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Thermovision system for aircraft landing

Abstract

The paper presents the developed multispectral optoelectronic aircraft landing assistance and data transmission system for flight control. The purpose of the system is to provide information about the landing aircraft (in the day, at night and in the haze), such as the location of the aircraft in the runway axis, altitude, distance to touchdown and the condition of the plane components like landing gear etc. The system employs two infrared cameras working in spectral range of 3-5 μm and 8-12 μm and a video camera module. The system was tested in laboratory and in the field.

Keywords: Thermal imaging, thermal camera, aircraft landing support, airport security, aircraft assistance, airport equipment, airplane detection.

1. Thermovision system for aircraft landing assistance

On the civil and military airports multiple systems and devices are applied which main purpose is to assist flight control personnel. From analysis of equipment used at the airports and expectations of air traffic control staff, a concept of passive multi-spectral imaging system emerged to assist in landing the aircraft. The purpose of the system is to provide information about the landing aircraft (in the day, at night and in the haze), such as the location of the aircraft in the runway axis, altitude, distance to touchdown and the condition of the plane components like landing gear and other components of the plane. Data from optoelectronic system installed on airport runway is transferred to the airport controller's post, located in the airport control tower.

During development it was assumed that the system can work with existing airport control terminal. On the same time, the proposed technical solution does not exclude independent operation. The proposed imaging system will support the work of the flight controller and will contribute to raising safety level of flights during the day, night and especially on adverse weather conditions.

Detection and observation of an aircraft from larger distances at night, and difficult weather conditions was realized with the use of two third-generation infrared cameras with focal plane array photon detectors with resolution of 640 × 512 pixels.

One of those infrared cameras is working in (LWIR) Long-Wave InfraRed range (8 to 12 μm), while the other one works in the (MWIR) Mid-Wave InfraRed range (3 to 5 μm). The use of cameras working in two spectral bands increases the detection ranges in difficult weather conditions. In good visibility conditions during the day also a video camera is available for the operator.

Optoelectronic assembly consisting of observation cameras is placed in the axis of the runway at a distance of about 50 ÷ 150 m ahead of the runway threshold. The field of view of the camera system should be similar to the working angle of an ILS (Instrument Landing System). Design considerations led to four times surplus in the vertical angle, which allows the detection of an aircraft at higher and lower height relative to the three-degree glide path covered by the ILS. Two sets of optoelectronic assemblies with passive thermography observation cameras can provide landing assistance on both sides of the airport runway.

2. Aircraft landing assistance system

Optoelectronic, multispectral aircraft landing assistance system SWL-20 is used for online observation and recording of an aircraft, performing landing maneuver in a variety of weather conditions. The system is designed for installation on military airports and it is intended as yet another source of information for air traffic controllers on the aircraft approaching runway, complementary to the observation radar and optical observation with binoculars. The system is intended to provide information on the position of the landing aircraft with respect to glide path and about its apparent condition, particularly for confirmation that the landing gear is down. In regard to physical location of the SWL-20 components on the airport we can distinguish two functional modules of the system:

- observation post (set at the runway threshold)
- flight control post (set on the flight control tower).

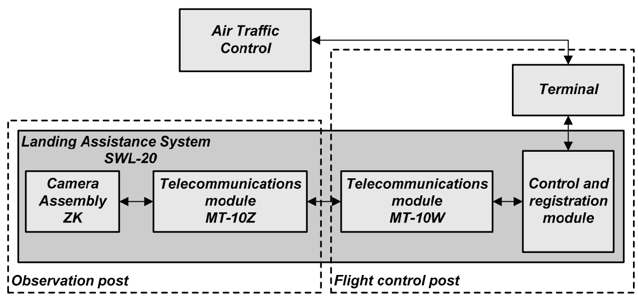

Fig. 1. Landing Assistance System SWL-20 –structure and system environment

In order to accomplish the tasks, image from Camera Assembly (ZK) has to be transmitted from the place where the observation post is installed to the system operator at the flight control post. For this purpose, the MT-10 Telecommunications Module was designed. The telecommunications module MT-10 can transmit data using radio frequency or optical fiber. In addition, the module provides integration with the existing airport flight control system, which is installed on the flight control tower. MT-10 consists of two parts: a MT-10W (internal) installed in the control room and MT 10Z (external) installed outside the building on the runway.

