilas, T., Letondal, C., Mackay, W. 2009. Musink: composing music through augmented drawing. In CHI '09). ACM, New York, NY, USA, 819-828.