Automated Visual Verification of Avionics Cockpit Displays

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- M. Onur Güngör will receive the master’s degree in Computer Science from the Istanbul Technical University in 2022. He is a expert software verification engineer in ASELSAN Inc since 2017. Leading the BSP & Driver test case development team. Providing test development infrastructure in accordance with avionics standards.

- Interests
  - Artificial Intelligence, Embedded Systems, Avionics

Agenda

1. Background of Visual Verification
2. Problem Definition
3. Automated Visual Verification
4. Experiments and Results
5. Conclusion and Future Works

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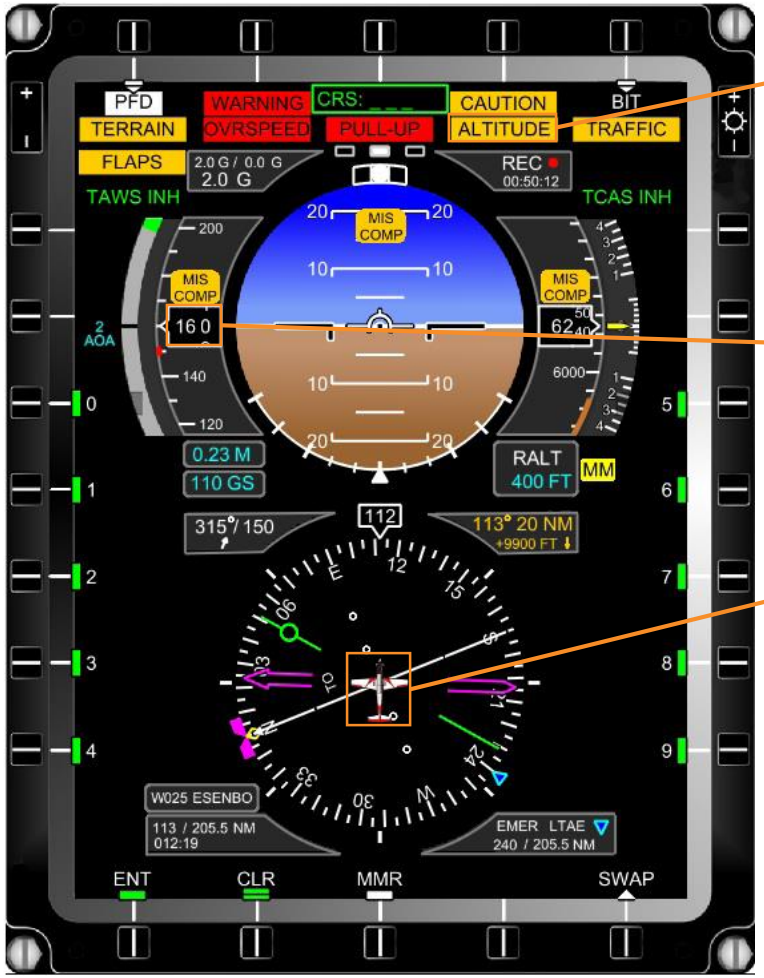
Visual Verification of Avionics Cockpit Displays



- **Foreground and Background Colour Verification:** Is the background colour of the Altitude Label is YELLOW and foreground colour of the Altitude Label is BLACK?
- **Text Verification:** Is the text of the rolling counter is 160?
- **Object Verification:** Is the Aircraft symbology visible in the center of the HSI area?

All of the contents on the page should be verified according to software requirements.

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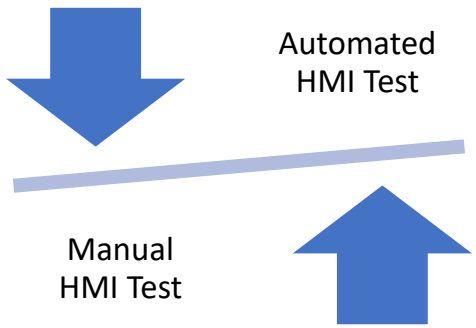
Problem Definition

- Visual verification test cases are usually performed by **manual comparison** of the values on the display systems with the expected values.

- High Cost: More Time and Resource
- Prone to Human Error: Less Accuracy



- Increase the Scope of Testing
- CI/CD and DevOps Implementation
- More Accurate Tests

Aims and Contributions

- The purpose of the study is to design a system to **automate the visual verification** of avionics cockpit displays using digital cameras.

- It is possible to **take a screenshot** of the cockpit display system **using a digital camera**.

- Calibrating the position of the DSLR camera using **Image Registration**.

