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NLR-TP-2017-540 | July 2018

Camera-based imaging flight test instrumentation

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Camera-based imaging flight test instrumentation



Problem area

Helicopter flight tests require real-time acquisition of on-board aircraft parameters. Cost-effective flight test instrumentation and equipment is asked for that can be adapted to multiple helicopter types. Per helicopter type the flight test campaign typically lasts one or two days, so expensive safety assessments and integration issues shall be avoided.

Description of work

On-board carry-on instrumentation composed of commercial of-the-shelf components has been developed. A novel technique has been applied accomplishing real-time acquisition of aircraft parameters by means of a video camera. An image processing software application has been developed to acquire the aircraft parameters in engineering units from images of the flight instruments captured by the video camera. The acquired parameters include indicated airspeed, vertical speed, altitude and main rotor rpm.

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Results and conclusions

Flexible and cost-effective measurement equipment and image processing software have been developed. The system has been used in four helicopter types in the Netherlands, and four different types in Spain. Successful test flights with real-time data acquisition have been performed.

Applicability

The range of application of camera-based instrumentation includes real-time acquisition of flight instrument readings. Camera-based instrumentation can be applied in many situations where instruments and displays are available for observation. By means of a video camera and image processing software parameters in engineering units are extracted in real-time.

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GENERAL NOTE

This report is based on a presentation held at the 28th symposium of the Society of Flight Test Engineers - European Chapter, Milan Italy, September 14, 2017.

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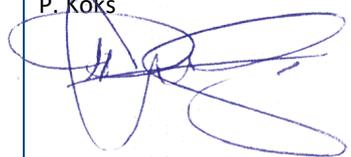
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Summary

To accomplish helicopter flight tests for the purpose of noise measurements, an on-board carry-on measurement system has been developed that can be flexibly adapted and installed in different types of helicopters. The main functions of the on-board system are to collect and store flight data, and to show a real-time guidance display to the flight test engineer.

The measurement system includes a GNSS receiver providing time synchronisation, aircraft position and velocity parameters, and an IMU providing linear acceleration and angular rate parameters, and aircraft attitude parameters. In addition, aircraft parameters that are visible on the cockpit instruments are acquired. The aircraft parameters include indicated airspeed, vertical speed, altitude, and main rotor rpm.

As a non-intrusive alternative for interfacing to aircraft systems, a novel method has been applied in order to acquire data from the cockpit panel. The method uses a video camera and imaging software. This paper describes the on-board system, with the emphasis on the aspects of development of camera-based flight test instrumentation. It is concluded that the use of a video camera and imaging software is a practical approach and a valuable method of non-intrusive data acquisition.



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Abbreviations

ACRONYM	DESCRIPTION
ALT	Altitude
CPU	Central Processing Unit
fps	frames per second
FTE	Flight Test Engineer
FTS	Flight Track System
GB	Giga Byte (2^{30} bytes)
GigE	Gigabit Ethernet
GIMP	GNU Image Manipulation Program
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
Hz	Hertz
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IDE	Integrated Development Environment
I/O	Input/Output
NLR	Netherlands Aerospace Centre
NR	Main rotor rpm
PGU	Pilot Guidance Unit
PoE	Power over Ethernet
RAM	Random Access Memory
rpm	revolutions per minute
s	second
SBAS	Satellite-Based Augmentation System
TODS	Time Of Day in Seconds
IMU	Inertial Measurement Unit
VS	Vertical Speed

1 Introduction

In the second half of 2016, NLR in conjunction with Anotec successfully executed a campaign of flight tests with the object of collecting helicopter noise and performance data. The collected data will form the basis for the development and validation of a numerical model for helicopter noise emission, to complement the existing set of aircraft noise models. This work has been performed within the scope of the project “Service provision towards the development of a public European environmental suite for aviation”.

Based on an analysis of the European helicopter fleet, a total of eight different helicopter types have been tested during this campaign. NLR has tested Robinson types R22 and R66 at the NLR-heliport in Marknesse and Eurocopter types EC120 and EC135 at former Air Force base *De Peel* in the Netherlands.

In order to acquire the helicopter data, a carry-on measurement system was developed, which can be flexibly adapted to different aircraft. The system is non-intrusive to the aircraft and has no parts that need to be fixed outside the aircraft.

The data is acquired and processed by the carry-on system in real-time. The processed data is sent to a guidance application which supports the flight test engineer and the pilot to correctly perform the flight tests. For noise measurements, it is important that all parameters (speed, rotor rpm, and flight path in relation to the microphones on the ground) are sufficiently close to parameters prescribed by the measurement protocols. This makes the measurements comparable and repeatable.

An industrial monochrome camera was mounted to the cabin ceiling between the front seats to acquire a view on the instruments panel. The camera is connected to the measurement system via Gigabit Ethernet. The measurement system analyses the images in real-time and also stores them for optional post-flight analysis and processing.

An imaging software application has been designed to recognise selected instruments and to get readings in engineering units. In this test campaign, the instruments readings for airspeed, vertical speed, rotor rpm, and altitude were acquired.

This paper describes the on-board measurement system with the emphasis on the acquisition of the cockpit instrument readings by means of the camera and imaging software.

2 On-board equipment

The on-board equipment can be easily installed in various types of helicopters. The mechanical mounting issues are kept to a minimum. The measurement system is battery-powered, and no electrical connection exists between the system and the aircraft.

2.1 System description

The noise flight test programme includes procedures at different airspeeds and with varying climb/descent slopes. The margins of the flight path, airspeed and main rotor rpm were adopted from certification procedures (ref [1]). During the flight tests, the actual measured parameters and the margins are presented on a graphical display (see figure 1) to the flight test engineer (FTE). The FTE assesses whether the parameters are within the margins and assists the pilot to fly a valid test-run within the margins. Section 2.3.3 gives more detailed information about the guidance display.



