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Computer Vision Based Leakage Detection System Dedicated for Use in Aviation Component Test Laboratories

Abstract. *Oil is used for lubrication and cooling in every standard jet engine. Therefore, hydraulic installations are one of main parts of most of component test rigs and in some cases, they could be large and complicated. Removing sources of leakages is significant task for engineers and technicians. Oil leakages generate costs, reduce reliability of tests and are difficult to detect with use of classic sensors. This paper describes implementation of computer vision methods in the aviation component test laboratory. Three algorithms were proposed and successfully tested.*

Streszczenie. *Olej jest wykorzystywany do smarowania i chłodzenia w każdym silniku odrzutowym. Z tego względu instalacje olejowe są jednymi z głównych części stanowisk badawczych, a usuwanie przyczyn wycieków jest znaczącym zadaniem inżynierów i techników. Wycieki oleju generują koszty, ograniczają wiarygodność testów i są trudne do wykrycia przy pomocy klasycznych czujników pomiarowych. Dokument opisuje implementację metod widzenia maszynowego w lotniczych laboratoriach badawczych. W ramach prac zostały zaproponowane i przetestowane trzy algorytmy.* ***(System detekcji wycieków oparty na widzeniu komputerowym przeznaczony do stosowania w laboratoriach badań komponentów lotniczych)***

Keywords: aviation, laboratories, Computer Vision, leakage detection
Słowa kluczowe: lotnictwo, laboratoria, widzenie komputerowe, detekcja wycieków

Introduction

In the aircraft engine, oil has a significant role and is responsible not only for lubricating the rotating elements, but also for their cooling [1]. Furthermore, the quality of the oil and its degree of contamination are the sources of information about the level of components wear. The results of periodical tests of oil are used to define repair and further operation plan [2]. In most cases, even a few seconds of cutting off the oil supply to the rotating elements cause damage that can lead to a dangerous situation. The test rigs must simulate actual operating conditions of the tested components as closely as possible, therefore oil systems are important parts of the infrastructure of most test stands (Fig. 1). Oil systems are one of the most complicated installations used during component testing. Oil lines are made of hoses, metal pipes, pumps, heaters, nozzles, valves and many connectors, so the risk of leakage in connection points is quite high. If the pressure accidentality cross the limits for the components or the temperature is too high it could cause cracks on the connectors and oil supply hoses or damage the seals. The basic way to prevent leakages on the component test rig is to monitor the oil level in the tank located at the beginning of the oil system. However, the oil level changes during test as a result of following test points. Depending on the type of test, oil could accumulate in the test head, supply lines, scavenge lines and pumps. In some cases, oil is intentionally diverted to measurement tank standing on a scale to determine the mass flow on individual sections of the test head.