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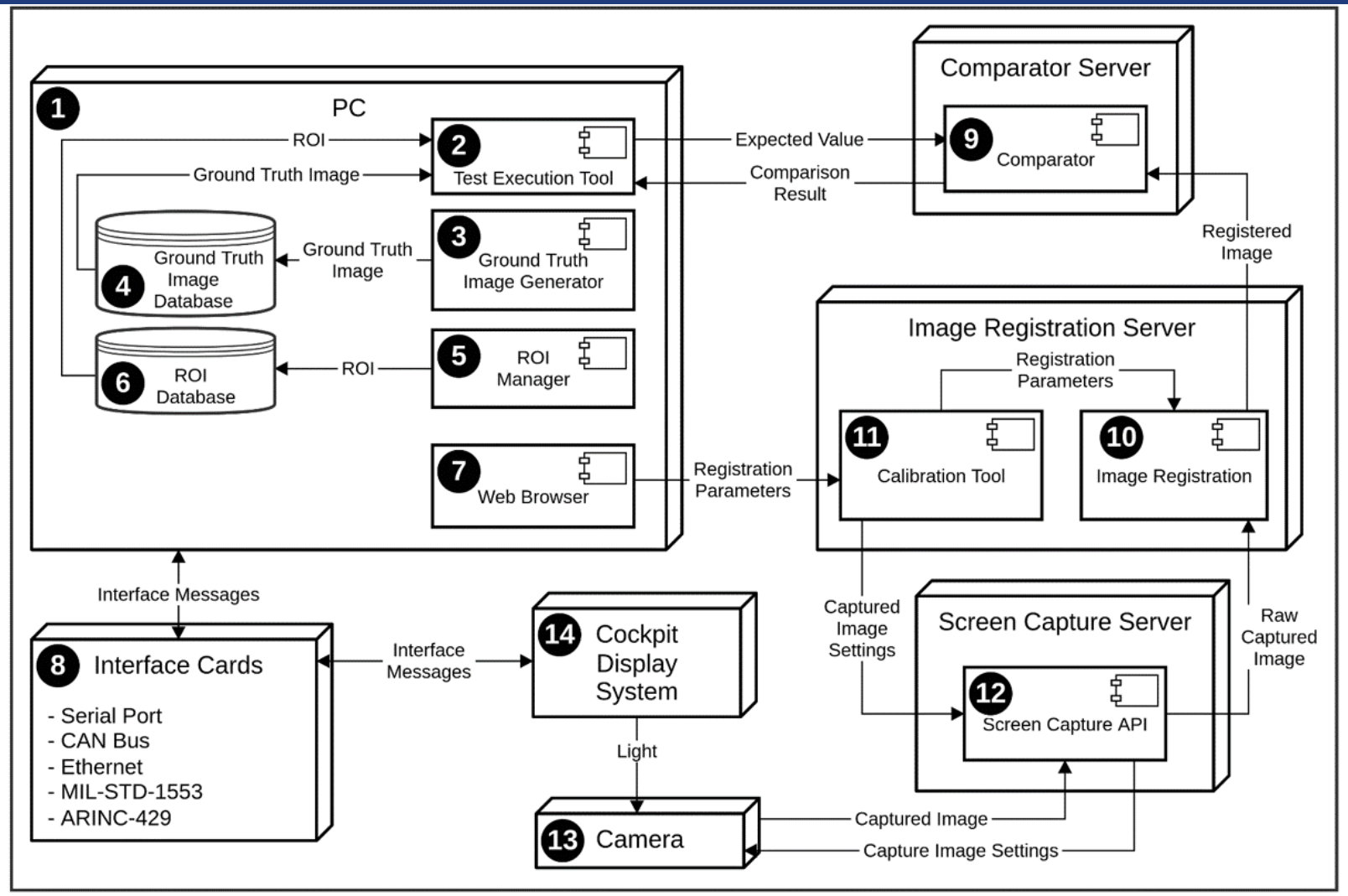
