Head-up display architecture development for perspective civil aircraft

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Abstract. Nowadays the civil aircraft head-up displays available on the market could not be easily integrated onboard due to architectural aspects. Particularly, these systems usually contain a dedicated computer unit performing the data processing to generate the appropriate image. This leads to increases in the overall avionics weight and size and limits the scope of head-up displays application in general. However, the mentioned characteristics could be improved by the usage of the integrated modular avionics concept for architecture design. According to that approach, the common hardware platform is used by different functional consumers to share computation resources. Thus, the required data processing function could be performed by the equipment already available onboard (without the need in additional hardware). The paper proposes the head-up display architecture for civil aircraft based on integrated modular avionics which significantly reduces the system’s weight and size compared to characteristics of existing analogous. Also, this way allows reducing the time expenses for aircraft development, testing and certification, as well as the vehicle operational cost.

1. Introduction

Today, there are trends in aircraft avionics functionality expansion with a decrease in weight and size. This goal can be reached by using modern ways in the avionics design. For example, with the aid of the integrated module avionics (IMA) concept application.

IMA approach implies a high-integrity, partitioned environment that hosts multiple functions on a shared computing base. This provides advantages in weight and power since computing resources can be used more efficiently compared to previous avionics design concepts – distributed and federated principles [1-3].

Also, the application of the IMA concept allows to easily install new systems as a part of existing onboard equipment complexes. One of such systems is the head-up display (HUD) which allows pilots to read primary flight and navigation information without eyes refocusing from the external environment to the multifunctional displays on the instrument panel. It projects information on the special transparent screen (combiner) placed between the pilot’s eyes and the cockpit windshield. Thus, the HUD usage reduces the crew workload and decision-making time in critical situations. The mentioned advantage is especially important during the takeoff and landing [4, 5].

Currently, HUDs are being developed under the federated approach i.e. the system represents by a number of self-contained units including separate computer. The purpose of this paper is the development of the HUD architecture designed following the IMA concept that is the novelty of the
The proposed solution allows to significantly reduce the system’s weight and size, time expenses for the aircraft development, testing, and certification as well as operational cost.

2. Avionics architecture types

There are the following avionics design concepts at the current stage of aviation development:

- distributed architecture;
- federated architecture;
- IMA.

2.1. Distributed architecture

The distributed architecture was widespread at the beginning of avionics development. By this approach, the onboard equipment complex represents by a set of “self-sufficient” systems and instruments performing local functions. Such system usually consists of:

- sensors which collect the data about the external environment, aircraft position, etc.;
- converters transducing data into a format suitable for further processing;
- computers processing the information received;
- indicators displaying in the cockpit the measured values.

Each onboard system is aimed to measure and display several flight parameters. Signal processing is performed through elementary operations. Communication between systems is normally absent (the same data is measured independently by different equipment).

The advantages of this concept include ease of implementation and the no impact of one system failure on the other equipment performance. The main disadvantages are the duplication of data in individual systems and a large number of indicators cluttering the cockpit dashboard and leading to a crew workload increasing.

Nowadays the distributed architecture is recognized as obsolete and is not used practically.

2.2. Federated architecture

The growth in the number and complexity of the flight functions required an increase in the level of onboard equipment integration compared to the principle described earlier. The combination of autonomous systems performing similar functions has reduced the number of computers to one for each merged system. It was put in the federated architecture basis.

By this approach, onboard electronic equipment consists of:

- concentrator providing data obtaining from sensors;
- central computers that process signals from the concentrators and provide information to consumer equipment;
- aircraft systems using data from computers to perform the corresponding flight functions.

The systems exchange data via common interfaces, which allows the use of the same information by different consumers at the same time.

The advantages of the federated approach are the ease of certification, no need to collect information by each system separately, their high reliability, small overall dimensions of avionics relative to the distributed concept. However, the federated principle does not provide the flexibility for increasing and modification of the functionality since the integration of new systems negatively affects the avionics weight and size.

Aircraft developed following this concept are Boeing B737, Airbus A320, Tupolev Tu-204, etc.

2.3. IMA

The IMA is deprived of the federated approach disadvantages. It involves the usage of open network architecture and a common hardware platform for computing resources, which determines its flexibility in terms of modification. The functions of aircraft equipment are performed by software applications running a real-time operating system on a computing platform [1].
The IMA concept is used during modern and perspective aircraft design (in particular, Boeing B787, Irkut MC-21, CRAIC CR929, etc.).

The IMA concept has the following advantages compared to the federative architecture:

- the possibility of avionics functionality increase while maintaining the same weight and size characteristics;
- no need to recertify all software components when introducing changes to only one of the applications;
- reduction of time spent on the development, verification, and certification;
- overall aircraft operational cost reduction due to the equipment unification, etc.

The disadvantage of IMA is the complexity in managing the individual avionics functions design since it is impossible to provide independent development of software applications located on a single hardware.

3. Cockpit display systems (CDS)

The advantages of the IMA concept make it possible to integrate new aircraft systems into the avionics complex, which also include modern CDS.

At present, the main displays in the cockpit used in civil aviation are:

- traditional multi-functional displays located on the dashboard;
- HUD.

HUD projects graphic information on a special almost transparent screen (combiner) which is located between the pilot’s eyes and the cockpit windshield. HUD usage can increase the situational awareness of the crew [6]. An example of a HUD image is shown in figure 1.

![Figure 1. Example of a HUD image.](image)

Currently, there are several HUD types differ in the optical system as refracting, catadioptric, and waveguide.