In the drawing (Fig. 1) the whole SWL-20 system is shown, including the telecommunications module. Data transmission system STD-10, which is a part of the Camera Assembly, provides the connection to the MT-10Z module using a fiber optic line. Fiber optic link is robust to external electromagnetic noise sources, it doesn't generates electromagnetic interference to the fragile airport systems and provides low latency data transfer. Image signal from the infrared cameras is transmitted to STD-10, where it is converted to optical form and further distributed to the telecommunications module MT-10Z where, through a telecommunication system SWL-20, it is transferred to the flight control operator. STD-10 in addition to data transfer also provides control for Observation Post modules.

MT-10 modules can communicate with each other using three communication media: radio frequency with the use of LANCOM OAP-54-1 Wireless module, free space optics using optical transmission module WBXT100 WAVEBRIDGE L.E.D. and fiber-optics using single mode 1310 nm wavelength fibre.

Using the aforementioned devices telecommunication system has been realized based on two modules MT-10W and MT-10Z, capable of transmitting the image at the distances exceeding 2 000 m.

3. Camera Assembly

Camera Assembly consists of the following modules: Data Transmission System STD-10, Optoeletronic System SOE-10, Protective cover module, Fiber optic unit ZS1, Power connector ZZKP1, Service jack ZZKS1. The functional diagram of the camera assembly (ZK) is shown in Fig. 2.

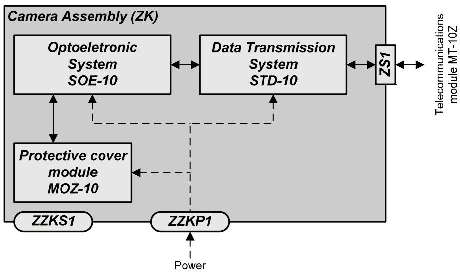

Fig. 2. Block diagram of Camera Assembly (ZK)

Camera Assembly is placed in a monolithic hermetic enclosure and it is equipped with three connectors: power ZZKP1 connector, telecommunications connector ZS1 and ZZKS1 service jack. Photography of constructed Camera Assembly is shown in Fig. 3.

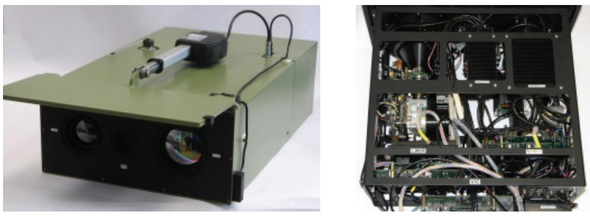

Fig. 3. Photography of Camera Assembly (ZK) comprising two infrared cameras working in MWIR and LWIR spectral range and video camera working in visible spectral range

One of the elements of the Camera Assembly is the Data Transmission System STD-10. Data Transmission System STD-10 enables the transmission of images from the Optoelectronic System SOE-10 and control commands from the flight control post through telecommunication route built with MT-10 module.

Another element of the camera is Optoelectronic System SOE-10. The Optoelectronic System SOE-10 is composed of the following elements: Thermal camera imaging module working in spectral range of 3-5 µm (MWIR), Thermal camera imaging module working in spectral range of 8-12 µm (LWIR), Video camera module working in spectral range of 0,38-0,78 µm (VIS), Control Unit (MS-SOE-10), Power Unit. The Optoelectronic System SOE-10 is schematically shown in Fig. 4.