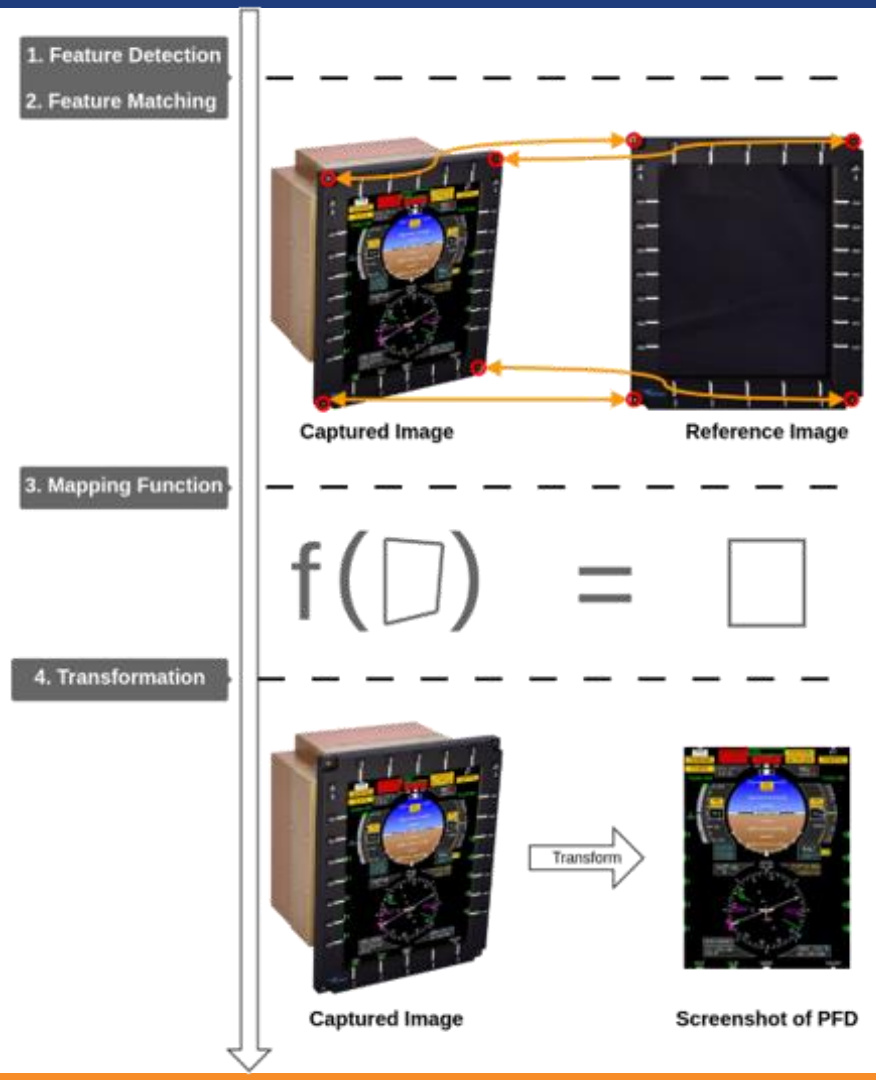
Automated Visual Verification System