Figure 1: Guidance display

The measurement system needs to acquire the helicopter position, airspeed, vertical speed and rotor rpm. Additionally, the helicopter acceleration and attitude parameters were acquired to create a more complete data set. All measured data were recorded on-board for later analysis.

To fulfil aforementioned requirements, the measurement system consists of the following components:

- Laptop computer for data processing and recording
- SBAS GNSS receiver (with single antenna) for aircraft position and ground speed
- Inertial Measurement Unit (IMU) for aircraft attitude and accelerations
- *Power Gorilla* portable power supply for the GNSS receiver, IMU, and camera
- Industrial video camera for image capture of the cockpit flight instruments
- Tablet computer for the guidance display used by the flight test engineer

2.2 Measurement system base plate

Figure 2 shows the measurement system components that are mounted on a plate. The following components are visible:

1. GNSS receiver
2. IMU
3. laptop computer

A portable power supply is mounted underneath the laptop computer.

The base plate is clamped down to the floor of the helicopter. Depending on the helicopter type, it is attached to the floor via seat-rails or under a passenger seat. Figure 2 shows the plate mounted underneath the back seat of an EC120 helicopter.

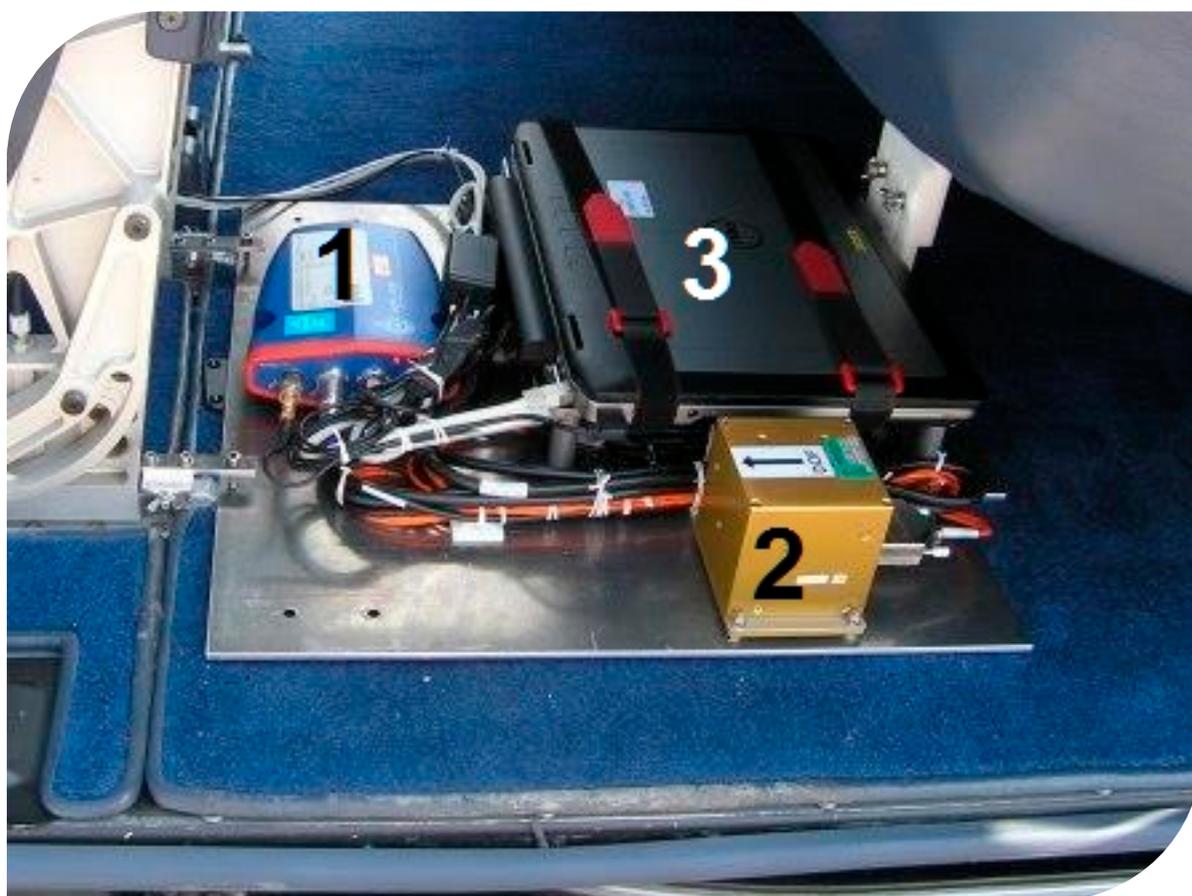


Figure 2: Measurement system base plate

2.3 Other system components

Besides the components mounted on the plate, the measurement system consists of the following components:

- GNSS receiver antenna
- Camera
- Pilot Guidance Unit

2.3.1 GNSS receiver antenna

Ideally, the antenna for the GNSS receiver would be mounted outside the aircraft, to get an unobstructed view of the sky. For practical reasons, and especially certification reasons, no modifications to the aircraft will be endeavoured, so no measurement system components will be mounted outside the aircraft. The next best thing is to mount the antenna inside behind an up-facing window.

Especially the reception of the SBAS satellites required some experimenting to determine the best position of the antenna. Figure 3 shows the antenna mounted inside an EC135 helicopter.



Figure 3: GNSS antenna mounted inside

2.3.2 Camera mounting

The mounting of the camera requires some preparation and improvisation. For example, in the EC135 the mounting point of a map reading light could be used. A part was made in the NLR workshop to fit in the mounting point, and a universal camera mount was used to point the camera to the cockpit instruments. Figure 4 shows the camera mounted in the helicopter. Section 4.1 gives further information about the camera position.



