

An Avionics Touch Screen based Control Display Concept

Michaël Mertens^{*a}, Herman J. Damveld^b, Clark Borst^b

^aBarco N.V. Defense & Aerospace, President Kennedypark 38, 8500 Kortrijk, Belgium

^bDelft University of Technology, P.O. Box 5058, 2600 GB Delft, The Netherlands

ABSTRACT

In many cockpits, control display units (CDUs) are vital input and information devices. In order to improve the usability of these devices, Barco, in cooperation with TU-Delft, created a touch screen control unit (TSCU), consisting of a high-quality multi-touch screen. The unit fits in the standard dimensions of a conventional CDU and is thus suitable for both retrofit and new installations. The TSCU offers two major advantages. First, the interface can be reconfigured to enable consecutive execution of several tasks on the same display area, allowing for a more efficient usage of the limited display real-estate as well as a potential reduction of cost. Secondly, advanced graphical interface design, in combination with multi-touch gestures, can improve human-machine interaction. To demonstrate the capabilities of this concept, a graphical software application was developed to perform the same operations as a conventional CDU, but now using a direct manipulation interface (DMI) of the displayed graphics. The TSCU can still be used in a legacy CDU mode, displaying a virtual keyboard operated with the touch interface. In addition, the TSCU could be used for a variety of other cockpit functions. The paper concludes with a report of pilot and non-pilot feedback.

Keywords: Touch Screen, Navigation, Direct Manipulation, Gestures

1. INTRODUCTION

Since the introduction of the flight management system (FMS) in commercial aircraft in the late 1970s (Walter, 2000), the flight efficiency has increased significantly and the FMS helped to reduce fuel burn and decreased the pilot workload. The first series of FMSs were installed in cockpits that were equipped with electro-mechanical indicators. Although the control display unit (CDU), the pilot's central input and output device with the FMS, allowed the flight crew to (re-)plan a flight, the electro-mechanical instruments did not provide any feedback on the inserted information. As a result, programming the FMS was a cumbersome task for pilots and did not really support the pilot's situation awareness (Walter, 2000). Since the emergence of computer technology into the cockpit in the early 1980s, together with the introduction of electronic instruments, more feedback on the inserted information and the FMS output could be depicted on the primary flight display (PFD), the navigation display (ND), and the multi-function display (MFD). Especially the ND in map mode, that displays a bird's eye view on the flight trajectory, was a huge improvement in terms of pilot situation awareness (Abbott, 2000).

* michael.mertens@barco.com; phone +32 (0)56 233271 ; fax +32 (0)56 233588; www.barco.com

Although the electronic interfaces can depict information from the FMS in a more intuitive way than the legacy electro-mechanical instruments, the revision of a flight plan during flight is still regarded to be a cumbersome task. The specification of the sequence of waypoints, flight levels, and speed and time constraints typically needs to be entered alphanumerically through the keypad of the CDU. Not surprisingly, in the case of obstructive weather cells, pilots often do not bother with altering the flight plan in the FMS but simply request permission from air traffic control (ATC) to deviate from it using the autopilot mode control panel. This provides a workaround in traditional ATM operations, be it at the cost of reliable arrival time and fuel burn predictions. The need for pilots to manipulate the powerful functionality of the FMS quickly and accurately to perform this task proficiently calls for a redesign of the flight planning functionality. Ideally, the ability to directly manipulate and interact with the graphical representation of the flight plan would be desired to facilitate this concept.

In general, a direct manipulation interface (DMI) is an interface that has the goal to give the operator the feeling that he or she is directly interacting with the objects under control through the interface (Hutchins *et al.*, 1986). Amongst other things, this feeling of directness is mainly created by using real-world metaphors of the objects under control. For example, manipulating the shape of a triangle is much easier to do when the user can directly manipulate (e.g., click and drag) the control points of a visible triangle instead of changing the triangle's coordinates in a matrix representation. Similarly, when pilots want to alter their flight plan, repositioning the waypoints by means of directly interacting with the visual representation of the waypoints on the navigation display is much more intuitive. Of course the advantage of a DMI may be clear. That is, it can alleviate the user from making mental translations between his or her actions and what is actually being controlled. However, current CDU and electronic displays are not able to provide such DMI functionalities.

