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Parameters evaluation of cameras in embedded systems

***Abstract**. The article presents a comparison of micro cameras for video data acquisition. The tested cameras can be used in conjunction with embedded systems, in particular in the system for detecting mechanical damage of airport lamps. The work verified the compatibility of operation with microcomputers: Raspberry Pi 4B, Google Coral, NVIDIA Jetson Nano and NVIDIA Jetson Xavier AGX and cameras: Raspberry Pi Camera HD v2, Waveshare 16579, IMX477 and Logitech C922. Tests were performed under laboratory conditions based on an ISO 12233 standard test chart.*

***Streszczenie.** W artykule przedstawiono porównanie mikrokamer do akwizycji danych wizyjnych. Testowane kamery mogą zostać użyte w połączeniu z systemami wbudowanymi, w szczególności w systemie do wykrywania uszkodzeń mechanicznych lamp lotniskowych. W pracy sprawdzono kompatybilność działania z mikrokomputerami: Raspberry Pi 4B, Google Coral, NVIDIA Jetson Nano i NVIDIA Jetson Xavier AGX oraz kamery: Raspberry Pi Camera HD v2, Waveshare 16579, IMX477 i Logitech C922. Testy przeprowadzono w warunkach laboratoryjnych, w oparciu o standardową tablicę testową ISO 12233. (**Ocena parametrów kamer wizyjnych w systemach wbudowanych**).*

Słowa kluczowe: systemy wizyjne, systemy wbudowane, przetwarzanie obrazu, ISO12233
Keywords: vision systems, embedded systems, image processing, ISO12233

Introduction

The development of embedded systems enables advanced analysis of video sequences in real time. It is possible due to the techniques of TinyML (Tiny Machine Learning) [1] that it allows to transform machine learning into a domain of small devices limited by efficiency and power. Harnessing the potential of this field requires a thorough knowledge of applications, algorithms, hardware, and software. In the case of video signals, it is adequate to use relatively high-performance modules, which will be presented in the article.

Vision systems with cameras that enable the acquisition of video data are installed in cars and autonomous vehicles [2, 3], in city monitoring [4], but also in specialized applications, such as created by the author a measurement platform for quality testing of airport lamps [5]. This device enables the measurement of the luminous efficiency of each of the in-pavement lamps on the airport areas and evaluates their wear. The system classifies then the lamp as either unusable or needing to be replaced. The luminous efficiency is reduced due to unfavorable weather conditions and the day-to-day operation of the runway and taxiways (in particular by clearing snow from airport areas).

Additionally, each time it is necessary to check the mechanical damage of airport lamps and their prisms. This very often determines the repair method (lamp, prism or bulb replacement). Fig. 1 shows a comparison of a damaged lamp (left) and a new in-pavement lamp (on the right) installed on airport areas, together with an approximation of the prisms in Fig. 2.

Fig.1. Runway center line lamp - damaged (left) and new (right)

Fig.2. Runway centerline lamp prism - damaged (left) and new (right)

Vision system for mechanical quality lamp testing

The implementation of the system for the classification of mechanical damage to airport lamps and prisms requires obtaining high quality and detailed visual sequences. These cameras provide input data to the microcomputer, which analyzes texture and classifies a given lamp. The principle of the system operation is presented in Fig. 3.

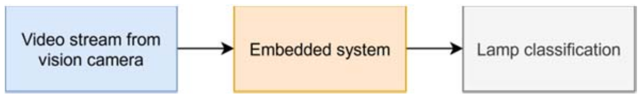


Fig.3. The principle of operation of the system for the classification of mechanical damage to airport recessed lamps

Embedded systems allowing the analysis of data from cameras enable obtaining satisfactory results and relatively low purchase cost compared to the use of traditional computing units [6, 7]. The following can be used in embedded system: Raspberry Pi 4B, NVIDIA Jetson Nano, NVIDIA Jetson AGX Xavier and Google Coral. These systems enable connection with visual cameras both via the MIPI CSI-2 and USB interface. The comparison of the features of individual interfaces is presented in Table 1 [8].

Table 1. MIPI Camera vs USB Camera – a feature by feature comparison

Features	MIPI CSI-2	USB 3.0
Availability on SoC	Many (Typically 6 lanes available)	On high -end SoCs
Bandwidth	320 MB/s/lane 1280 MB/s (with 4 lanes)	400 MB/s
Cable Length	< 30 cm	< 5 meters
Space Requirements	Low	High
Plug-and-play	Not supported	Supported
Development Costs	Medium to High	Low

To compare the cameras, a standard ISO 12233 test chart [9] was used, which allows to determine the resolving power of the camera matrix and / or its lens in laboratory conditions. It is one of the most photographed objects in various tests of photographic equipment. The view of the chart is shown in Fig. 4.