Figure 4: Camera mounted in the EC135

2.3.3 Pilot Guidance Unit

For an adequate execution of the noise flight tests, the Anotec FTS software program is used. It runs on the laptop computer (labelled 3 in figure 2) that is mounted on the base plate. The FTE uses a tablet computer that wirelessly connects to the laptop computer to display and control its desktop. The tablet computer is called the Pilot Guidance Unit (PGU). On the PGU the FTE controls the FTS program and selects the measurement type, test configuration and run number. The FTS program displays relevant data and a guidance display on the PGU, which aids the correct execution of each test run. In all helicopter types the wireless connection functioned well and no problems were encountered.

Figure 1 gives an example of the guidance display as presented by the FTS program to the FTE. During a test run, two graphs show the aircraft position in an altitude profile (top graph), and in a lateral profile (bottom graph). The horizontal axis is the longitudinal distance to the reference point (the blue vertical line). The yellow line depicts the actual position, while the white lines delimit the margins. Also, the four parameters that are acquired from the cockpit instruments via the camera are visible:

- IAS (indicated airspeed)
- VS (vertical speed)
- ALT (altitude)
- NR (main rotor rpm)

The PGU also shows the validity of the data from the camera images and the GPS receiver. Based on the graphs, numerical values and validity, the FTE decides whether the run is valid, or must be repeated.

3 Camera-based instrumentation

A camera-based imaging application makes it possible to acquire data from the instrument panel without electrical or physical contact to the underlying system. To create such an application, NLR and Anotec have used Matrox Design Assistant 4.0.

Matrox Design Assistant is an integrated development environment (IDE) by which imaging (machine vision) applications are created by constructing flowcharts and using standard building blocks. In addition, the IDE is used to create an operator interface to the application.

The application may run stand-alone in a Matrox Iris GT smart camera. This is a camera with built-in processor and I/O. It is also possible to operate the application in conjunction with an external generic industrial camera, which is connected to the host computer by means of a Gigabit Ethernet connection.

We have chosen the latter possibility (external camera), mainly for the following reasons:

- a computer is needed anyhow, for the Anotec FTS program, and data recording
- a computer offers more flexibility, processor power, and performance
- an Ethernet camera is smaller than a Matrox smart camera, so it can be mounted more easily

3.1 Camera and lens

For the purpose of acquiring instrument panel readings, a colour camera is not necessary, a monochrome camera suffices. Recognition of dials and hands is based on shapes, not colours (see section 3.2.4).

A Basler acA1300-30gm camera is used, which has the following features:

- CCD sensor, optical size 1/3"
- 1296 x 966 pixels
- progressive scan
- global shutter
- electronic exposure time control
- maximum frame rate 30 fps
- minimum exposure time 16 μ s

Global shutter (as opposed to rolling shutter) and progressive scan (as opposed to interlaced scan) are important features that prevent vibration-related distortion of the images. To increase the rate of successful recognition, uneven lighting on the instruments should be prevented, see section 3.2.4.

The lens that is used is a Computar T10Z0513 CS-3, 5-50mm, F1.3. The zoom range makes it possible to adjust the field of view so that the instruments fill the camera image as much as possible.

Figure 5 shows the camera and lens, including Ethernet cable and power supply cable. The camera is able to receive power over Ethernet (PoE), or via a separate cable. The choice was made to use a separate power supply cable,

because this precludes the employment of a PoE-capable Ethernet switch in the measurement system. That way, the camera can be connected directly with the laptop computer via the Ethernet cable.



Figure 5: GiGE camera and lens

3.2 Matrox Design Assistant

Matrox Design Assistant 4.0 is the IDE in which the developer builds the imaging application. During the flight tests, this is also the environment in which the application runs. After starting the application in the IDE ('deploy'), a web browser is started automatically showing the graphical operator interface.

3.2.1 Initial flowchart

When creating a new project in Design Assistant, the IDE shows the initial flowchart of the application, see figure 6.

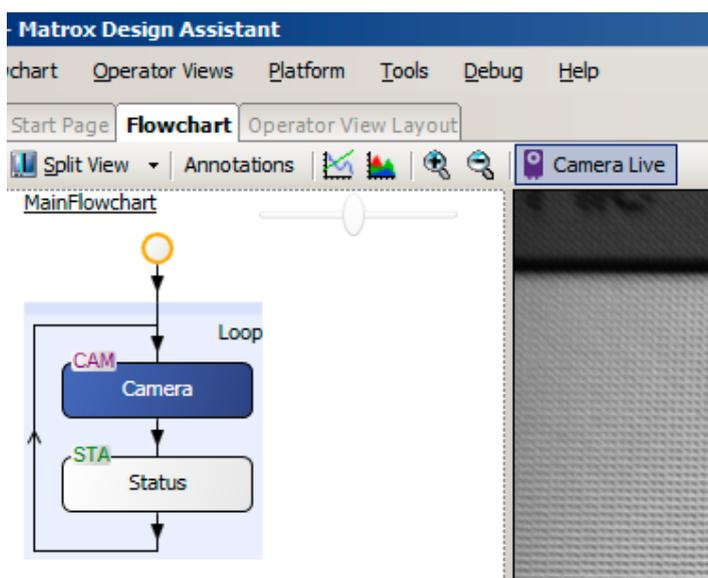


Figure 6: Initial application flowchart

The initial flowchart shows the basic structure of the application: a loop that continues as long as the application is running. In the *Camera*-block an image is grabbed from the camera. This image will be processed to extract the desired features.

3.2.2 Adding steps

Constructing the application is accomplished by inserting steps into the flowchart via the 'Add Step' function, see figure 7.