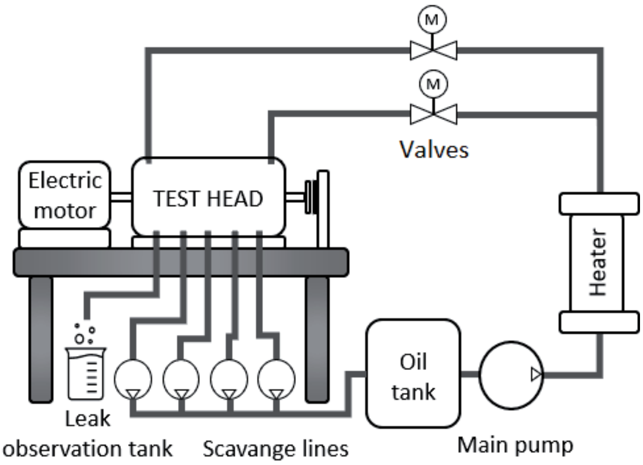

Fig. 1. Simplified diagram of oil system used in bearing test rig

When the alarm levels of oil in the main oil tank are set near the level corresponding to the standard operation of the test rig, it is quite easy to trigger the safety system carrying out the emergency shutdown procedure. This makes it necessary to extend the ranges of alarm limits, which results in a decrease of leakage detection sensitivity. In some component tests oil flow measurement have to be performed with high accuracy and even small oil leakage is unacceptable, which disqualifies oil level measurement as an accurate method of diagnosing failures. Despite the difficulties with automatic detection of typical leakages (Fig. 2), they are identified with quite high efficiency by the test operator during short tests. The biggest problem occurs during long-term test campaigns performed according to the test program without operator supervision. During that type of research test rig simulates work cycles to check durability of components [3, 4]. For bearings it could be more than 30000 test cycles where rotational speed, load and oil flow are changed the same way as it is performed in real engine during take off, cruise and ground idle conditions. Such conclusions were the basis for research on the implementation of a leakage detection system using computer vision. The main goal of the research is to help laboratory teams in supervision of long test campaigns and increase the safety and comfort of testing. There are some computer vision based leakage detection systems on the market. Most of them are based on analysis of thermal imaging and machine learning [5]. Typically they are quite complicated systems which needs training on the base of leakage pictures and expensive hardware. Solutions proposed in this paper are possible to implement by an intermediate programmer. All proposed functions could be

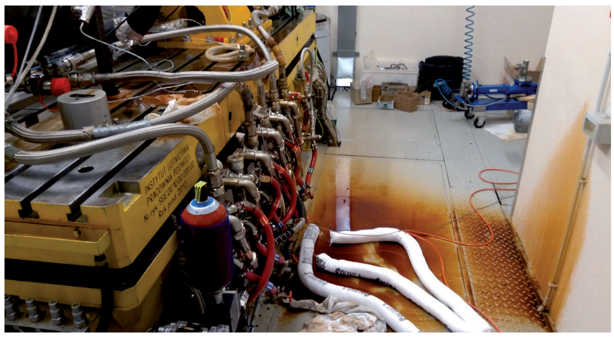

Fig. 2. Example of oil leakage in component test laboratory

implemented with less than 1000 lines of code and not expensive camera, so the potential benefits are very high in comparison to the efforts. Self implemented leakage detection algorithms may give better results in aviation laboratories because they could be prepared according to demands of specific test campaign. Computer vision may be used for leakage area and position detection, monitoring of self defined regions or drops counting for leakage volume estimation.

Methods

A. Design requirements and concept of the system

Analysis of various failures from the previous tests performed in component test laboratory helped to define set of requirements for computer vision system. Following requirements have been identified:

- ability to detect oil and cooling fluid leakage;
- detection of too low or too high level of oil;
- area and coordinates of leakage calculation (in pixels);
- visual indication of emergency states;
- change of output state in case of leakage detection;
- change of output state in case of change detection in the region of interest (e.g. in the effect of falling drop);
- real time operation of proposed algorithms.

A Raspberry Pi 4B computer and Arducam camera connected via a USB connector, were used to build a test stand for testing automatic leakage detection algorithms (Fig. 3). Camera use Sony IMX477 12.3Mpix image sensor (max resolution for photo) with 6mm CS-Mount Lens. The Open CV library and the Python language were used to analyze the image. Such a combination of hardware and software made it possible to quickly start research using the available functions for transforming the image from the camera [6, 7, 8]. The use of Raspbery Pi computer will also allow in future to use the designed smart leakage sensor as a part of safety system dedicated for use in laboratory.

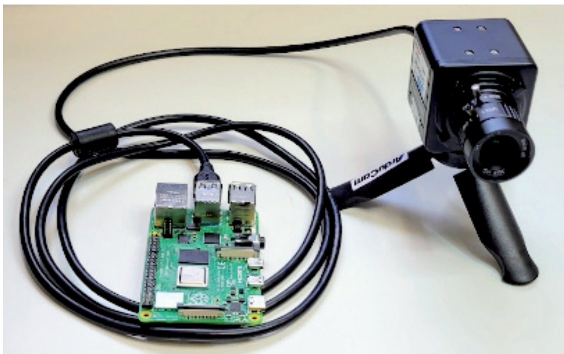

Fig. 3. Rasperry Pi and camera used in tests

In order to meet requirements shown above three computer vision algorithms have been designed, implemented and tested. First program detects leakage with use of canny edge detection, second base on observation of selected regions with triggering from mean colour value, the last also use mean colour triggering but with different approach to trigger level estimation which is needed for falling drops detection. Each of algorithms have different application, but together they could work in one system which could detect leakage, monitor changes in selected regions (e.g. critical level of oil) and detect falling drops (e.g. for size of leakage estimation). All tests were performed on movies registered by camera installed in the top corner of a test room to see test stand and floor or close to oil measurement cup.