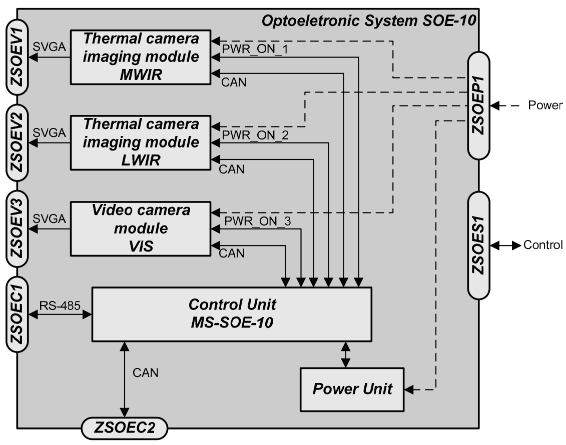

Fig. 4. Block diagram of Optoelectronic System SOE-10

In the construction of a high-resolution thermal imaging camera one can distinguish the following basic components: the lens (specially designed for the infrared range), infrared-sensitive focal plane detector array, control and digital image processing module, power unit and a display module. The general diagram of the thermal imaging camera is shown in Fig. 5. The most important and most technologically advanced element in a thermal imager is a focal plane array of infrared detectors. In the Optoelectronic System SOE-10 there are two thermal imaging cameras with different detector types for two spectral ranges MWIR and LWIR. Both of them consist of 640 × 512 detector array. Thermal resolution of camera has a value of less than 0.025°C (for MWIR) or 0.04°C (for LWIR). These parameters ensure the long-distance detection of approaching airplanes.

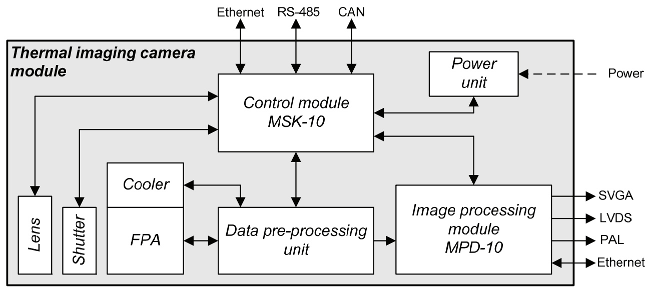

Fig. 5. General scheme of the thermal imaging camera with most essential components indicated

Each camera in the SOE-10 has three separate connectors: power connector, monitor connector for image transmission in SVGA standard and control connector. The camera is controlled via RS-485 based serial interface developed in the Military University of Technology (MUT) with the use of proprietary communication protocol. With use of the control protocol an operator can remotely control infrared camera operation, and thanks to the protocol properties, it is possible to control several camera systems connected to the same bus. In order to reduce the complexity of the electronic design, an unified control module MSK-10 and image processing module MPD-10 were used in each of the cameras. MPD-10 and MSK-10 modules together form a technologically advanced thermal imager electronic subsystem.

Control module MSK-10 and image processing module MPD-10 were built based on two basic components: programmable logic device and microcontroller device. Programmable FPGA circuit realizes the image processing algorithms that demand high computational power [5, 6]. Its basic tasks include: generating the image control signals to the infrared focal plane array readout circuit, execution of non-uniformity correction for every individual detector in the array, defective pixel signal correction, generation of VGA compliant signals and timings for external video interface. A microprocessor performs all operations associated with controlling the unit and other operations that have relatively low computational demands.

Based on the analysis of commercially available microcontrollers, a STMicroelectronics STM32F407 microcontroller was the integrated circuit of choice. This microcontroller represents the family of 32-bit ARM processors. As a FPGA device an EP4CE15F23 ALTERA Cyclone IV family FPGA was used. This set of components provides the required processing performance yet demanding relatively low power.

a) b)

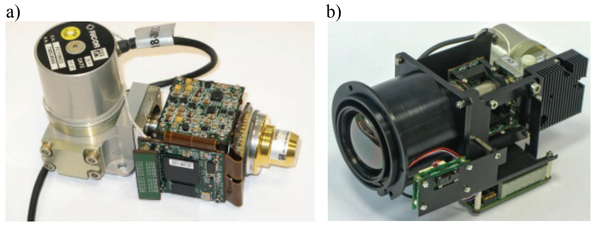

Fig. 6. a) Photo of Pelican D detector from SCD company, b) detection unit assembly for MWIR camera

MWIR camera module is an observational infrared camera unit working in a range of 3-5 µm. MWIR camera module includes the following main elements: Pelican D detector system from SCD company with K508 cooler and electronic systems, lens system 19-275 mm F/5.5 type 65196 from OPHIR company, control module MSK-10, image processing module MPD-10.

