Complex-Object Visual Inspection: Empirical Studies on A Multiple Lighting Solution

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Abstract

The design of an automatic visual inspection system is usually performed in two stages:

- Selecting the most suitable hardware setup for highlighting most effectively the defects on the surface to be inspected;
- Development of algorithmic solutions to exploit the potentials offered by the collected data.

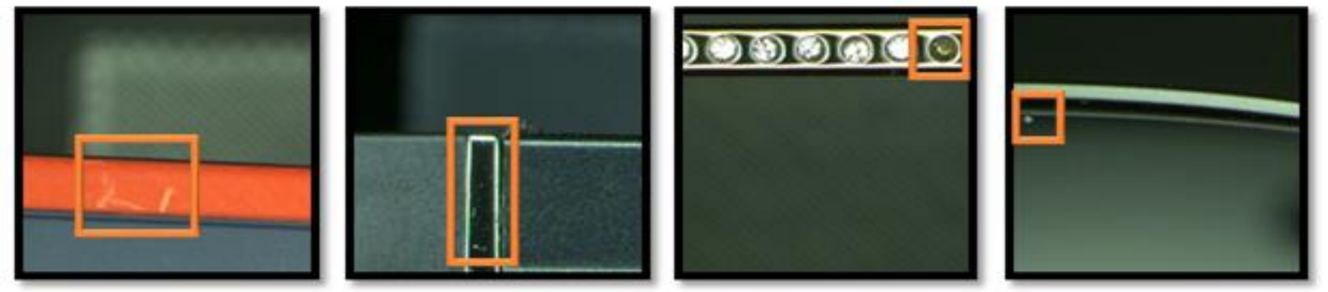
We present a novel illumination setup embedding four illumination configurations to resemble diffused, dark-field, and front lighting techniques.

We analyze the contributions brought by deploying the proposed setup in the training phase only, mimicking the scenario in which an already developed visual inspection system cannot be modified on the customer site, and in both training and evaluation phase.

Complex-object

We define a complex-object as an object characterized by a variable surface characteristics, which cannot be determined a priori:

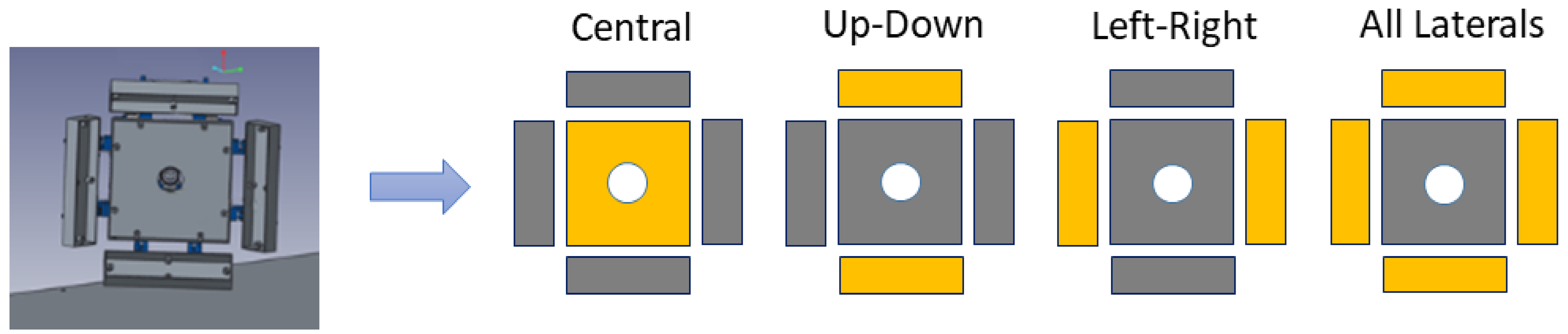
- **Geometrical Shape:** flat, curved or prismatic;
- **Materials:** specular, diffusive, directional or transparent materials;
- **Patterns and adornments** can be present;
- **Defects and irregularities** are heterogeneous and not fully categorizable.