The advent of touch-screen technology, and in particular multi-touch, in consumer electronics has clearly demonstrated the advantages of direct manipulation concepts. Not surprisingly, some avionics manufacturers have picked up these trends and are (independently) working on touch-screen replacements for the legacy CDU to improve the pilot's interaction with the FMS.

In this paper we present a prototype touch screen control unit (TSCU) to potentially replace the CDU. Differently from other touch-screen CDUs that mainly support single touches, the TSCU consists of a high-quality multi-touch screen that supports gestures. To demonstrate the flexible capabilities of this new concept, a DMI application was developed that employs multi-touch gestures to aide pilots in performing the primary FMS function: in-flight management of the flight plan. The prototype TSCU was displayed at the Le Bourget Air show in 2011 and was also evaluated by a number of professional airline and military pilots. The results of this subjective evaluation and their general comments are also included in this article.

The outline of this article is as follows. First, the TSCU system will be elaborated. Then, the supported gestures and the applications developed for this prototype will be presented. Finally, the results of the pilot evaluation will be discussed, followed by the conclusions and the recommendations for future investigations.

2. SYSTEM SET-UP

The system is intended as a concept demonstrator and consists of a TSCU and a standard Barco MFD screen. The content of both screens is generated by a PC. The touch interface on the TSCU is

read out by the same PC. Some external power supplies are providing the A/C power to the TSCU and MFD units. The setup is depicted in Figure 1.

As the display content of the MFD and the TSCU are interconnected via the same PC, and the touch interface is also interpreted by this PC, collaboration between the screens is possible. This set-up is considered a correct functional model of a real avionics installation.



Figure 1. Hardware setup consisting of the TSCU and MFD display.

3. THE TSCU TECHNOLOGY (HARDWARE)

3.1 Introduction

The touch sensor in the TSCU is based on projective capacitive technology (PCT) this sensor is bonded to the LCD panel. Special attention is given to the optical characteristics of the optical stack, as high contrast and sunlight readability or essential for avionics display units.

3.2 Projective Capacitive Touch Screen Technology

Projective capacitive touch screen technology is currently the fastest growing of all touch screen technologies. It is on its way to soon to overtake analogue resistive: the current leader of touch screen technologies.

Principles of operation:

- Below a protective glass cover, transparent conductive patterns: both for driving and sensing are applied
- The conductive patterns are connected to a controller board
- This controller board establishes oscillation frequencies on the pattern.

- When the glass is touched by a conducting element (e.g. a finger), a change in capacitance occurs which changes the oscillation frequency in the surroundings of the contact point.
- By means of software, the sensor contact point is translated to an absolute screen position.
- This is possible for multiple positions on the touch sensor, enabling real multi-touch capability.