Control module MSK-10 controls the Camera Assembly for MWIR via Video Processing Board (VPB) to ensure communication with Pelican D detector. Control module MSK-10 also has to ensure communication and control of objective lens system that has a variable and electronically controllable focal length 19-275 mm and a constant *f*-number of 5,5. Communication takes place via RS-485/422 Full Duplex interface.

Photography of the assembly for MWIR camera is shown on Fig. 6.

LWIR camera module is an observational infrared camera unit working in a range of 8-12 μm. LWIR camera module includes the following main elements: focal plane array detection system type CMT 640×512 LWIR with K508 cryogenic cooler with electronic boards, lens system with two switchable FOVs of F#/2,05 from PCO S.A. company, control module MSK-10, image processing module MPD-10.

a) b)

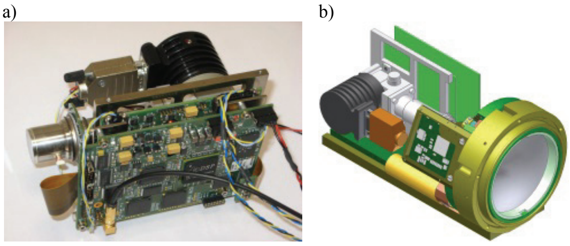

Fig. 7. a) Photo of LWIR detector from AIM company, b) image of CAD design of LWIR camera module prototype

Detection module working in LWIR spectral range was built based on the focal plane array from AIM company (Germany) (Fig. 7). This cooled focal plane array have the arrangement of 640×512 detectors, where a single detector has a size of 15 μm. Control Module MSK-10 controls LWIR detection system via L-HPVIP and CCE4K modules. Additionally MSK-10 system ensures communication with a mechatronic system moving optical elements in a specially designed lens system.

VIS camera is an observation device working in visible light spectrum 0,38 ÷ 0,78 μm. VIS camera module consists of: VIS camera assembly with FCB-EX1010P camera module from SONY company, control module MSK-10, image processing module MPD-10. The control module MSK-10 controls the VIS camera assembly through RS-232 communication interface.

4. Infrared cameras parameters measurement and determination

A characteristic feature of the infrared focal plane detector array is a non-uniform response (in terms of electrical signal) of the detectors to the same incident infrared radiation. Non uniform response of the focal plane to the uniform radiation flux is caused by the technological imperfection of detectors and the readout circuit. Therefore, it is necessary to compensate for it by applying the NUC procedure (Non-Uniformity Correction) [1, 2], which incorporates digital processing techniques for detector characteristics correction. Correction factors are calculated based on previously recorded response signals of detectors for several values of the incident radiation flux, done on a laboratory controlled calibration stand. Moreover each detector array has defects that make some of the detectors in the array a faulty ones. Faulty detectors are called defective pixels (or bad pixels). Defective pixels are detected most often during camera calibration. Determination of parameters and NUC coefficients was made on a special laboratory bench.

Determination of most crucial parameters of infrared camera system was carried out in Certified Laboratory in Institute of Optoelectronics MUT on a dedicated METS-S-12 measurement stand. Measurement stand consists of infrared collimation system, reference infrared source, rotating disk with a set of tests, a computer with a video card and specialized controller software (Fig. 8).

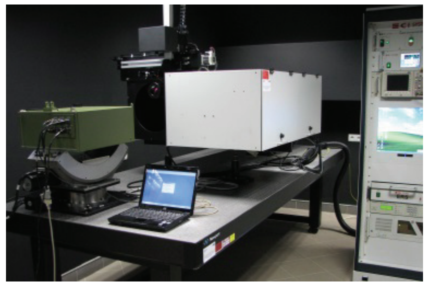

Fig. 8. Photo of the testbench for infrared camera parameters determination (Laboratory of Institute of Optoelectronics MUT)

On the test bench measurements of the following parameters of the camera were carried out: Modulation Transfer Function MTF, Signal Transfer Function SiTF, Minimal Resolvable Temperature Difference characteristics MRTD and 3D noise parameters evaluated with well-established methodology proposed by Webb [7] and adopted in accredited laboratory at MUT [8]. One of the most important parameters for observation systems is the characteristics of MRTD determined in accordance with the procedure laid down by the standards of NATO STANAG 4349.