B. Leakage recognition with edge detection algorithm

First algorithm based on an idea of finding leakage with use of contour detection (Fig. 4). In the beginning of a program run we store initial frame of movie. Next program enters to the main loop where initial and current frame are subtracted. The effect of subtraction shows what have changed from the time when the program was started [9]. When there is no difference the effect of subtraction is black image without any shapes. Unfortunately, small unwanted colours cha-

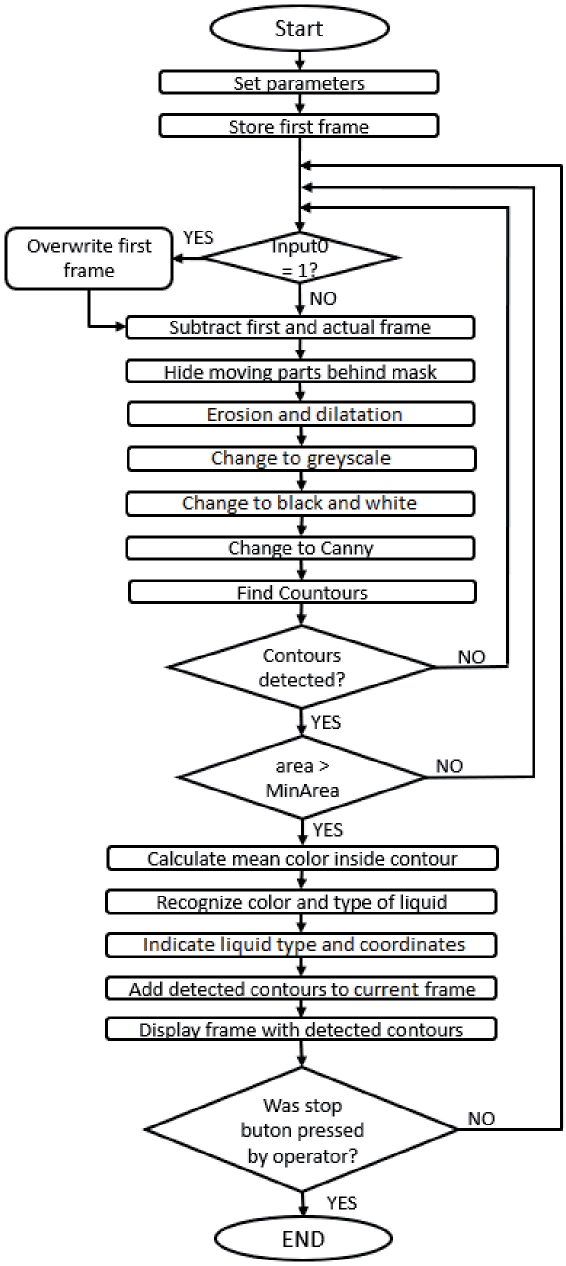

Fig. 4. Leakage detection algorithm

nges could occur, as a effect of camera vibration, light change or displacement and rotation of objects in test room. Therefore, special data processing and filtration had to be implemented. Moving and rotating parts have to be hidden to not trigger the system. To do that masking and boolean operation were implemented in the program. Every moving and rotating object is hide by the white shape in the mask prepared by the operator, and as a result is deleted from processing of an image frame. Image filtration starts from erosion and dilatation function.