Screen Capturing

- Two ways for getting the screenshot of the cockpit display system:
  - Through the screen buffer of the graphics card:
    - **Software Level:** It is **a destructive method** while considering a real-time system.
    - **Hardware Level:** It is **not time and cost efficient** while considering different hardware architectures.
  - Taking the photo of cockpit display system via DSLR camera.
    - Use **image registration** technique for **position calibration**.
    - Consequent **image processing** techniques for **color calibration.**

Four steps of Image Registration



Transformation

- **Calibration Tool** is used to **match** common points on **reference image** (rendered image of cockpit 2D CAD model) and **captured image**.

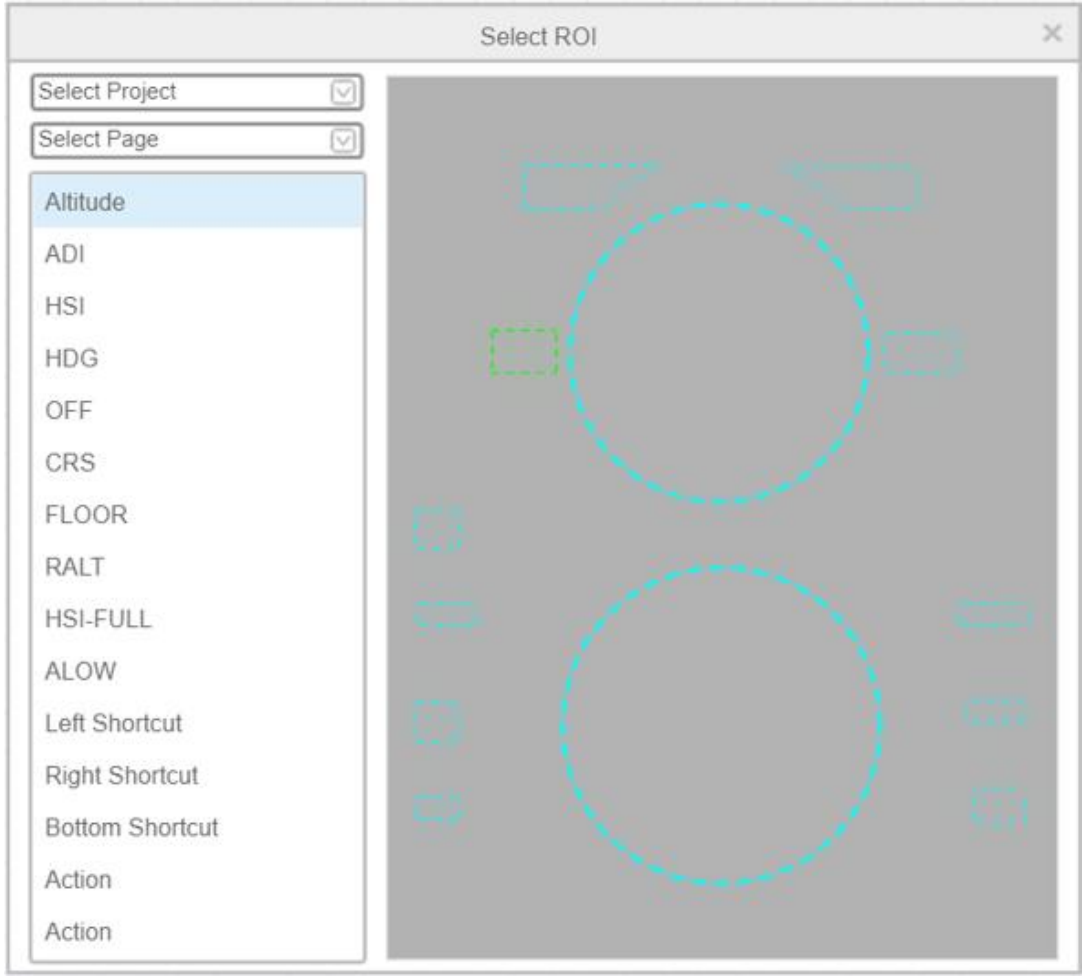
- The mapping function is used to **calculate transformed** image using equations given below:

$$x' = \frac{h_{00}x + h_{01}y + h_{02}}{h_{20}x + h_{21}y + h_{22}} \text{ and } y' = \frac{h_{10}x + h_{11}y + h_{12}}{h_{20}x + h_{21}y + h_{22}} \ ,$$