Based on elaborated MRTD characteristics theoretical ranges were estimated for detection, recognition and identification of a standard NATO target according to STANAG 4347 norm. Estimated results are put together in Tab. 1.

Tab. 1. Theoretical ranges for detection, recognition and identification of a standard NATO 3×4 m target

Parameter	Value
Detection range	17000 m
Recognition range	6800 m
Identification range	3400 m

5. Infrared cameras parameters measurement and determination

Field tests of the entire optoelectronic system were carried out on a military airport. On the control tower a setup of communication antennas was placed while in one of the control rooms a workstation with MT-10W module was installed. One of the monitors was displaying image from the selected infrared or video camera with the use of different image representation methods and image processing techniques [4].

Designed landing assistance camera system was installed in the axis of the runway (75 m before the runway threshold), in proximity to MT-10Z communication module and to mast with two WiFi antennas for data transmission.

For observation targets two airplane types were chosen: training aircraft PZL-130 Orlik and passenger-transport aircraft PZL M28 Bryza. Infrared and visible light images for aircrafts approaching airport were recorded on Flight Control Manager workstation on the airport control tower.

During the test, there was a haze limiting optical visibility to approximately 1.5 km and cloud level was low (approx. 200 m). Despite the limited optical visibility, by using the thermal cameras the control tower staff could observe the planes from the distance of 8 to 10 km. LWIR camera (spectral range: 8 μm to 12 μm) presented better image quality allowing to distinguish crucial airplane components like flaps and landing gear. With this camera planes were detected from the distance of about 12 km from the runway, and the evaluation of landing gear condition and flaps position was possible from the distance of about 4 km. MWIR camera (spectral range: 3 ÷ 5 μm), in same testing conditions, offered shorter detection distances. Aircraft was detected from about 10 km distance to the runway, and the evaluation of landing gear condition and flaps position was possible from the distance of about 2 km.

The worst results were obtained with a VIS camera. In that case planes were detected from the distance of about 3 km from the runway. Exemplary images recorded during testing with a short description are shown in Fig. 9 and Fig. 10.

a) b) c)

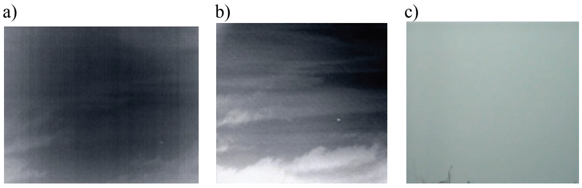

Fig. 9. Exemplary images recorded during observation of ORLIK airplane from the distance of 8 km with use of a) MWIR camera, b) LWIR camera, c) VIS camera

a) b) c)

Fig. 10. Exemplary images recorded during observation of BRYZA approaching runway from the distance of 2 km: a) MWIR camera, b) LWIR camera, c) VIS camera

6. Summary

Developed, manufactured and tested system is an innovative and original solution, which uses the latest technology of high resolution infrared focal plane photon detector arrays.

Obtained results clearly indicate that the state of the art level of technology has been achieved in the field of optical design and manufacturing technology, precision mechanical engineering, advanced electronics and software, in particular in developing new methods of real-time processing of infrared image data.

The system was tested in practical operation at the airport, where it was proven to be useful especially in difficult weather conditions. Despite the limited optical visibility (about 1.5 km) the use of thermal imaging cameras allowed the flight control crew to observe airplane thermal picture at significantly longer distances of 8-10 km. We have concluded that with proper adaptation the solution could enable the direct control and guidance of an aircraft approaching runway from distance of min. 10 km. Additionally, the detailed observation of a landing gear from the distance of approx. 3 km is possible regardless the weather conditions what is an unique safety feature.

The developed system can be used both for military airfields and civil airports. The system informs the flight manager if the plane is in the axis of the runway, what is the approximate distance and whether it is at the correct height and proper glide slope.

All elements of the system supporting the landing of planes have been examined in a laboratory and during the field testing. The results confirmed the expected theoretical technical parameters and correct operation of the system in real conditions.

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