Refracting and catadioptric HUDs consist of an optical system, a high-brightness projector, and a combiner. The system is integrated into a single housing located above the pilot’s head. The indicated HUD types have a similar principle of operation: the image is projected onto the lens which forming a collimated light beam and then projected onto the combiner. Combiner glass reflects the incident light in the direction of the pilot. The main difference between these HUD types is the combiner design: the refracting HUD has a flat shape, and the catadioptric one is curved.

Figures 2, 3 show the operation scheme of refracting and catadioptric HUDs (1 – electron-beam device, 2 – mirror, 3 – lens, 4 – combiner, 5 – point of view.

The perspective waveguide HUD is principally different from the types above mentioned. It does not have a projector; the overhead part is implemented as a compact monoblock that significantly reduces...
the overall system dimensions. The image generator is located at the top of the monoblock. The lens refracts the light at a certain angle. The combiner is two parallel transparent waveguides. The light arrives at the first waveguide at the full reflection angle. At the intersection of the beams and the alignment plate, the incident light is reflected towards the front plane of the waveguide. Thus, the first waveguide rotates the image horizontally, and the second – vertically and project it in the pilot’s view direction [7].

Figure 2. Refracting HUD operation scheme. Figure 3. Catadioptric HUD operation scheme.

Figure 4 shows the operation scheme of the waveguide HUD (1 – image generator, 2 – lens, 3 – alignment plate, 4 – first waveguide, 5 – second waveguide).

Figure 4. Waveguide HUD operation scheme (a – main view, b – side view).

Coupled with the mentioned means of information indication in the cockpit, technical vision systems (TVS) are used, which make it possible to increase the crew situational awareness regarding the external environment in hard weather conditions.

The following types of TVS are used in aviation [8]:
- enhanced vision systems (EVS) displaying infrared images according to the onboard cameras data;
- synthetic vision systems (SVS) that allow reconstructing an underlying earth surface three-dimensional model taking into account obstacles and airport infrastructure objects;
- combined vision systems representing the symbiosis of the two mentioned TVS types and combining of sensory and synthesized information;

The HUD and TVS are optional, but they are being installed on modern civil aircraft frequently since it allows reducing the crew workload and decision-making time in critical situations.

The HUD and TVS combination also called enhanced flight vision system allows a continuing approach in low visibility conditions. In other words, it provides operational credit in terms of decision height (DH) reduction.
According to the relevant flight operations standards for an instrumental approach, the DH is 200 feet (category I) [9]. Besides, the crew should evaluate the flight and navigation parameters and the external environment during the landing. In the traditional cockpit (without HUD and TVS) it is carried out by reading data from displays on the dashboard and transferring a view at the environment to search visually for relevant landmarks on the ground. If there are HUD and TVS on board, the use of them eliminates the pilot’s eyes accommodation. Thus, the approach can be made even if the actual flight visibility is less than the instrumental approach required by reducing the DH to 100 feet [10].

4. Developed HUD architecture based on IMA concept

Now the HUD is being designed under the federated principle. Besides, a catadioptric HUDs are being chosen for installation onboard which is not optimal according to the weight and size criterion. In this paper, the waveguide HUD architecture using the IMA concept for modern and perspective civil aircraft is proposed.

The developed architecture based on the IMA concept includes (figure 5):

- waveguide HUD;
- avionics central computer unit issuing data from onboard systems necessary for the displaying formats generation;
- CDS computer unit which receives and processes information from the central computer and also generates the resulting image as a combination of layers of symbolic information and TVS images;
- ambient light sensor that determines the current ambient light level;
- EVS;
- SVS;
- onboard data server containing SVS digital databases of the relief, obstacles and airports infrastructure;
- control panel that allows adjusting the HUD image parameters (in particular, brightness, contrast).

![Figure 5. The developed HUD architecture based on the IMA concept.](image)

The main components of the developed architecture are HUD and SVS software applications hosting in the CDS computer unit. The SVS application generates an external environment three-dimensional model based on information from the onboard data server. The HUD application generates a layer of symbolic information, combines it with TVS images and outputs the resulting format to the image generator.

Data from the avionics central computer unit and onboard data server are sent to the CDS computer via the ARINC 664 interface. The received information is stored in the HUD and SVS applications. The CDS computer and image generator interact via the ARINC 818 interface. The resulting image is converted into a light stream and projected onto the waveguide.

The ARINC 664 interface was chosen because of the high bandwidth required for transferring large data. In addition, it allows transmitting information with speed up to 100 Mbps, which is a key aspect for ensuring the requirements of the regulations in part of updating the image displayed.
The ARINC 818 interface is required for transmitting video to displays. The fiber-optic data channel speed is up to 28 Gbps.

Commands for adjusting the HUD image parameters are issued by the control panel via ARINC 429 interface. The ambient light sensor that makes it possible to change format brightness automatically depending on the ambient light level, also interact with the CDS computer via this interface. The choice of ARINC 429 is due to the lack of the need to transfer a large amount of data.

The proposed architecture meets the requirements of guidelines applied in civil aviation: DO-315B [10], DO-297 [11]. Compliance with DO-315B is achieved through HUD interaction with TVS. The matching with DO-297 requirements consists of the following aspects implied by the IMA concept:

- platform (CDS computer) resources are shared by multiple applications (particularly, by HUD and SVS);
- robust partitioning of shared resources;
- application may be designed independently of other applications (e.g. HUD and SVS);
- applications are independently modifiable and reusable etc.

5. Conclusion

The paper presents the analysis of current aviation CDS and TVS. Based on the requirements of the standards and the analysis of avionics architecture types, the HUD architecture based on the IMA approach is proposed. The developed architecture allows to significantly reduce the HUD weight and size compared to the characteristics of existing analogous.

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