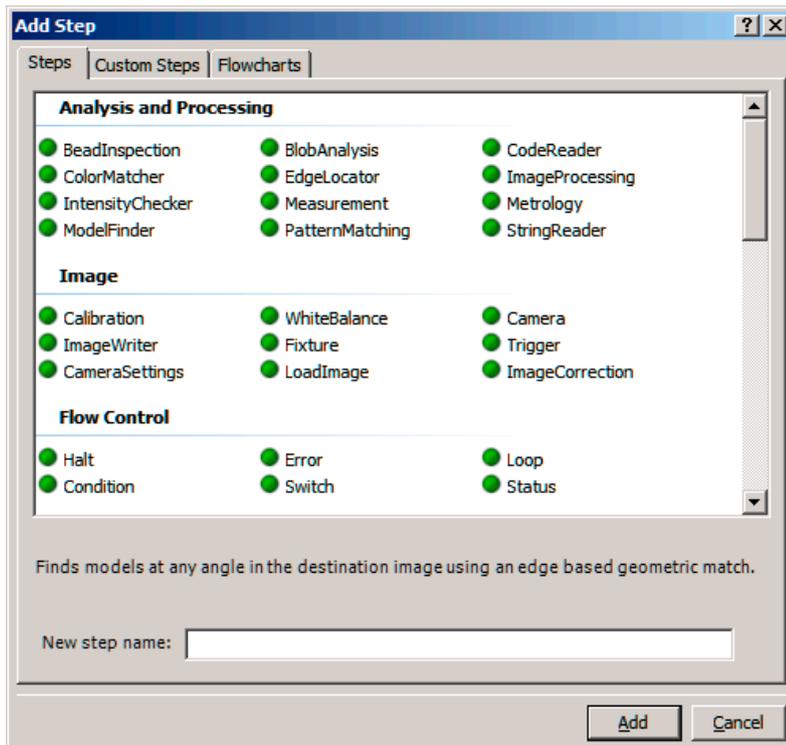


Figure 7: Add a step to the flowchart

Steps that can be added to a flowchart include processing and flow control steps, as well as steps to perform I/O.

3.2.3 Application flowchart

The following refers to the application that has been built. Figure 8 shows the flowchart (divided into three sections) starting with several initialisation steps, and then entering the main loop.

The main loop starts with the following steps (left section):

- *AdjustCamera*: adjust the camera settings based on operator inputs (auto exposure on/off, exposure time, etc.)
- *Camera*: grab an image
- *AdjustImage*: perform adjustments such as rotating the image if the camera is mounted upside-down
- *FindReference*: find the predefined reference in the image, which is the base for further processing
- *RefFound*: change the control flow depending whether the reference was found or not

FindReference is a *Model Finder*-step that tries to detect the shape that has been defined as reference. Refer to section 4.3 for more detailed information.

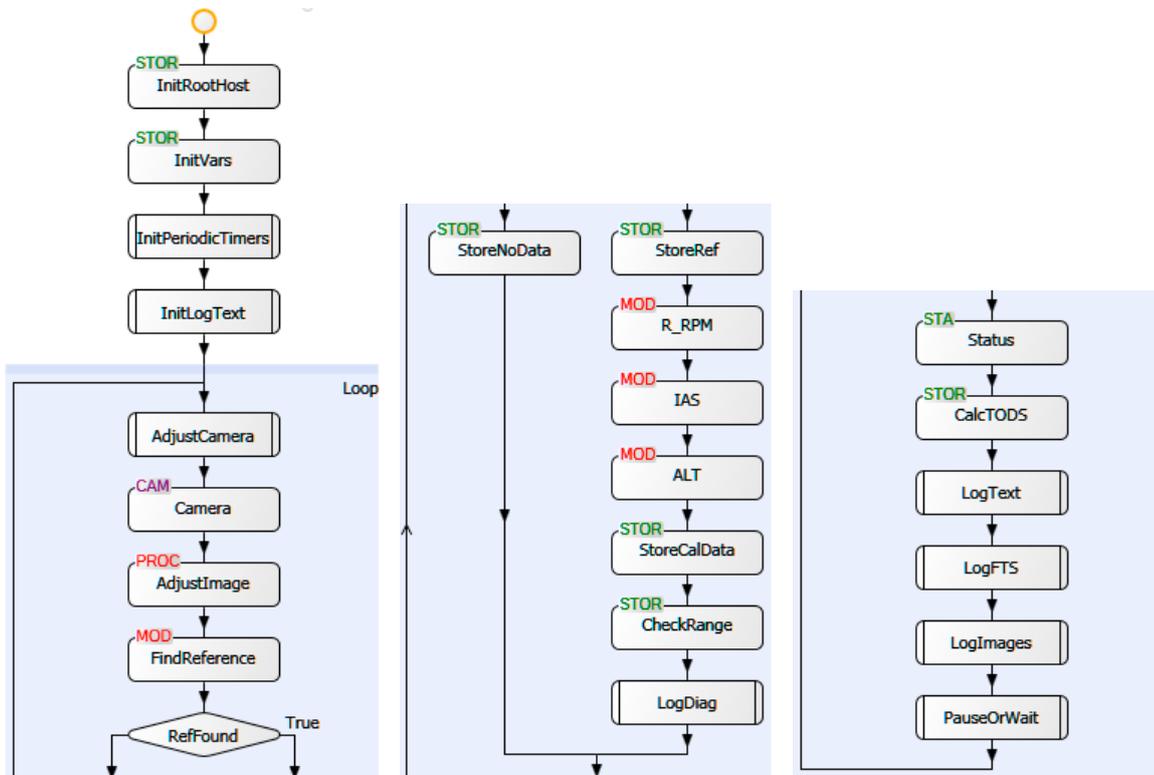


Figure 8: Application flowchart

In the middle section of figure 8 three other *Model Finder* steps are visible: *R_RPM*, *IAS*, and *ALT* detect the instrument needles indicating main rotor rpm, airspeed, and altitude respectively. In step *StoreCalData* the measured data is calibrated (see section 4.4) and stored as engineering units.

In the last part of the main loop shown in the right section of figure 8, data and images are logged by *LogText* and *LogImages*, and the data is sent to the FTS program by *LogFTS*. Communication with the FTS program is achieved via the file system. Anotec expanded its FTS program to make reception of the instrument parameters possible.

The *LogFTS*-step writes measured data into a data file which the FTS program reads. For synchronisation, *LogFTS* creates a second file after it has created the data file. The FTS program waits for this synchronisation file and deletes it after it has read the data file. *LogFTS* checks that the synchronisation file has been deleted before it writes the data file. This scheme ensures a mutual exclusion of simultaneously reading and writing of the data file.