Erosion function remove all small areas from the effect of subtraction, but it also reduces the area of bigger shapes like leakage stain. In order to restore the area of detected leakage image is processed with dilatation function. That function increases area off every object in a movie frame. Next, processed image is changed to greyscale and to black and white image with threshold. That form of image is convenient for Canny edge detection which is one of the most popular way of edge detection in Computer Vision [10, 11]. Image with edge detected was processed by implemented contour detection function (Fig. 5). That function is used also for calculation of area, center of leakage and colour inside detected contour. Only objects with area above defined limits are indicated and processed. Recognized mean colour of pixels in the center of detected shape is used for liquid recognition. Program works in a loop and it could be stopped by the operator. Initial reference image could be actualized by pressing the button in any moment.

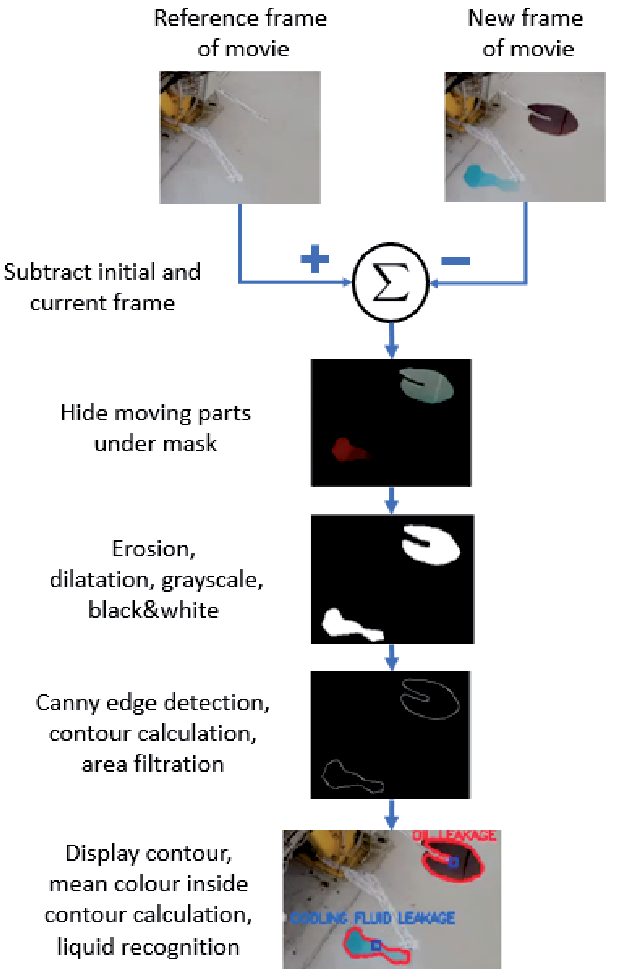

Fig. 5. Image transforamation during loop of the program

C. Change detection in regions of interest

Second algorithm enable control system to check the changes in specific areas defined before test (Fig. 6). That approach was proposed mainly for critical oil level detection. In the beginning, program sets parameters of selected areas according to user configuration. Next program enters to the main loop, and selected areas are shown to the operator in form of blue squares. When the operator presses the activation button program stores mean colour from selected areas (for further comparison) and change state to activated. In active mode of operation mean colours from initial frame are compared to actual mean colours in selected areas. If the program detects event and change of mean colour is above threshold, colour of square will be changed to red. It could be used as a trigger signal for emergency system in the laboratory and source of stop signal for test rig. Program works in a loop and it could be stooped by the operator. Initial frame could be actualized by pressing the button in any moment, as in previous algorithm.

