Rapid Integration and Evaluation of Functional HMI Components in a Virtual Reality Aircraft Cockpit

Matthias Oberhauser, Daniel Dreyer, Thomas Convard and Sebastien Mamessier

Abstract This research presents a Virtual Reality Flight Simulator (VRFS) for the rapid integration and evaluation of Human Machine Interface (HMI) prototypes in a functional aircraft cockpit environment. In contrast to engineering mock-ups or full flight simulators, the digital cockpit mock-up of the VRFS presented here has a major advantage—it can be adapted without time- and cost-intensive hardware conversions, which is ideal, particularly in the early stages of the design process. The virtual cockpit is also connected to a flight simulation. This means that not only ergonomic but also cognitive aspects of new HMI components can be evaluated. This leads to the main objective of the VRFS: Demonstrating novel systems alongside existing cockpit components while using realistic operational scenarios. Thus, the subject's feedback does not only include comments on the HMI but also on its functional interaction with the cockpit ecosystem. This paper shows the technical setup of the VRFS and demonstrates the integration and evaluation of an HMI component in a use case.

Keywords Virtual reality · Humane machine interface design · Flight simulation · Human factors evaluations · Robot operating system

1 Introduction

The modern flight deck is a sophisticated workplace that controls a complex system with no room for errors. Flight decks, crew communication and the underlying systems have evolved over the last decades, making flying one of the safest means of mass transportation. The introduction of new technologies and operational needs has led—and will continue to lead—to new cockpit components [1]. With the

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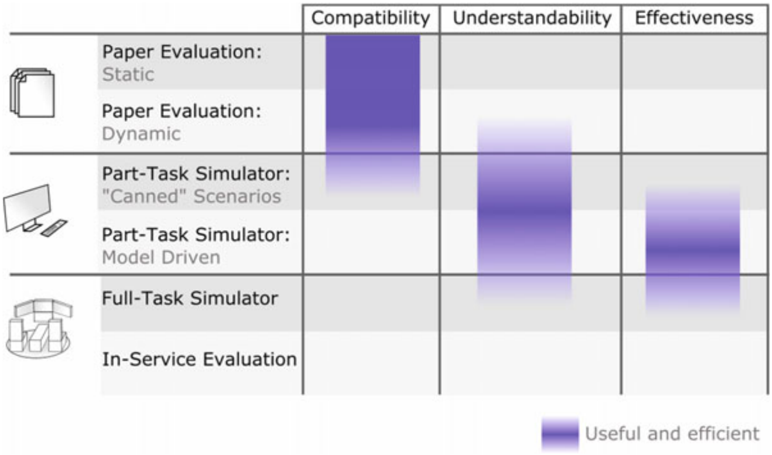

Fig. 1 Levels of evaluation and the evaluation environments

introduction of these new components, existing problems in the Human Machine Interaction (HMI) can be solved. Yet, others might arise—especially with the interplay of existing components and procedures. In order to counter potential issues, Human Factors (HF) engineering has to play an important role in all design phases, including HF evaluations in all stages of the design process [2].

There are three different levels of evaluation: Compatibility—Can the system be used by a human? Understandability—Is it possible for a pilot to communicate with the system? And effectiveness—How does the pilot perform with the system? Abbott presents different means of evaluation environments ranging from paper based evaluations, part-task and full-task simulators to in-service-evaluations that have been time-tested and proven. As shown in Fig. 1, there is an environment for every level of evaluation that is both useful and efficient. Early in the design process, compatibility and understandability can be evaluated in a part task system. Later, however, the effectiveness should be evaluated in a full-task environment [1]. Some types of simulators deliver useful results for multiple levels of evaluation, yet, they are not efficient to use at this stage of the design process. For instance, an in-service evaluation gives useful insights on HMI components; but at this point, it is costly to implement necessary changes and therefore is not efficient.

This research leverages Virtual Reality (VR) for the evaluation of single systems in a holistic environment for all levels of evaluation. With the presented Virtual Reality Flight Simulator (VRFS), early research demonstrators as well as more advanced prototypes can be integrated and evaluated in a virtual cockpit. This paper describes interfaces for the integration of prototypes as well as the possibilities of Human Factors evaluations in an HMI development use case.

2 The Virtual Reality Flight Simulator

The Virtual Reality Flight Simulator consists of several modules. The core of the system is a six degrees of freedom optical tracking system that provides information on the head and hand position as well as the rotation. A virtual cockpit is rendered in a 3D engine with the camera rotation and position driven by the tracking system. For visualization of the virtual reality environment, a Head Mounted Display (HMD) is used. The hand and finger tracking data that is provided by the tracking system is used to position a 3D hand representation in the virtual world. Different types of interactions with the cockpit are possible with this finger tracking system.