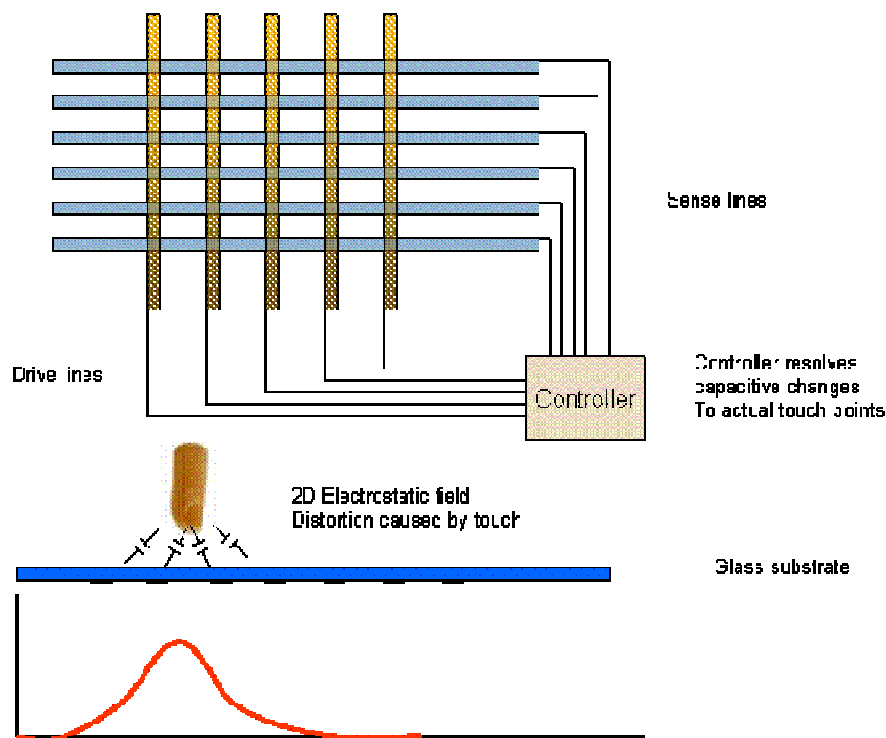


Figure 2. Projected capacitive touch screen technology.

The projective capacitive technology was chosen for its inherent advantages like: ruggedness, durability, intrinsic night vision imaging system (NVIS) compliancy and cost effectiveness. A concern with the technology is that it is sensitive to external electromagnetic fields and does not give a tactile feedback. These areas of concern need to be elaborated more to create adequate solutions.

3.3 The display Technology

The core display technology is: in plane switching (IPS) LCD. To build a sunlight readable avionics display great care is given to the full optical stack which can be quite complex for avionics displays. Each layer added to the LCD panel includes the risk to increase reflection of the ambient light and degrades the contrast of the display in high bright environments. The unique Barco lamination process, with optical matching of all interfaces, allows reducing the effects of the additional touch sensor to the bare minimum, resulting in an excellent display performance. The prime parameters for

good readability of an avionics display are: luminance (should be high) and reflection (should be low). There is a direct relation between luminance and total optical transmission of the optical stack. Because of practical reasons the transmission is taken as parameter. We consider the following values as design targets:

- Full stack reflection < 1.0 %
- Full stack transmission > 85 %

When taking a standard PCT sensor, the ITO patterns are typically not optically matched with the glass, resulting in increased display reflectance and a visible pattern in reflection. Therefore several alternative configurations were investigated by integrating dedicated layers in the optical stack. The first interfacing surface is coated with a highly effective Antireflective Coating (AR) for minimum ambient light reflections on the front surface.

The resulting configuration is shown in Figure 3, with total reflectance values to be expected of 0.3 to 0.7 %.

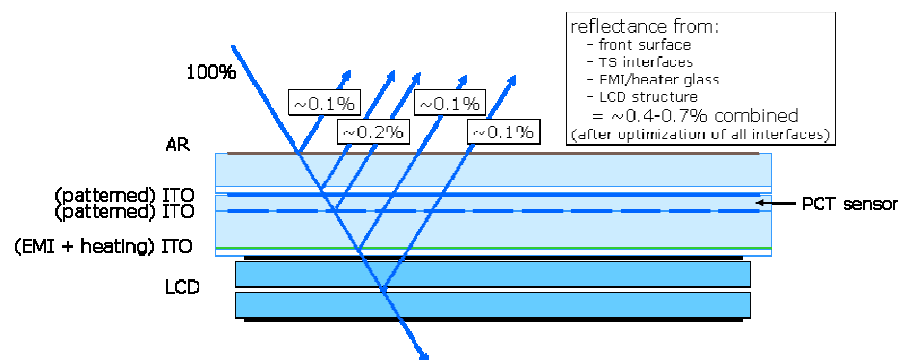


Figure 3. Panel assembly configuration optimized for low reflection.

3.4 Test results

The full optical stack has been build and tested for its optical performance. The specular reflection has been measured as a function of viewing angle. The results are shown in Figure 4.