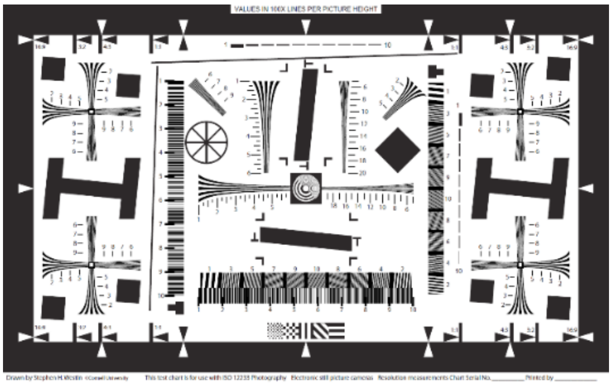


Fig.4. ISO 12233 Standard Test Chart

The smooth change in the thickness of the test field lines allows to precisely recognize the border at which the lens (plus the matrix) cease to recognize details. The resolution is defined in lines per picture height (lph), which means that if the most densely distributed but still recognizable lines of the test field lie at the number 16, then 1600 lines can be recognized along the entire height of the horizontal frame. The vertical and horizontal resolutions are usually not identical, and the smaller of the readings is taken as the test result. To determine the score, it is necessary to develop them, converting the highest result achieved in the frame center to a 1-megapixel matrix. This conversion means dividing the result by R, where R is the number of millions of image points in the camera used for the test. Thanks to this operation, it is possible to easily refer to each other the image resolution obtained in cameras with sensors of different resolution. This conversion allows to assess how the lens and camera work together or the use of a camera with a higher resolution of the matrix will result in a correspondingly higher resolution of photos, etc.

Embedded systems for processing vision sequences

As part of the work and tests, it was decided to check the compatibility of the cameras with microcomputers in the form of Raspberry Pi 4B (Fig. 5), Google Coral, NVIDIA Jetson Nano and NVIDIA Jetson Xavier AGX. These systems are often used in machine learning as central units of autonomous cars [10] and in detecting events with the use of neural networks [4].

Fig.5. Raspberry Pi 4B microcomputer

The Raspberry Pi 4B has a Broadcom BCM2711 64-bit Quad-Core ARM Cortex-A72 processor clocked at 1.5 GHz and ARMv8-A architecture. The model used was equipped with 8 GB of LPDDR4 RAM.

Google Coral (Fig. 6) is equipped with a SOM chip, which includes eMMC memory, an integrated circuit based on NXP i.MX 8M (Quad-Core ARM Cortex A53 + ARM Cortex M4F, wireless communication and a Google Edge TPU accelerator coprocessor. It has 1 GB of RAM and 8 GB of eMMC memory.

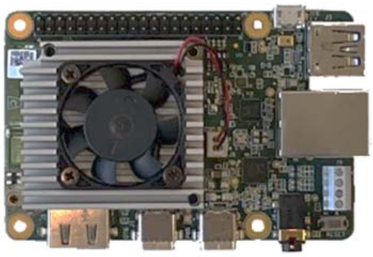


Fig.6. Google Coral microcomputer

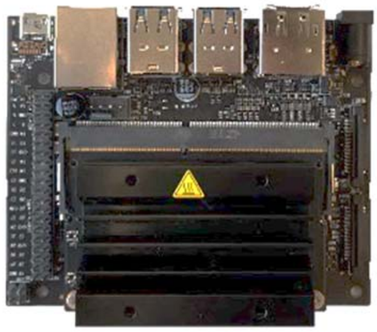


Fig.7. Nvidia Jetson Nano 4GB microcomputer

The third microcomputer is an NVIDIA Jetson Nano (Fig. 7). This device has a quad-core ARM A57 processor clocked at 1.43 GHz and 2 GB of 64-bit RAM LPDDR4. NVIDIA Jetson Nano is also equipped with a 128-core Maxwell graphics processor clocked at 921 MHz. This unit, in comparison with the Raspberry Pi 4B, has much greater possibilities of performing operations based on graphics processors, which is of great importance in the case of algorithms using machine learning. Depending on the model of neural networks used, the performance of NVIDIA Jetson Nano may be up to three times greater in this comparison [11].