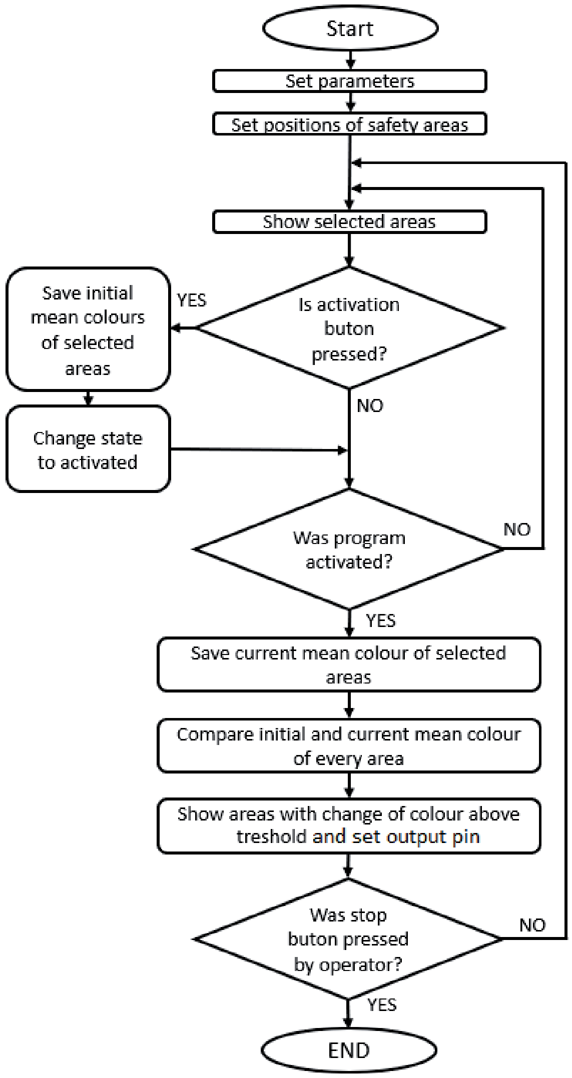

Fig. 6. Region of interest monitoring algorithm

D. Falling drops detection

Drops counting is well known method of leakage estimation in aircraft component testing. Computer vision could simplify that procedure by sending falling drop detection signal to another system. Program detects every drop which is crossing the selected region of interest. Operator have to select position of region on the way of falling drops in the same way as it was used for algorithm described in point C. The event is recognized by the change of mean colour value above threshold, which is calculated in real time based on mean value of configurable number of previous measurements. In the beginning of a research there were some attempts to use first algorithm based on edge detection, but the image of falling drop was not optimal for that type of processing. Drop on the image was blurred and sometimes it was visible as a line due to limited camera capabilities, as it is shown in the results of performed test (Results point C).

Results

A. Test of leakage recognition with edge detection

A series of algorithm tests were performed, where the input was an image from a camera, and the output was visualization with a marked leakage and coordinates displayed in the terminal (Fig. 7). As a result of the program, a preview window is displayed, which is simultaneously recorded to the file. The tests were performed on images from the camera in real time. Makeshift installation was constructed, which deliberately lead to the oil leak and coolant fluid on the floor. Program uses the colour of the liquid to distinguish the type of substance and calculates the leakage surface area and coordinates (in image pixels). The border is drawn around every detected leakage. Measurements are displayed in the terminal window. Results of performed tests show high effectiveness of tested algorithm.

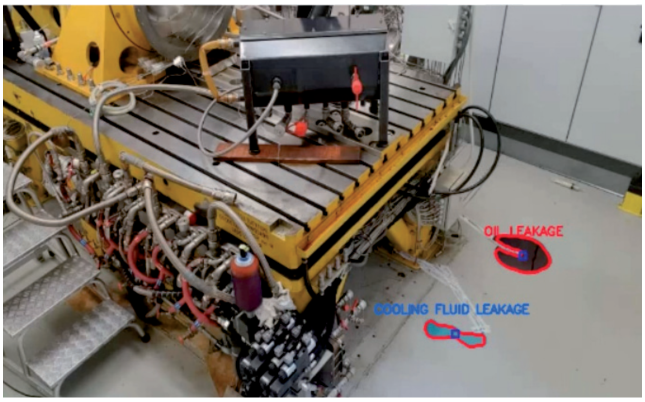

Fig. 7. Detected areas of leakages

B. Test of change detection in selected regions

The second program, is more interactive and requires pressing the key during the stable operation of test rig to store the current mean colours within the selected squares. Thanks to this, it is possible to detect changes in various conditions. The program was used as an oil level indicator. Both too high and too low oil level are monitored. To start monitoring operator have to select the regions of interest placement in alarm position of oil in the hose, and press the button when the oil is between these points. As soon as one of the levels is exceeded, the square changes colour from blue to red (Fig. 9). Thanks to this, it is possible to trigger an alarm to warn the operator about exceeding the level. The terminal window shows which area has been changed and its coordinates are given, in the same time output pin change its state.