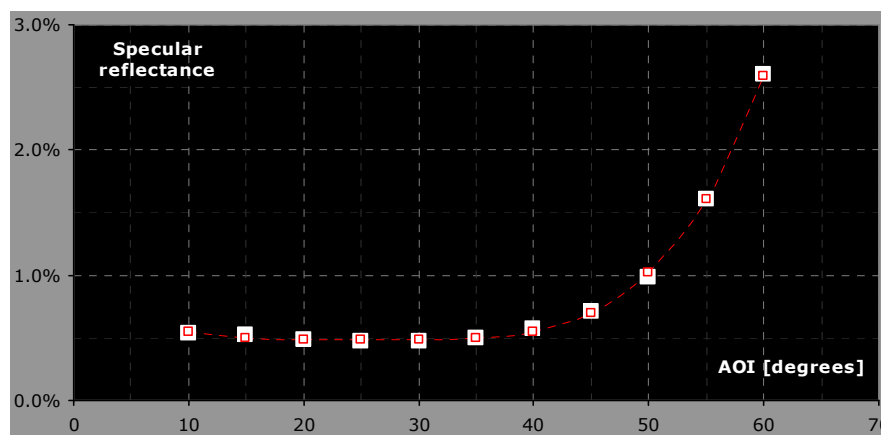


Figure 4. Specular reflectance of the TSCU. The horizontal axis contains the Angle Of Incidence (AOI)

As can be seen, the specular reflectance is about 0.47% at 30 degrees viewing angle. This is within the range of the theoretical estimation of 0.3-0.7. The transmittance of the optical stack is measured and amounted to a reduction of approximately 15%. This is exactly at the target value creating a total transmission of 85%.

3.5 Remaining Concerns

With the introduction of the PCT touch technology some concerns came up. Having good haptic and tactical feedback is confirmed to be essential for a touch screen in an avionics environment. Optical degradation due to finger print residue is seen as a major issue. Reliability of the touch actions in a highly dynamic environment must be assured. These concerns are briefly analyzed below.

Haptic and tactile feedback

When using traditional keyboards, users need to overcome an activation force (= tactile force) and get some tactile feedback at a key press. These confirmation clues are not present when using a touch screen, these feedback mechanisms need to be restored. Haptic and tactile feedback could bridge the usability gap between touch screens and mechanical controls. Several studies have revealed that operation of touch screens with good haptic feedback leads to higher input speed, greater accuracy, less fatigue and less frustration. The type of haptic feedback can vary in complexity from simple vibration (like that applied in mobile phones) to multifaceted effects driven by complex mathematical models. This latter type of feedback is called 'high-fidelity haptic'

Fingerprint residues

Fingerprint residues degrade the effectiveness of the front glass AR coating and thus increase ambient light reflection. The result is poor sunlight readability of the display unit. Research is being done on special anti-fingerprint coatings. These new coatings create a high contact angle with the front surface for the contaminants. These so-called oleo-phobic or hydrophobic coatings are able to repel water, oil and other contaminants in such a way that they become less visible and easy to clean. To our knowledge no current solution can completely suppress fingerprint visibility.

Touch reliability in dynamic environments

The cockpit of an aircraft can be highly dynamical, subjected to vibrations and acceleration. This creates extra difficulties for pointing to the right spot on the touch screen and can result in false or non detected touches. Precautions such as finger and wrist rests can help a lot by isolating the vibrations of the A/C from the pointing fingers. Also the definition of the HMI symbology on the display plays a key role. This topic is not yet fully studied and further research work is needed.

4. GESTURES

4.1 Introduction

To create an ergonomic operation of the touch screen, a dedicated set of gestures is implemented. These gestures are bridging the gap between the hardware and the user application. In the application a strict distinction was made between single touch and multi-touch gestures. The single touch gestures modify elements in the displays, such as waypoint locations or button states. The multi

touch gestures were strictly used to modify viewport elements, such as changing the active interface (DMI, CDU or CCD), or pan or zoom in the active interface. This strict distinction ensures that pilots will not accidentally modify or activate elements of their route while their intention was to modify the viewport.

4.2 Single touch gestures

Single click

A single click is detected when one finger is briefly touching the surface. It is used for actions like pushing a virtual button. The action is executed when the touch sensor is released.

Long press: select and activate

A long press is detected when one finger is touching the surface for a long time > 2 sec. It is used for selecting and activating symbols e.g. a graphical representation of a route segment. In this case, when detected, the color of the symbol changes from magenta to white.

Double click: twice a single click within a short time

A double click is detected when one finger is briefly touching the surface twice within a short time. It is used for restoring a default situation, for instance track up and default zoom level in the map mode on the MFD.