3.2.4 Detecting shapes

The foundation of the imaging application is detecting shapes. In the case of a clock-type instrument, such as an altimeter or speed indicator, the shapes to be detected are:

- the stationary dial, and
- the rotating needle (or clock hand(s))

The application is capable of detecting a predefined shape within a given search region. It produces the following properties when a shape is found:

- *location*: (x, y)-coordinates in the image
- *rotation*: angle
- *size*: scale (zoom) factor

In the case of an indicator needle or clock hand, the rotation angle represents the value that the instrument indicates. The angle of the dial is used as a reference angle for the needle. By combining the needle angle and the reference angle, the measurement is not affected when the camera is mounted with a slight rotation angle.

Detection and recognition of shapes is negatively influenced by direct incident sunlight and cast shadows on the instruments. Uneven lighting should be prevented as much as possible, because it creates local overexposure and underexposure in the images, and artefacts that deteriorate the recognition of shapes. A remedy is to avoid certain flying directions in relation to the sun, if possible.

3.2.5 Reference

In the case of a single instrument, there is one reference: the dial. The instrument can be found in the camera image by finding its dial. The search area for the dial may be the complete image, or it may be limited to a part of the image. In general, this will speed up the detection process.

The search area for the needle is defined relative to the location of the reference, which is the centre of the dial.

The cockpit instrument panel contains four instruments of interest: IAS (indicated airspeed), VS (vertical speed), ALT (altitude), and NR (main rotor rpm). Each instrument could be handled separately, each with its own reference.

However, it is also possible to define one reference for the entire instrument panel. Thus, the locations of the needles of the instruments are defined relative to this single reference. The angle of the reference applies to all instrument needles.

In our application, we have chosen the single-reference approach. The advantage is that the effort to create the application is lower and the performance will be higher. The drawback is that there will be no data at all if the reference was not found in the image.

A suitable reference on the instrument panel is a distinctive stationary shape with sufficient size and contrast. In general, an instrument dial is a suitable reference.

4 Application development

To develop the application with Matrox Design Assistant, the following steps were followed:

- Determine the camera position in the cockpit
- Capture reference images of the cockpit panel
- Isolate the shapes to be found
- Create the calibrations
- Add additional functions
- Create the operator interface

4.1 Camera position requirements

The camera position must meet the following requirements and conditions. The camera shall not interfere with the pilot, and the camera view on the instruments should be obstructed by the pilot as little as possible. Also, the view should be perpendicular to the instruments as much as possible. The most practical position turns out to be above the shoulder of the pilot, between the left and right front seat.

4.2 Reference images

The imaging application can use captured images instead of live camera images. In this way, the application can be developed further without the need for access to the helicopter cockpit. The camera position during the flight tests and the position from which the reference images were taken must be the same.

When possible, images containing instruments indicating different values should be captured. This will be used to create the transfer functions that convert the angles into engineering units (see section 4.4).

Figure 9 and figure 10 show the cockpit panel images of the R22, R66, EC120 and EC135 captured by the video camera.



Figure 9: Instrument panel of R22 (left) and R66 (right)

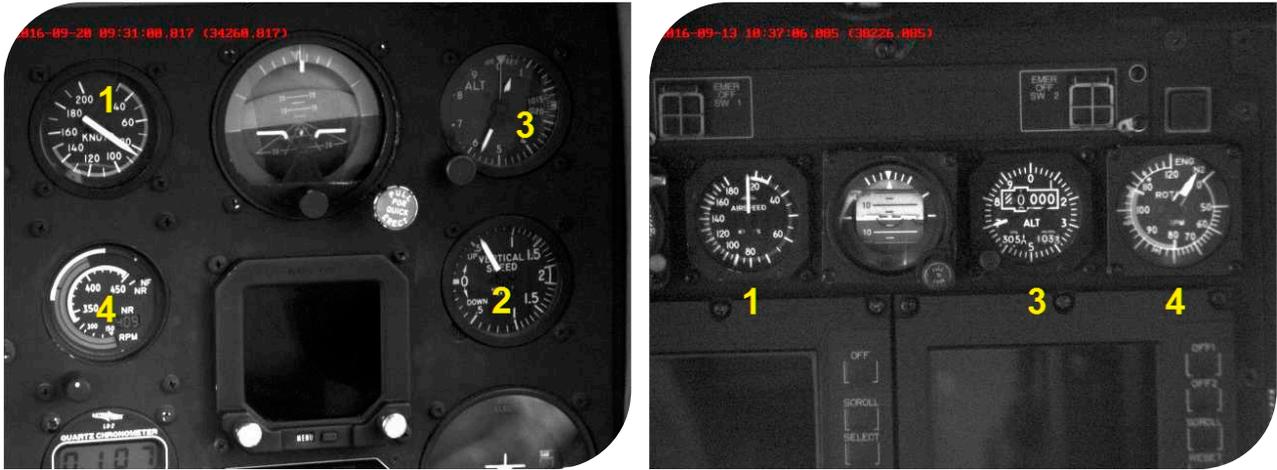


Figure 10: Instrument panel of EC120 (left) and EC135 (right)

In the figures, the instruments are labelled as follows:

1. IAS
2. Vertical speed
3. Altitude
4. Engine/rotor rpm

4.3 Shapes to be found

The step that detects a shape in an image is called a *Model Finder*. In figure 8, step *FindReference* (labelled *MOD*) is the model finder that tries to find the reference. The airspeed indicator dial is used as the reference in the EC135.

The user draws a rectangular area in the captured image that surrounds the reference shape, and Design Assistant subsequently detects the characteristic features as shown in the left picture of figure 11. The red symbol shows the reference point and orientation of the model. The needle must be excluded from this model, because here we are only interested in the dial. To do so, the user draws a mask, as shown in green in figure 11.