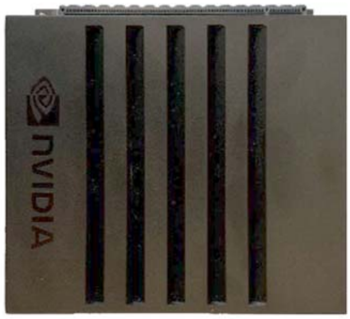


Fig.8. NVIDIA Jetson Xavier AGX Developer Kit 32GB microcomputer

The NVIDIA Jetson AGX Xavier (Fig. 8) is the most powerful embedded device in the comparison. It has an octa-core, 64-bit ARM®v8.2 processor with 8 MB L2 cache and 4 MB L3, NVIDIA Volta ™ GPU with 512 cores and 64 Tensor cores, two NVDLA engines, 32 GB 256-bit LPDDR4x memory and 32 GB of mass storage.

Micro cameras dedicated to embedded systems

During laboratory tests, 4 cameras were tested, the characteristics of which are presented below.

Camera modules are equipped with IMX219 sensor (Fig. 9) with a resolution of 8 MPx and a viewing angle of 62.2° (a) or 160° (b). The cameras allow to record video sequences in the following modes: 1080p30, 720p60 and

640×480p90. Both cameras have a CSI connector. Despite having an identical sensor, the camera (b) is not compatible with the Raspberry Pi 4B and Google Coral microcomputers. Relevant libraries have been made available for servicing them via devices from the NVIDIA Jetson family [12].

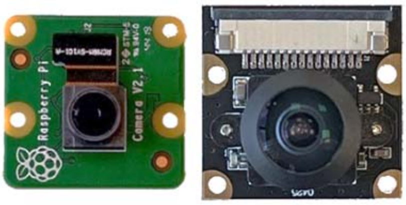


Fig.9. Raspberry Pi Camera HD v2 with a viewing angle of 62.2° (a) and Waveshare 16579 160° (b)

Fig.10. Camera IMX477 with 6mm CS-Mount lens

The camera in a protective, metal housing is equipped with an IMX477 (Fig. 10) sensor 12.3 MPx in the format 1/2.3" with a maximum image resolution of 4056×3040 px. It has a lens with a focal length of 6 mm. To connect the camera CSI - HDMI adapter was used for microcomputers It enables recording in two main modes: 60 fps in full 4k2k resolution and 60 fps in 1080p [13].

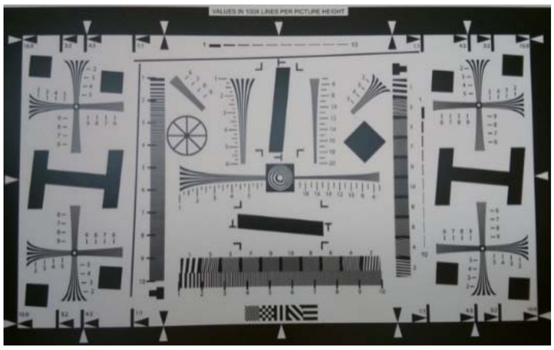
Logitech C922 camera (Fig. 11) with max resolution: 1080p / 30 fps and 720p / 60 fps and a viewing angle of 78º. The camera is operated via the USB interface.

Fig.11. Camera Logitech C922

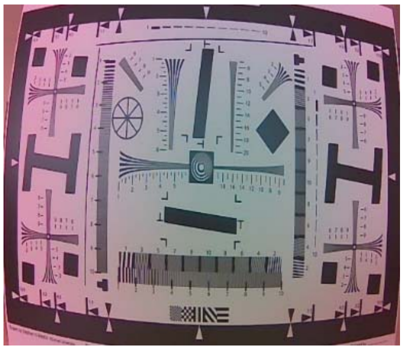
Comparison of micro cameras quality

As part of laboratory tests, a series of photos and recordings of video sequences were made on the basis of a standard ISO 12233 test table. An Aputure Amaran 100x studio lamp with the Godox QR-P90 parabolic softbox was used to obtain uniform illumination. The cameras were positioned at an appropriate distance so that it was possible to investigate the distortion of the lens and the detail of the image. A subjective assessment of the acquired resolutions for individual settings and selected areas (e.g., in the center and peripheral areas) is presented in the next part. Fig. 12 shows a comparison of images obtained from the tested micro cameras. Fig. 13 presents a comparison of the detail of the selected fragment of the obtained image.