Drag

A drag is detected when one finger is gliding over the screen. It is used to move around display elements in the screen.

4.3 Multi touch gestures

Two-finger Pan

A two-finger pan is detected when two fingers are touching the surface and are gliding over the surface while maintaining the same relative distance between them. It is used to pan the full image on the TSCU

Pinch or zoom: two touches change relative distance

A zoom is detected when two touches change in relative distance. It is used to zoom in and out the full screen of the TSCU.

5. THE APPLICATION

The purpose of the demonstrator was to illustrate that, by implementing a touch screen interface; different functionalities on the software level can be ascribed to a single hardware interface. In the current TSCU demonstrator we have implemented three of these functionalities:

- a direct manipulation interface (DMI),
- a virtual control display unit (CDU), and
- a cursor control device (CCD).

The TSCU application is not limited to these functionalities, and can easily be extended with other features such as communication panels, check lists or circuit breaker panels. All of the

functionalities share one touch event handler, which distributes the touch events. A block diagram of the application components is shown in Figure 5.

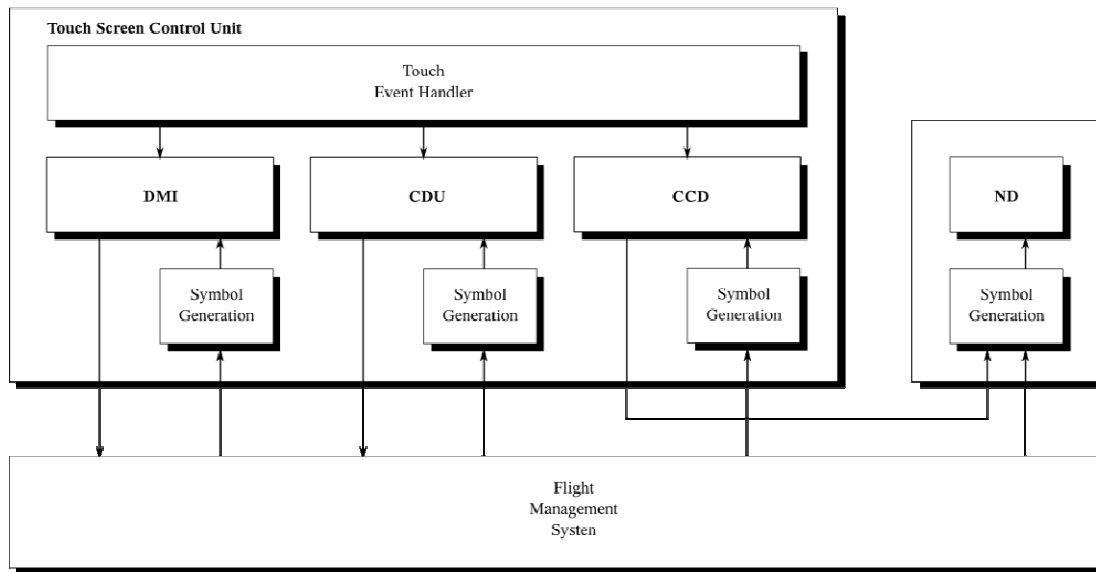


Figure 5. Application block diagram.

The TSCU has three interface pages (see Figure 6). Each of these pages provides its own functionalities and interactions with the flight management system as described below. Switching between interface pages can be done by making a sliding gesture on the bottom bar. Currently, the prototype is limited to route manipulation only. The task of the user is to re-plan and modify a planned route to avoid weather cells obstructing the route. In the application the aircraft will follow a looped trajectory around the Le Bourget. airport near Paris.

To insert a waypoint, a finger should be placed somewhere on the route where a new route point was desired. After holding the finger at that desired position for two seconds, a modified route (white route) appeared. Now a new route point was visible and could be dragged to a new location. The new route point could also be snapped to an existing waypoint in the database. The application will then automatically insert this route point in the FMS. Not snapping the route point to a waypoint created a new custom waypoint. To make the modified flight plan active, the virtual EXEC button on the touch screen should be pressed.

Further, an existing waypoint along the route could also be modified by placing and holding the finger on the existing waypoint. By dragging the waypoint to a new location a circle appeared that showed readings of the radial and DME distance offsets.