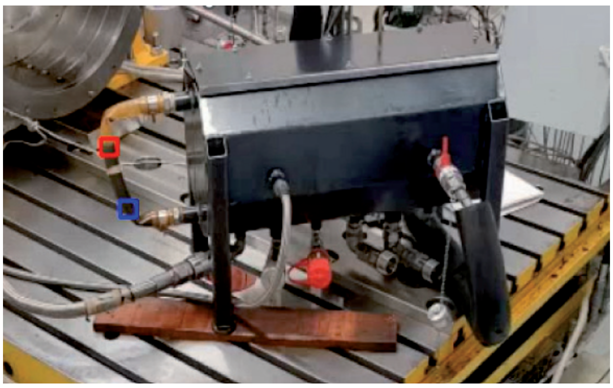

Fig. 8. Detected too high level of oil

C. Test of oil drops detection

In proposed test the output pin change its state during every drop detection. The signal is sent to oscilloscope and could be observed online or stored for further analysis. To check the operability of a program the simple test rig which could simulate the oil leak was proposed (Fig. 9). Drops drip into a glass transparent tank, as it happens in real component tests. The frequency of falling drops could be modified by the change of valve opening. As it was mentioned the shape of oil drop is not fully visible (Fig. 10). That effect probably could

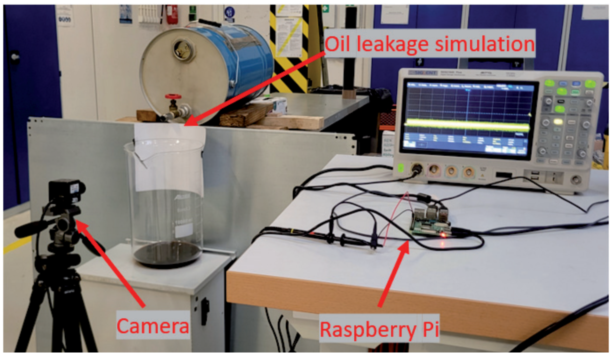

Fig. 9. Test setup prepared for oil drops detection test

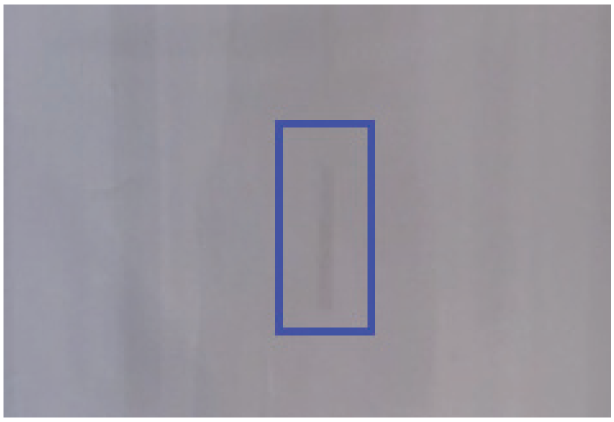

Fig. 10. Falling drop visible on an image from a camera

be reduced by faster camera with higher resolution. Most of object counting methods described in the literature use edge detection but in tested setup proposed solution based on mean colour monitoring gives better results. Due to limited camera capabilities and variable light conditions the change of mean colour in the region wasn't the same in every event, so it was hard to define the constant threshold value for all