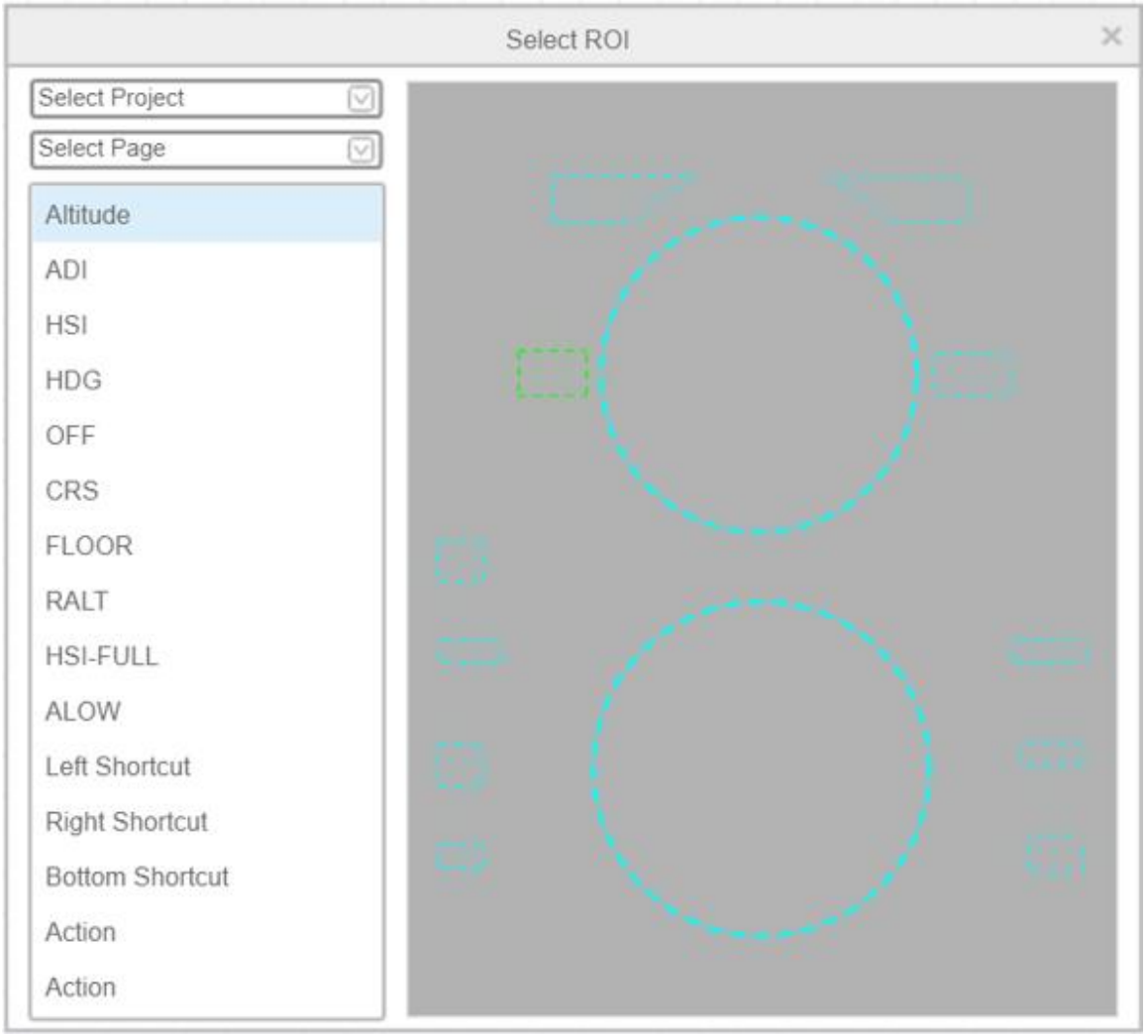
where **x'** and **y'** are the **new x and y coordinate** of the given pixel and h_{ij} corresponds to the element of the transformation matrix in row i and column j.

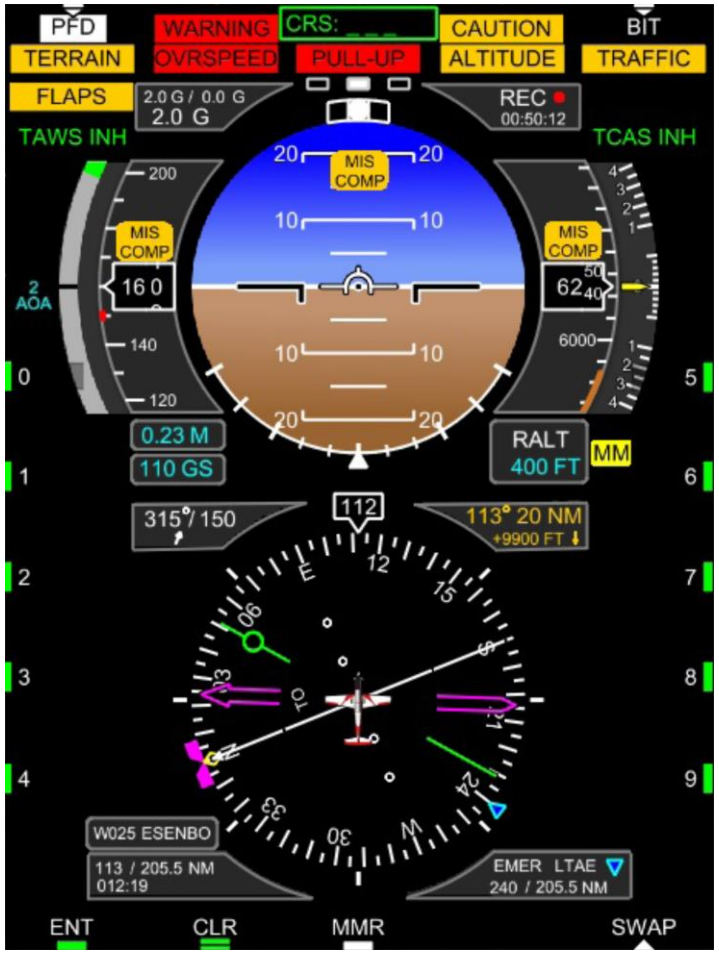
Screenshot Partitioning with ROIs (Region of Interests)

- ROI Manager application is used for **partitioning** the pages of the Cockpit Display System.
- These partitions (ROIs) are used while developing automated test cases.
- Using the ROIs within the test cases allows the test cases to be run again **without modification** in case of position changes in that region.