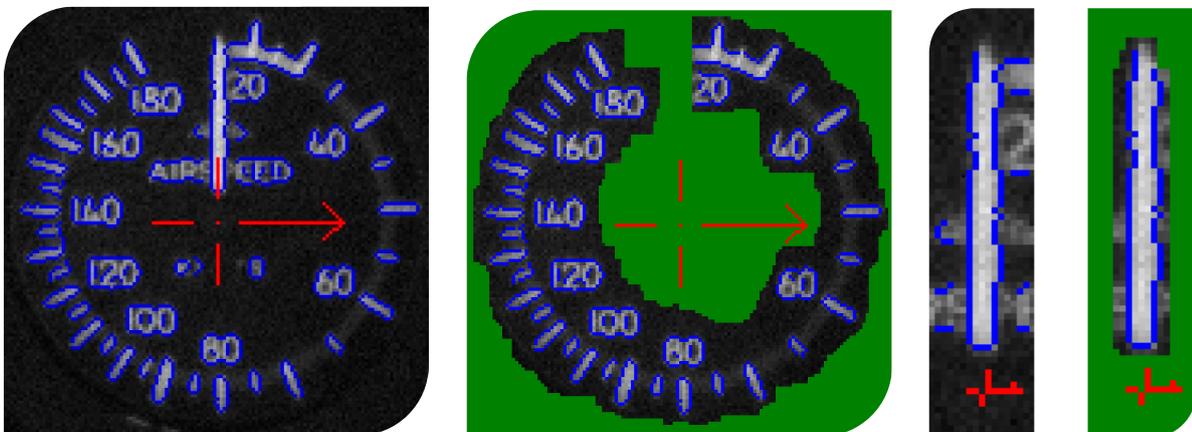


Figure 11: EC135 reference (without and with mask) and airspeed needle (without and with mask)

Using the same captured reference image, a *Model Finder* is configured for all instrument needles, for example the airspeed needle shown on the right side of figure 11.

The search area of a shape applies to its reference point. It is important to set the reference point of the needle to its centre of rotation, because then the search area for the needle can be limited to a small area around the centre of the dial.

Design Assistant uses the 3 o'clock orientation as 0° angle. This explains the 90° offset between the reference orientation (red arrow) and the orientation of the dial and the needle.

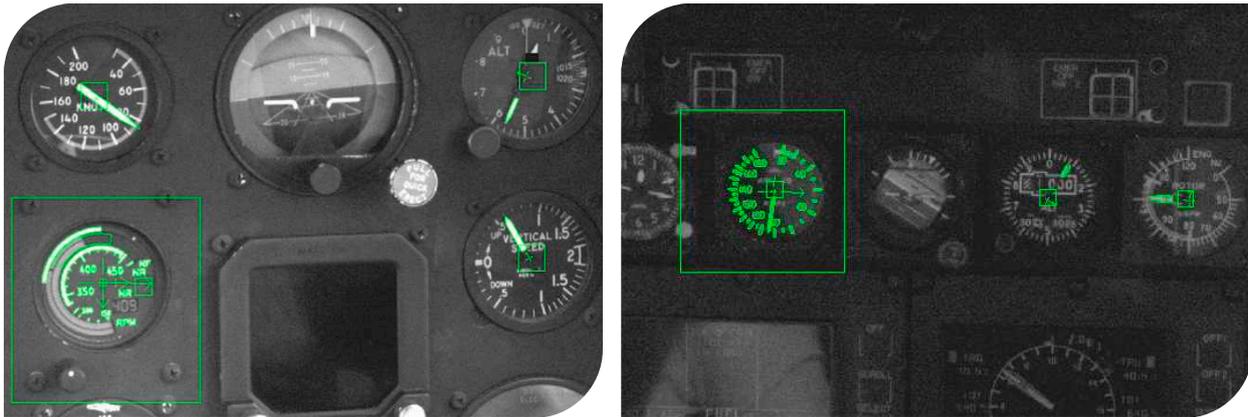


Figure 12: EC120 (left) and EC135 (right) panel image

Figure 12 shows the EC120 and EC135 instrument panel with the detected shapes highlighted in green

A special case forms the engine/rotor rpm indicator in the EC120. The indication is a curved bar graph. Figure 13 shows the indicator including annotations in green. The curved bar graph is labelled 1. Arc 2 defines an area of the bar between 380 and 430 rpm. Rectangle 3 defines a brightness reference area.



Figure 13: EC120 rpm indicator

Determining the deflection of the bar is accomplished by counting the number of pixels in arc 2 with brightness above a threshold defined by the brightness of rectangle 3. This number divided by the total number of pixels in arc 2 gives a measurement of the indicated engine/rotor rpm.

4.4 Calibration

Once all models (shapes) have been defined, a method must be devised to convert the rotation angle of a needle (combined with the reference angle) into engineering units. To accomplish this, we need data points in the form of rotation angles and corresponding indicated values. The rotation angles come from captured reference images.

Some instruments such as the altimeter can be set manually. Images of different settings can then be captured to get the data points for the calibration. Another possibility is to capture an instrument during power-up self-test. For example, the engine/rotor rpm indicator in the EC135 makes a full sweep after applying electrical power.

For other instruments that don't give different readings when on the ground, the reference image can be manipulated with an image editor such as GIMP. In the editor, the needle can be cut out and added to a separate layer, which can be rotated at will.

The following shows an example of the EC135 IAS indicator. The reference image was edited with GIMP to set the needle to the scale markers. The images were presented to the imaging application, which gives the corresponding rotation angle of the needle. The resulting data points are shown in table 1.

Table 1: EC135 IAS calibration data points

IAS (kts)	Angle (degrees)
15	0
20	12.07
30	29.09
40	57.56
50	90.24
60	121.63
70	157.98
80	179.92
90	198.79
100	213.39
110	227.55
120	241.91
130	256.91
140	270.62
150	285.24
160	302
170	315.9
180	331.44

Using the MATLAB Curve Fitting Tool, a 4th order polynomial was calculated (fit type poly4) as shown in figure 14.