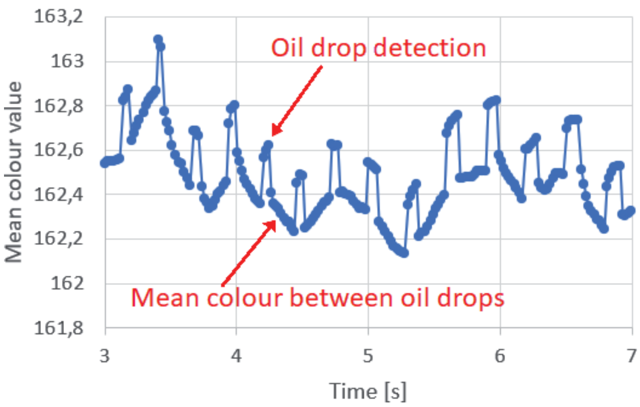

Fig. 11. Change of mean colour in region due to falling oil drop

situations (Fig. 11). That issue was solved by implementation of function which calculate the mean value of colour from selected number of previous data points to estimate threshold value in real time. Threshold value is always set to higher value than calculated mean value. As a result, output pin changes state when the drop is crossing the selected area (Fig. 12).

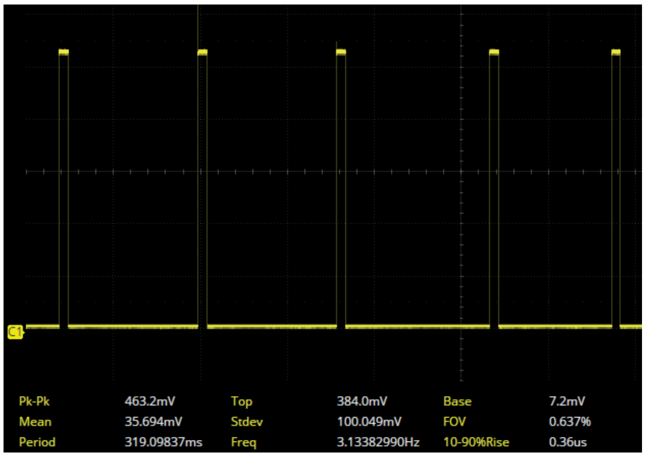

Fig. 12. Output signal from Raspberry Pi observed on oscilloscope

Future use of the system

The results of the conducted research contributed to the application of designed smart leakage sensor as a part of a new test rig instrumentation in Łukasiewicz Research Network - Institute of Aviation. The main goal of prepared test is to find correlation between parameters like temperature, flow or pressure and leakage measured in drops per second from sections of a test head. The drops in time counting is the main and most important measurement in the test campaign. Other solutions like weighting the oil mass with precise scale have been rejected because of too high temperature and too low pressure in the place of potential sensor placement. The oil leakage during test is also too small to be measured by the change of oil level in the tank. Oil drops will be detected through a glass cup (Fig. 13) installed under pressurized tank which is a part of new test rig. Moreover, first tested algorithm based on edge detection could be used to monitor unexpected leakage on the whole test rig. Test need high accuracy of oil flow control on the input and output of the test head so there is no place for any unexpected leakages. Every leakage could reduce reliability of a test campaign and lead to incorrect conclusions.

Fig. 13. Measuring cup used for oil drops detection

Conclusions

This paper describes implementation of computer vision methods in the aviation components test laboratory. Three algorithms were proposed and successfully tested. First implemented procedure could enable control system to detect oil and cooling fluid leakages with use of image processing and Canny edge detection. Conditions for that approach are optimal because there is no access to the test cell when the test is operating which cause constant view from a camera. Second program could be used to monitor changes in selected regions e.g. critical oil level through sight glass. Third algorithm was used for automatic oil drops detection and can be used for leakage volume estimation. Performed tests show high effectiveness of proposed procedures. Output of the system could be connected to the main data acquisition system of the laboratory and can be used as a trigger of the safety system. Proposed set of computer vision procedures will be used during one of ongoing test campaigns in Component Test Laboratory in Łukasiewicz Reserach Network - Institute of Aviation. In future upgrades of the system it will be also possible to transmit information about leakages, changes in selected regions and oil drops detection wirelessly through Bluetooth Low Energy or WiFi. Performed research shows wide range of possibilities for use of computer vision in aviation component test laboratories.

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