ROI Manager

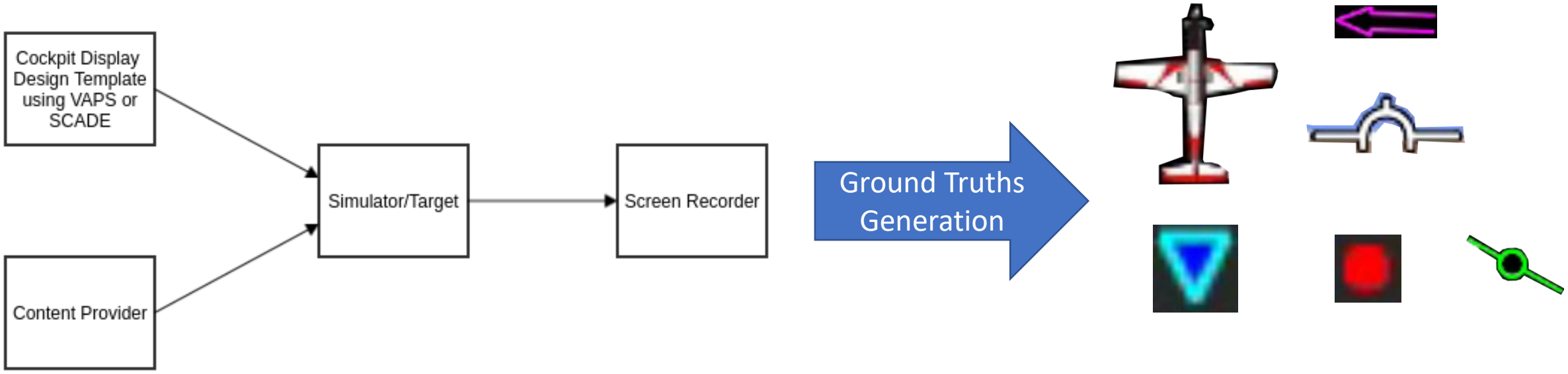

Select ROI
Select Project
Select Page
Altitude
ADI
HSI
HDG
OFF
CRS
FLOOR
RALT
HSI-FULL
ALOW
Left Shortcut
Right Shortcut
Bottom Shortcut
Action
Action


PFD
WARNING
CRS:
CAUTION
BIT
TERRAIN
OVRSPEED
PULL-UP
ALTITUDE
TRAFFIC
FLAPS
2.0 G / 0.0 G
2.0 G
REC
00:50:12
TAWS INH
TCAS INH
MIS COMP
AOA
0.23 M
110 GS
RALT
400 FT
MM
315°/ 150
112
113° 20 NM
+9900 FT
W025 ESENBO
113 / 205.5 NM
012:19
EMER LTAE
240 / 205.5 NM
ENT
CLR
MMR
SWAP

Ground Truth Generation

- Ground truth image is needed for **symbology and object verification**.

- Outputs **of cockpit display design tools** were used to produce ground truth images.



Comparison Techniques

- **Text Compare:**
  - Reading the ROI field **using Optical Character Recognition (OCR)** techniques.
  - **Tesseract** is used for OCR.
  - Performance **improvement using parameters**: number of lines, language, white list characters, etc.

- **Object Compare**
  - Object or symbology in the ROI field is compared with ground truth image by using **Template Matching** algorithm.

- **Color Compare**
  - **Support Vector Machine (SVM)** is used for color **classification**.