Control elements can be fully virtual. Therefore, a separate module checks the finger positions for possible collision areas [3, 4]. If functional hardware elements are added to the environment, a so-called mixed reality is created, which enhances the usability of the system (see Fig. 2). Adding hardware elements is a trade-off between a very flexible, fully virtual system and a rather inflexible but highly usable system with various hardware parts [5].

The virtual environment is connected to a flight simulation with an aircraft system simulation, a flight physics simulation and an outside visual. This is important to create realistic scenarios for pilot evaluations. All components of the VRFS communicate using the Robot Operating System (ROS). This network layer offers the possibility to interconnect heterogeneous soft- and hardware components in an open source peer-to-peer network [6]. In the VRFS, the flight simulation component publishes the aircraft telemetry data, the tracking system publishes data about the movement of the pilot using the system, and the collision handler publishes interactions with the virtual cockpit. For post-analysis or development, the

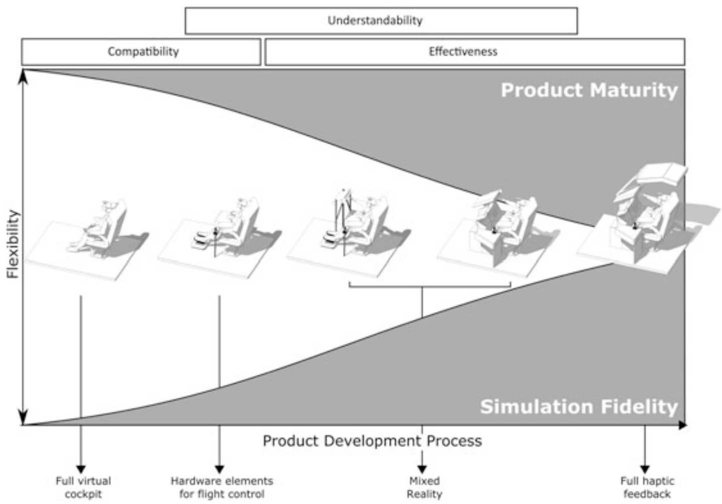

Fig. 2 The VRFS in the product development process

complete communication between the different nodes can be saved in a time stamped data file, a so-called rosbag.

3 Prototype Integration

ROS offers a modular and distributed approach. Data, audio, and video streams can be shared between different applications, independent of the operating system or the programming framework [7]. Thus, almost every hard- and software component that is network capable can communicate with the ROS system, whether it is a PC-based system, a mobile application or a highly integrated micro-controller. This flexibility makes ROS an ideal candidate for interfacing with third party components. It is possible to add new system simulations, to provide external software with telemetry data, or to stream the content of an external display into the virtual cockpit. Either one or multiple of these options in combination can be used. If you take display prototypes for example, this results in different levels of integration: (a) a non-interactive playback of display content, (b) display content that is driven by telemetry data, or (c) a fully interactive display.

A non-interactive display prototype (a) can be a video or a static image of a proposed display. To integrate the content of such an external display, a screen capture software, which can be connected to the ROS network, is necessary. For the VRFS, Virtual Network Computing (VNC) is used to stream display content as it is a widely used standardized protocol. If the display prototype should be driven by the flight simulation data (b), the display prototype has to listen to messages provided by the ROS network. If an interactive feedback (e.g. a touch screen) or hardware buttons (e.g. line select keys) are needed, a bi-directional ROS connection has to be implemented and the display has to be placed at the exact same position as in the virtual mock-up. Figure 3 shows the interaction with a touch screen that has been integrated in the use case, which will be presented in the next section.

Fig. 3 Interaction with hardware components in the VRFS

4 Use Case: Touch-Based Device

Here, a study about a touch screen device for aircraft system management will be presented as a use case to show the integration and usability of a prototype and its evaluation in the VRFS. The aim of the presented device in this use case is to simplify the task of managing aircraft systems by providing fewer, more general functions and by presenting these functions on a touch-based HMI in the head-down area. With this display, a pilot is able to control non-critical system management functions that usually are controlled in the overhead panel. Critical, irreversible functions are not part of this display due to safety considerations.

The touch screen device was implemented as a demonstrator on a mobile tablet device. The compatibility and the understandability of the device were tested in a part-task evaluation with test pilots. Based on the feedback gathered here, the prototype was further enhanced and integrated into the VRFS. It is accompanied by an overhead panel that offers access to irreversible functions that are not suitable for a touch screen device. Only with the combination of the touch screen device and the overhead panel, it is possible to create a realistic scenario. Hence, a part-task simulator is not sufficient to evaluate the effectiveness of the system integrated in the cockpit.

The prototype is implemented using web technologies (HTML 5 and the Jquery mobile framework), which can easily be connected to the ROS network. The different elements in the display, i.e. button states or system states, are driven by telemetry data from the flight simulation as shown in Fig. 4. User inputs on the other hand are translated into ROS commands and subsequently processed by the flight simulation. By placing the display at the exact same position as in the virtual cockpit, a mixed reality is created. Therefore, the pilot is able to use the touch screen in the virtual environment as shown in Fig. 3.