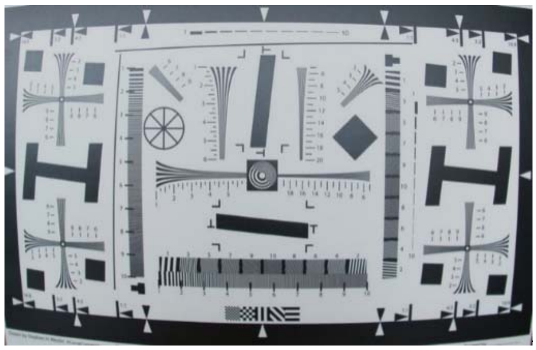
The worst effects of the tested cameras were obtained when using the wide-angle lens in the Waveshare 16579 camera and the viewing angle of 160° (Fig. 12 B). It is characterized by good sharpness and quality in the frame center. Outside of it, however, the image becomes unreadable, there is high vignetting in the photo. In addition, the camera takes reddish photos in daylight due to the lack of an IR filter in the CCD (charge-coupled device), but for this reason the camera sees in the dark due to the IR LEDs. The use of this camera in a system that requires high image detail seems to be inadequate.



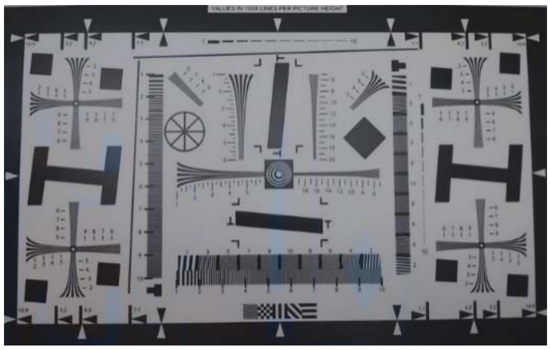
A. Image from Raspberry Pi Camera HD v2



B. Image from Waveshare 16579 camera



C. Image from Camera IMX477 with 6 mm CS-Mount lens



D. Image from Logitech C922 camera

Fig.12. Comparison of ISO 12233 standard test chart images obtained with tested cameras

Table 2. Comparison of EXIF data from the obtained images of the tested cameras

Camera model	Raspberry Pi Camera HD v2	Camera Waveshare 16579	Camera IMX477 with 6mm CS-Mount lens	Camera Logitech C922
Color space	RGB	RGB	RGB	RGB
Color profile	sRGB IEC61966-2.1	sRGB IEC61966-2.1	sRGB IEC61966-2.1	sRGB IEC61966-2.1
Focal length	3 mm	6 mm	6 mm	3,7 mm
Aperture value	f/2.0	f/2.35	f/2.0	f/2.0
Exposure time	1/64	1/64	1/64	1/64
ISO	50	50	50	50

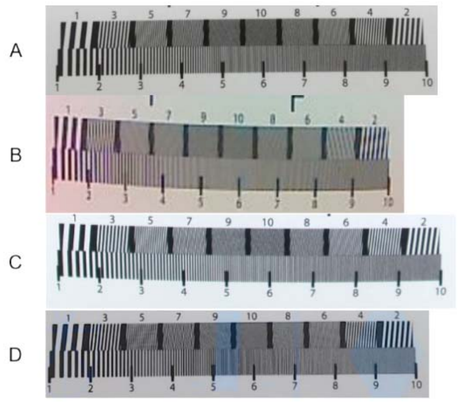


Fig.13. Comparison of image fragments of test charts obtained with the tested cameras

The Logitech C922 camera obtained a satisfactory result, but due to its construction and purpose (webcam camera) it is not possible to configure it fully manually. During the tests, satisfactory results were obtained several times, but they were not fully reproducible (Fig. 12 D).

The Raspberry Pi Camera HD v2 presents an image with high quality and detail (Fig. 12 A). In addition, it allows to fully adjust the parameters of the camera. The tested module is most often chosen by users due to its very simple and intuitive installation, but its design does not allow the use of universal lenses.

The IMX477 camera with 6 mm CS-Mount lens achieved the best result for the applications mentioned in this article. The resulting image is shown in Fig. 12 C. The design of this solution enables the use of professional DSLR lenses, such as the Canon EOS EF line, thus enabling its individual adaptation to the needs of the system that tests mechanical wear of airport lamps. In addition, the camera has a tight and resistant housing and allows connection via HDMI interface with a converter to CSI. This solution significantly facilitates the installation of the camera in the measuring platform for quality testing of airport lamps.

Summary

The article presents the possibilities of using various vision micro cameras that can be used with various embedded systems. As a result of the tests, it should be stated that the best results in the form of image detail were obtained by the Raspberry Pi Camera HD v2 and the camera IMX477 with 6mm CS-Mount lens.

In addition, the advantage of the IMX477 camera is its construction and the possibility of using lenses with a standard mount, the latter of the above-mentioned cameras gives much greater possibilities of adapting it to use in a measuring platform for quality testing of airport and in the area of mechanical damage control of airport lamps.

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