Proposed hardware

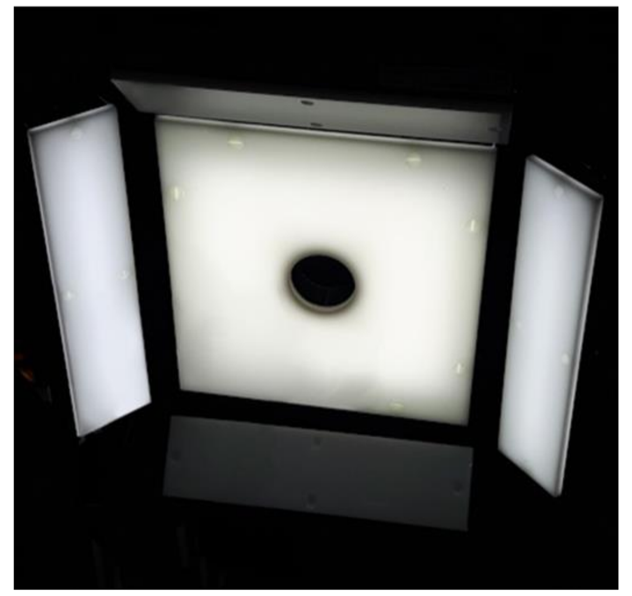
We designed and developed a lighting setup composed of five flat-dome lights that alternatively activate and deactivate in different combinations. The light positioning has been empirically studied to reproduce diffused, dark-field and frontal lighting techniques, while producing the least possible glares on the specular surfaces.

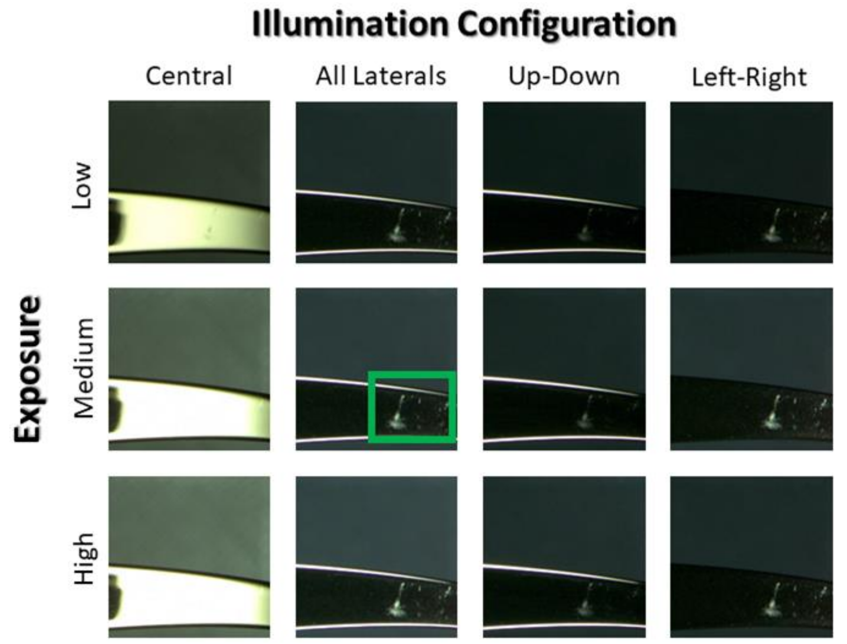
We identified four lighting configurations which allow the system to produce diffuse front lighting and dark-field lighting from vertical, horizontal and all lateral directions.



To ensure the appropriate illumination level in the acquired images, independently from the object surface reflective characteristics, each light configuration can be activated for 3 different time lengths (exposures).

Only 1 annotation per defect is required to annotate all the 12 images.





Results

Training: Single modality – Testing: Single modality

The standard industrial scenario is the baseline: we have to choose the lighting configuration to use in the system and use it for both testing and evaluation.

Train	Test	Precision	Recall	F1-score	AP
C	C	63.53	45.84	53.25	29.97
U D	U D	61.69	44.95	52.01	29.11
L R	L R	58.56	41.07	48.28	25.52
U D L R	U D L R	61.06	52.73	56.82	**34.69**

Training: Multiple modalities – Testing: Multiple modalities

In case the system deployed in production can be substituted, we can achieve the highest performance. It can be further improved using a **late-fusion** approach based on non-maximal suppression.

Train	Test	Precision	Recall	F1-score	AP
All Train	All Test	72.26	70.18	71.20	52.08
All Train + Late-fusion	All Test	58.23	90.56	70.89	**60.84**

Training: Multiple modalities – Testing: Single modality

Test time performance can be improved without changing the deployed illumination system: multimodal training makes the system able to better model the detection task to be solved.

The achieved performance using a single light modality is comparable to the one achieved deploying our custom system in test time.

The choice of test-time single illumination type does not affect significantly the achieved results.

Train	Test	Precision	Recall	F1-score	AP
All Train	C	72.61	70.23	71.39	52.29
	U D	70.69	71.22	70.95	52.27
	L R	73.76	68.87	71.23	**52.57**
	U D L R	72.11	70.37	71.23	52.38