To expose the pilot to a high workload situation, a multi-system failure was chosen as a scenario: An electrical failure is followed by a fuel leak. The pilot has to deal with the electrical failure, identify and stop the fuel leak, and reroute the flight. To rule out confounding factors that stem from the virtual environment, a comparative study was conducted [8]. Thus, the scenario was completed once with a classic system management approach with an overhead panel and once with the novel touchscreen.

For evaluating the effectiveness of the novel system management approach, objective and subjective HF methods have been used. By means of the tracking system, the head and hand movements were analyzed as shown in Fig. 5. The time, the pilot looked at the overhead panel, and the time, the pilot needed to interact in the overhead area, were measured. From these two parameters, the relative physical workload can be derived. As the fuel leak scenario is a time critical event, analyzing and comparing task completion times led to a comparison of the performance of the task. All quantitative measures were automatically calculated by a script based on the data in the recorded rosbags.

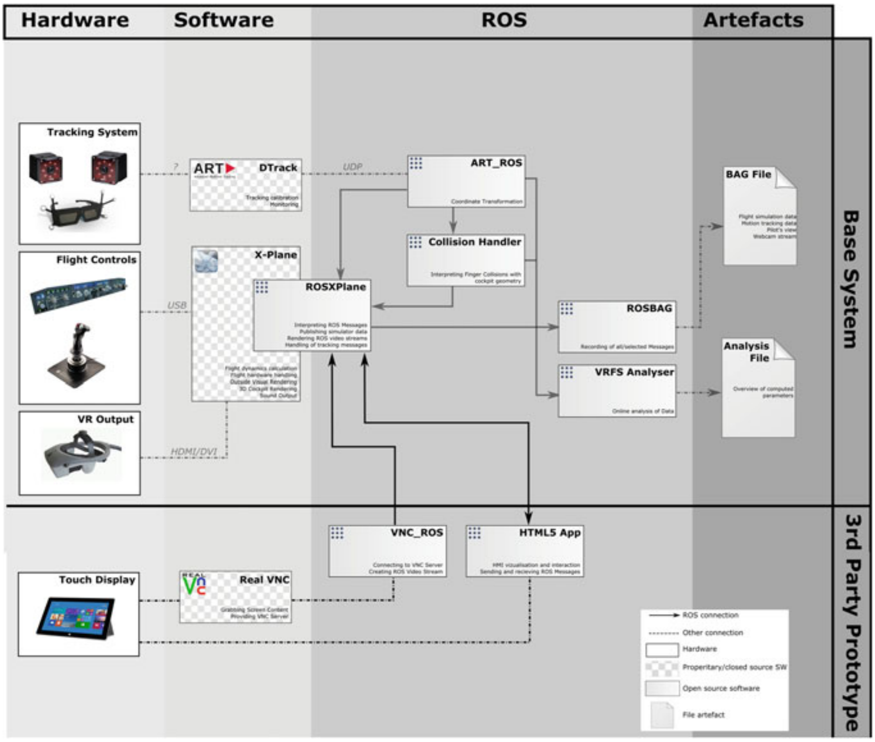

Fig. 4 The architecture of the Virtual Reality Flight Simulator

Fig. 5 Visualization of the recorded hand tracking data

These objective analyses were accompanied by subjective questionnaires to quantify workload and situation awareness, that is the NASA Task Load Index (NASA-TLX) and the Situation Awareness Rating Technique (SART) [9, 10]. These questionnaires were handed to the pilots after each scenario.

5 Discussion and Conclusion

This paper presents a Virtual Reality Flight Simulation environment for the integration and evaluation of HMI components. A use case is presented to show the integration and usability of a prototype as well as its evaluation in the virtual environment.

Today, in the cockpit development process, different types of evaluation environments are used depending on the level of evaluation and the development phase of the components, i.e. the technology readiness level. Due to cost and time constraints, the evaluation environments in the early phases of the design process are part-task simulators or even paper-based demonstrations. These environments are important for the in-depth evaluation of single system prototypes. Only later in the process, these prototypes will be integrated into a full-task simulator or are prepared for in-flight testing. At this point, ergonomic and cognitive aspects in the interplay with the existing cockpit ecosystem can be evaluated. The VRFS offers the advantage of a holistic full-task view on a prototype already in earlier stages of the design process. Paper concepts can be integrated as non-functional prototypes for compatibility or ergonomic assessments. Later, a functional virtual prototype or even a hardware prototype can be integrated and evaluated in a full scenario to get information on the understandability and effectiveness of the new system.

The goal of the VRFS is not to replace the current design and evaluation process of cockpit components but to supplement it with the possibility to integrate and evaluate components in a flexible, affordable and holistic cockpit environment in all stages of the design process. The presented use case shows the potential of part-task evaluations followed by the rapid integration and evaluation into the VRFS.

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