For the EC120 rpm indicator, data points were acquired during engine power up and during a small test flight. By limiting the area of interest between 380 and 430 rpm, the calibration could be made linear, as shown in figure 15.

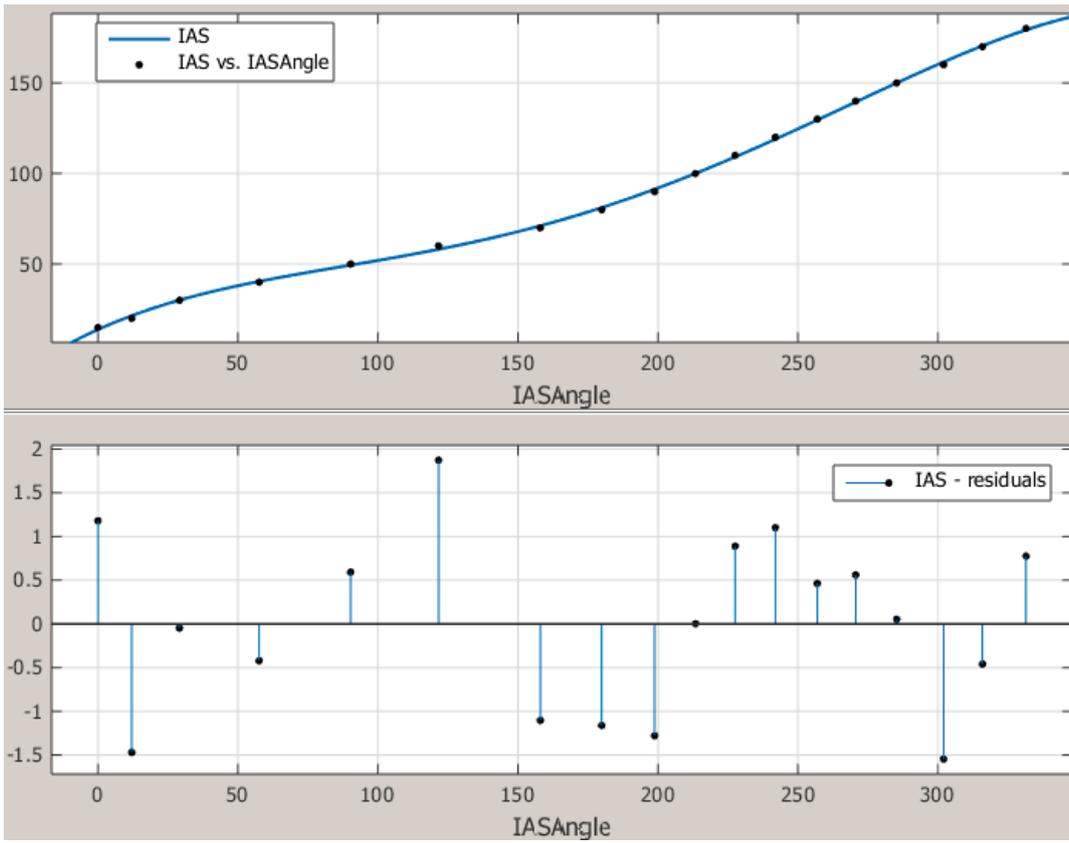


Figure 14: EC135 IAS curve fit

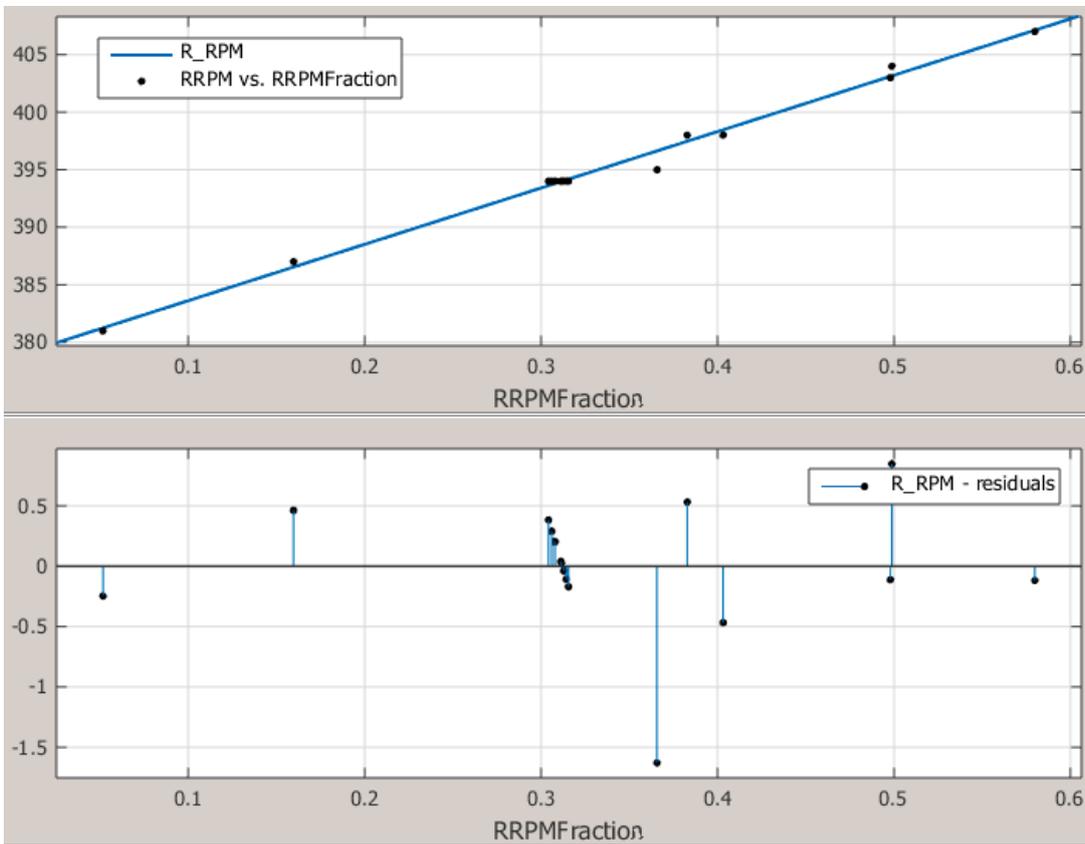


Figure 15: EC120 rpm curve fit

In Design Assistant, an expression to calculate for example a 4th order polynomial function can be constructed as follows:

$$SUM ([c_0, c_1, c_2, c_3, c_4], Item * Variables.Angle ^ (Index-1))$$

The result is calculated by the *SUM*-function, wherein the polynomial coefficients are defined as an array $[c_0...c_4]$ starting with the lowest-order coefficient. Variable *Index* counts from 1 to the number of array elements, while variable *Item* receives the successive array element values. Variable *Variables.Angle* is the angle to be converted into engineering units.

4.5 Additional functions

Additional functions that need to be added to the application are:

- Adjust camera settings
- Adjust camera image
- Log data in a text file
- Send data to the FTS program
- Log images

The first two items will be included in the operator interface and allow the user to change camera settings (auto exposure on/off, exposure time, etc.) and image adjustments (camera rotation 0° or 180°).

The last three items concern logging of data and images, and communication with the FTS program. Data and images are tagged with a timestamp, which is the time when the image was captured. The time is based on the local system time. Before the flight tests are started, the system time is synchronised with the time from the GPS receiver.

Images are logged as bitmap image files that can be accessed afterwards. The logging rate is limited to 1 Hz to limit the amount of data. Images are logged whether data was successfully captured or not. If necessary, images can be reprocessed afterwards.

4.6 Operator interface

The operator interfaces for the EC120 and EC135 are shown in figure 16 and figure 17. The left part of the operator interface shows the live camera image annotated with the detected features. The right part contains the operator controls and indicators.

The *Inspection Results*-block shows the four parameters that have been recognised from the instruments in the captured video image.

With the controls in the blocks *Camera setting inputs* and *Operator Inputs* the user can control camera settings and image processing parameters.

EC120

Data

Images

Ref deg Scale TODS

Quit

2016-09-20 09:31:00.817 (34260.817)

y:\proj\smartcam\projects\ec120\cam\test\20160920_093100_817.bmp

Global results	
Pass	
Total pass	1063
Total fail	0
<input type="button" value="Reset Counters"/>	
Benchmarks	
Analysis time	39 ms
Frame rate	15.5 fps
Inspection Results	
IAS	84 kts
VS	569 fpm
ALT	570 ft
R-RPM	404 RPM
Operator Inputs	
Log Data	Idle
Image log rate	1 fps
Acceptance	70 %
Certainty	90 %
Image rotate	0 deg
Image source	Set: Test
Image-set rate	Fastest <input type="button" value="Go"/>

Camera setting inputs	
Exposure	1/1000 s
GainAuto	Continuous
AutoGrayLevel	100
Gain	300
Other inputs	
Diagnostics	Idle
Image Contrast	1
Image Brightness	0
Search Size	50
Search Scale	1.2
RPM Inty Threshold	25

Figure 16: EC120 operator interface

EC135

Data

Images

Ref deg Scale TODS

Quit

y:\proj\smartcam\projects\ec135\cam\test\20160927_121638_982.bmp

Global results	
Pass	
Total pass	353
Total fail	0
<input type="button" value="Reset Counters"/>	
Benchmarks	
Analysis time	91 ms
Frame rate	10.2 fps
Inspection Results	
IAS	85 kts
VS	0 fpm
ALT	78 ft
R-RPM	101 RPM
Operator Inputs	
Log Data	Idle
Image log rate	1 fps
Acceptance	95 %
Certainty	100 %
Image rotate	0 deg
Image source	Set: Test
Image-set rate	Fastest <input type="button" value="Go"/>

Camera setting inputs	
Exposure	1/1000 s
GainAuto	Continuous
AutoGrayLevel	100
Gain	300
Other inputs	
Diagnostics	Idle
Image Contrast	1
Image Brightness	0
Search Size	20
Search Scale	1.2

Figure 17: EC135 operator interface

5 Results

An on-board measurement system has been developed that acquires data from cockpit instruments in real-time. Its flexibility makes it possible to adapt the system to different aircraft. The novelty is that data from the aircraft are acquired non-intrusively by means of a camera, and thus interfacing issues are reduced to a large extent.

Instruments that were captured by the measurement system include airspeed, vertical speed, altitude, and rotor rpm.

The instrument-digitising method has proved to be able to cope with vibration conditions found in helicopters. A global shutter with 1 ms exposure time prevents motion blur, while the adaptive imaging application is insensitive to displacement of the instruments in the image.

The largest issue that may obstruct successful data acquisition is direct incident sunlight causing cast shadows and uneven light on the instrument panel. In this respect, the harsh Spanish sunlight seemed to cause more troubles than the Dutch sunlight. If possible, the position of the sun should be reckoned with when determining the flight direction of the test runs. Dark clothing worn by the flight crew is beneficial to further prevent reflections in the images of the instruments. The least problems are to be expected with overcast skies.

A regular state-of-the-art laptop computer (Intel® Core™ i5-3340M CPU @ 2.70 GHz with 8 GB RAM) provides ample performance without high CPU loads. Average acquisition rates between 10 and 15 Hz were achieved.

The accuracy of the readings is comparable to or better than when reading an instrument by eye. In general, accuracy and success rate improve if instruments cover more pixels with more details.

6 References

1. ICAO Annex 16 - Environmental Protection, Volume I - Aircraft Noise; Sixth Edition, July 2011; International Civil Aviation Organization; ISBN 978-92-9231-837-6

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