Figure 7. Modification of existing waypoint

Finally, zooming in and out could be done by a two finger pinch gesture, whereas a two finger swipe gesture panned the top-down view. After panning, a double tap on the touch screen returned to the track-up view again. To declutter the view after zooming out, the ARPT, WPT, and STA buttons could be pressed to show/hide airports, waypoints, and nav aids beacons, respectively.

6. USERS FEEDBACK

The main purpose of the demonstrator was to investigate whether touch screens in general and the TSCU in particular are an improvement over the conventional systems. The practical improvements in terms of reusability of flight deck surface and potential situational awareness improvements have been discussed in the previous sections. The present section will deal with the pilot's view.

In order to deal with the large number of existing aircraft types, fulfilling many different roles, feedback was requested from three different groups: commercial airline pilots, military pilots and

non-pilots. The third group was added to study the effects of trained behavior and habituation, and to briefly investigate the intuitiveness of the DMI and CDU interfaces. The next three sections present a short summary of the feedback.

6.1 Feedback from Commercial airline pilots

CDU vs. DMI:

The most important finding was that the pilots at first sight preferred the virtual CDU interface over the DMI interface or even the conventional CDU with physical buttons.

Several suggestions to improve the virtual CDU interface included the possibility to scroll through the route legs page instead of stepping, and to adapt the fixed function keys as a function of the flight phase.

The DMI was considered an improvement over the CDU if direct selection of SIDS and STARS would be possible.

Other functionalities:

Other possible applications for the TSCU area includes virtually all functions currently present on the pedestal which will make them easier to reach.

General touch screen concerns:

Decreased readability due to smudging of the fingerprint residues, especially in direct sunlight.

6.2 Feedback from Military pilots

CDU vs. DMI:

A DMI will be hard to operate in high-g and high vibration environments such as fighter aircraft.

For military transport and tactical operations a DMI would be very profitable, especially for crew-resource purposes.

In addition a DMI requires less or no menu structures compared to the traditional CDU route pages.

Other functionalities:

The touch screen could serve as cursor control device to modify information on the head up display (HUD) or helmet mounted display (HMD).

General touch screen concerns:

Tactile feedback is essential for fighter aircraft in order to operate heads-up.

Operating a capacitive touch screen is cumbersome using gloves.

Dirty gloves from a preflight check will smudge the screen.

At least one hard key is required to immediately revert to a “known good” screen configuration.

6.3 Feedback from Non-pilots

CDU vs. DMI:

The DMI is much more intuitive, without any training the device can be operated.

Other functionalities

None.

General touch screen concerns:

Operation in heavy weather conditions such as turbulence.

Fingers on screen are always hiding symbols or buttons.

Lack of tactile feedback.

7. CONCLUSIONS

A new concept of interfacing in the cockpit was developed and demonstrated. The classic CDU is replaced by a Touch Screen Control Unit, allowing for a more intuitive Direct Manipulation Interface on its graphical representations. This concept not only improves the intuitiveness of the CDU functionality but also opens the path for more applications on the same surface. Adding a new functionality in the cockpit will basically result in a SW upgrade and does not require the installation of new equipment.

After the integration of the touch sensor, the optical characteristics of the display can be restored. This creates the right display performance for a cockpit environment and to allow full sunlight readability.

Early users feedback is very positive. Some concerns are still present like haptic and tactile feedback, optical degradation due to finger print residues and touch reliability in a dynamic environment. These need more analysis and are the subject for future research.

8. ABBREVIATIONS

Abbreviation	Description
A/C	Aircraft
AOI	Angle Of Incidence
AR	Anti-Reflective
ATC	Air Traffic Control
CDU	Control Display Unit
DMI	Direct Manipulation Interface
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Immunity
GUI	Graphical User Interface

HMI	Human Machine Interface
IPS	In Plane Switching
IR	Infrared
ITO	Indium Tin Oxide
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
MFD	Multi Function Display
NVIS	Night Vision Imaging System
PCT	Projective Capacitive Technology
RTE	Route
TS	Touch Screen
TSCU	Touch Screen Control Device

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