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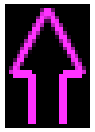
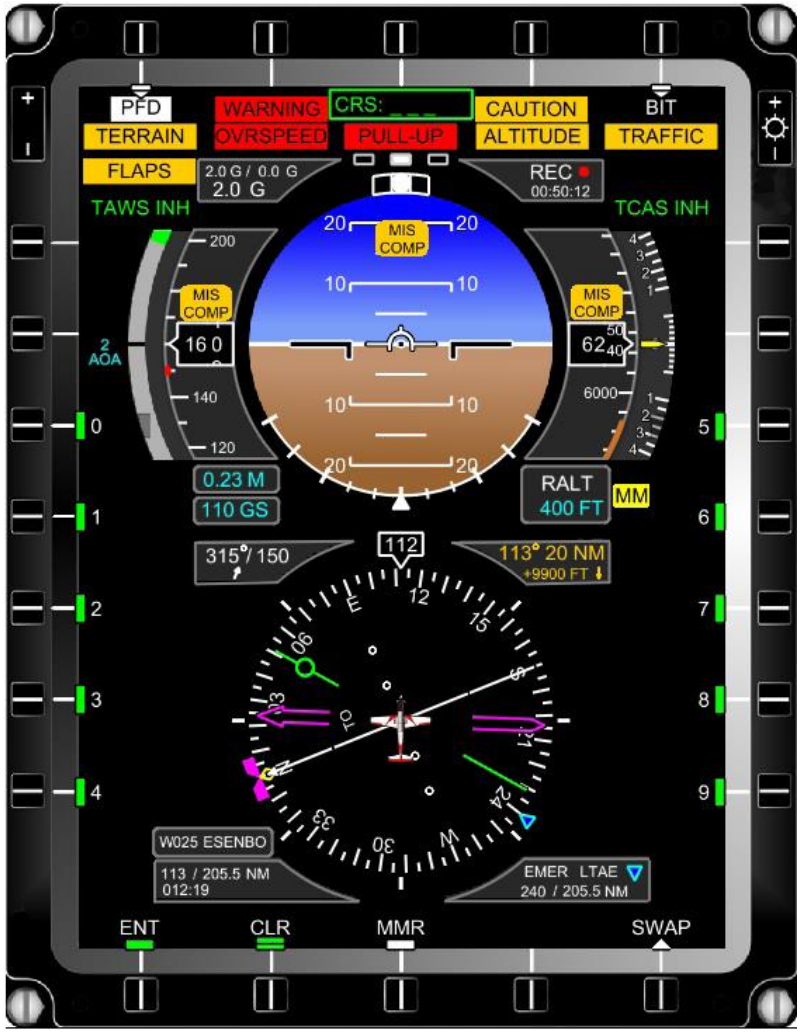
Recognition Performance Experiments

- Dataset Created using Cockpit Display Pages
  - 208 Text ROI created.

    TERRAIN RALT . . .

    16 0 W025 ESENBO
  - 6 Object ROI created.

      . . .



Text and Text Size Recognition

- The texts of 200 out of 208 ROIs were correctly recognized.

→ **113 / 205.5 NM**

→ **OVRSPEED**

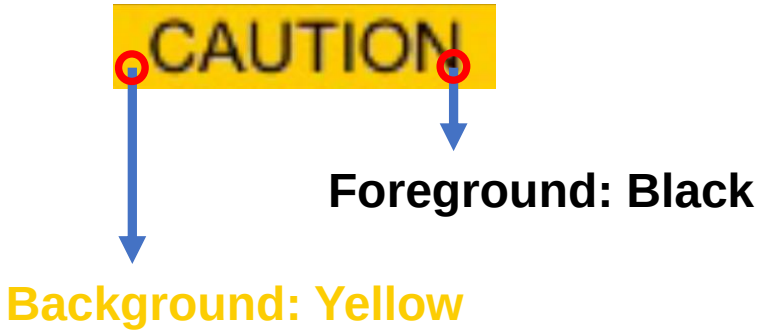
- Text sizes of 190 out of 208 ROIs were correctly recognized.

→ **Large**

→ **Medium**

Colour Classification

- SVM Model trained with 786432 pixels
- The accuracy of foreground color detection is 0.40865
  - Not an acceptable F1 score due to the anti-aliasing
- The accuracy of background color detection is 0.81731



BACKGROUND COLOR RECOGNITION

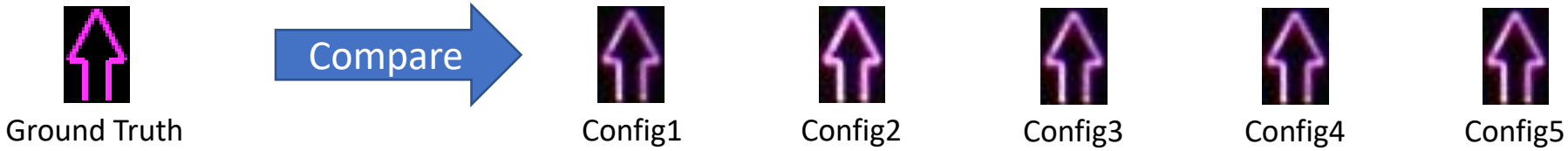
Color	TP	TN	FP	FN	F_1
Amber	5	208	0	0	1
Black	45	126	7	30	0.71
Dark Gray	116	54	30	8	0.80
Red	2	206	0	0	1
White	2	206	0	0	1

FOREGROUND COLOR RECOGNITION

Color	TP	TN	FP	FN	F_1
Amber	0	177	0	31	0
Black	0	199	2	9	0
Brown	0	170	38	0	0
Cloud	0	146	62	0	0
Cyan	0	206	0	2	0
Gray	0	177	2	31	0
Green	0	193	0	15	0
Light Blue	0	207	1	0	0
Magenta	0	207	0	1	0
Red	2	169	4	33	0.10
White	83	106	18	1	0.90

Object Recognition

- The average of the normalized cross-correlation for objects are 0.943.



- The normalized cross-correlation for each object and each config:

OBJECT RECOGNITION

Object	C_1	C_2	C_3	C_4	C_5
Plane	0.86	0.86	0.93	0.84	0.84
Arrow	0.94	0.93	0.93	0.94	0.94
Stop	0.98	0.98	0.98	0.98	0.98
Compass	0.96	0.95	0.96	0.96	0.96
Plane	0.96	0.96	0.96	0.96	0.96
Target	0.97	0.92	0.96	0.97	0.96

IMAGE CONFIGURATION

Configuration	AV	TV	ISO
Config1	3.5	30	100
Config2	3.5	30	200
Config3	3.5	50	200
Config4	4.0	25	100
Config5	4.5	25	100

Usability Experiments

- The usability of the system was measured with the SUS questions directed to **13 testers at different experience** levels.

- The participants were given 3 different types of tasks to perform using all the test tools in the system.

- These tasks are;
  1. **Camera Calibration**
  2. **ROI Identification and Ground Truth Generation**
  3. **Developing and Executing a Test Case with Defined ROIs and Ground Truths**

Usability Experiments

- 3 questions were asked about the:
  - Difficulty of the task
  - Adequacy of time
  - Adequacy of the technical support they received.
- The averages of the answers for each task are given in Figure below

- The **SUS score of the system is 71.92.**

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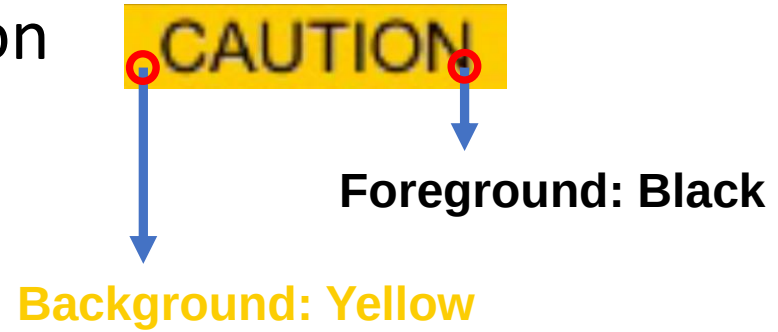
Conclusion

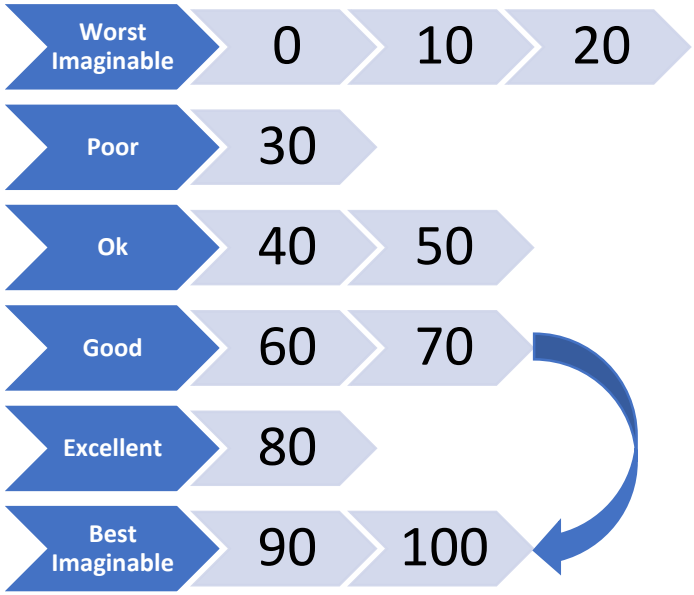
- **Perform automated visual verification** for cockpit display systems using camera.
- Captured images have been transformed using the **image registration** technique.
- The **cockpit screen has been successfully partitioned into regions**.
- Ground Truth Generator tool is used **to generate ground truth image.**

Future Works

- Color recognition should be improved.
  - Especially text foreground color recognition



- The SUS score should be increased



Thank you for your attention

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