Optical simulation of scratch repair in F/A-18C transparencies

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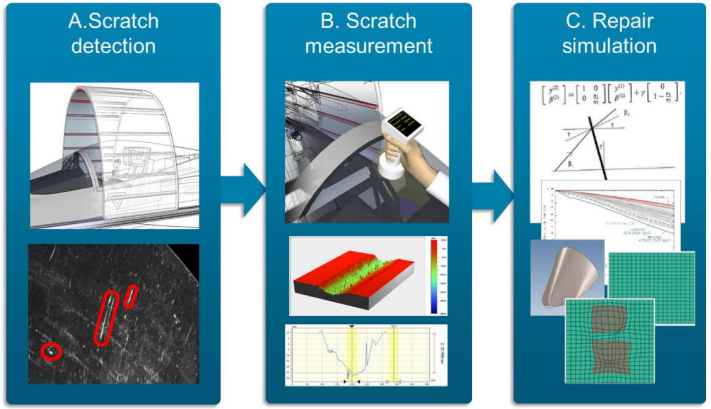
Outline

- Background (“XPARENCY” 2013-2016)
  - Quantify optical distortions in F/A-18C transparencies (“on a/c”)
    - Machine-vision based fully automatic “on a/c” system → new Life Cycle Support service product to Insta (NSN № exists)
  - Build add-on features onto developed “on a/c” system

- Assess scratch repair of transparencies (“on a/c”)
  - Expand above optical distortion system:
    - Scratch/dent detection
    - Scratch/dent measurement
    - Repair simulation



“on a/c” = on aircraft
“XPARENCY “ = Transparency (project name)

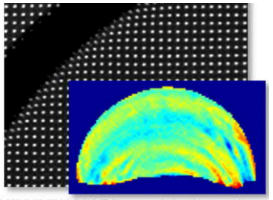
Background (see ICAF 2019)

Quantify optical distortions in F/A-18C transparencies (“on-a/c”)

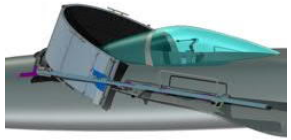
- The FINAF need
  - a fully automated capability to measure & quantify optical distortions “on a/c” transparencies
    - Systematic, reproducible results, remove subjectivity → an automated system
    - Classify transparencies to their usability (pass/fail/subject to repair) → provide information for maintenance
    - Service history in view of sustainment aspects → track changes in transparencies
    - Measure without removing transparencies from a/c
- FINAF tasked VTT
  - Develop an automated, “on a/c” optical distortion detection & quantification system for FINAF F/A-18 transparencies (windshield & canopy)

XPARENCY Phase 1 Lab system
ASTM F733 & F2156

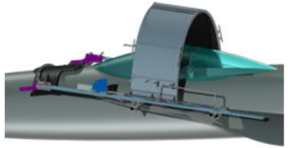
“Off a/c” system



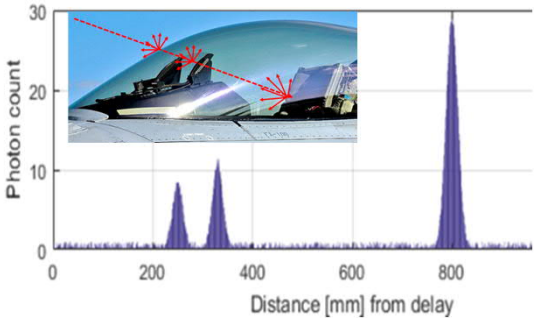
XPARENCY Phase 1 Lab system
Projector-based Approach (new)



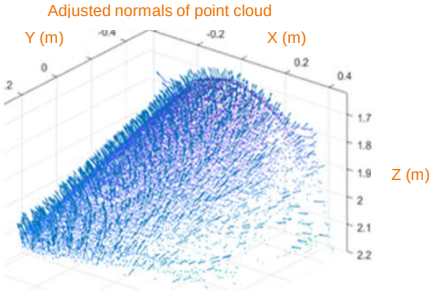
“On a/c “system



Scratch detection



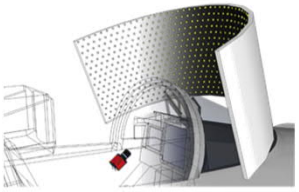
SPAD TOF: Laser pulse illumination (picoseconds), records individual scattered photons as a function of time (spot measurement, image by mechanical scanning)

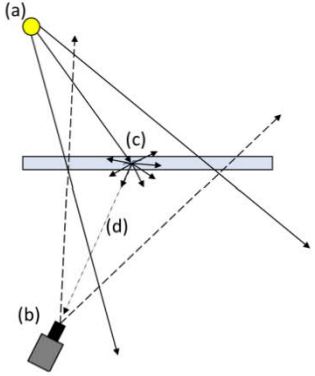


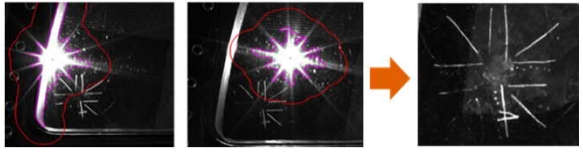
- Goal
  - Map scratches/dents (windshield & canopy) with preliminary information about their severity
    - Automatic, machine vison-based "on a/c" system
    - Pilot's view per zone (move eyes / head / torso)
      - Thru HUD & outside HUD

- Two techniques tested in feasibility phase:
  - 3D LIDAR imaging (SPAD TOF)
  - Dark Field Imaging (DFI)

Dark Field Imaging





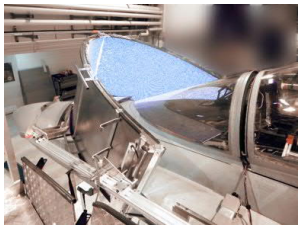


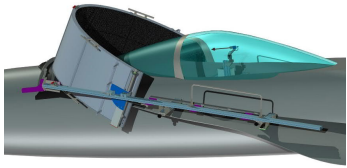
Scratch detection

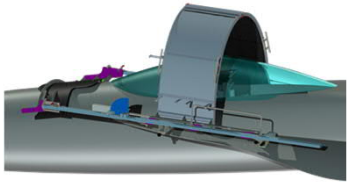
Chosen concept: Dark Filed Imaging

- Programmable matrix LED illumination embedded in the “arch”

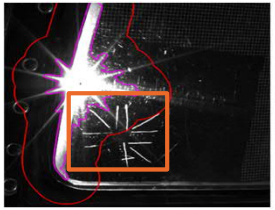
- Measurement process
  1. Turn each led on individually
  2. Take image
  3. Extract the dark field area (areas surrounding the led)
  4. Add to stack







LED 1



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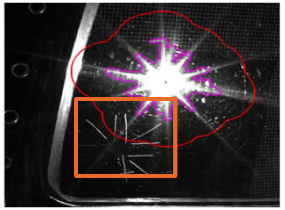
LED 2



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LED 3-*N*

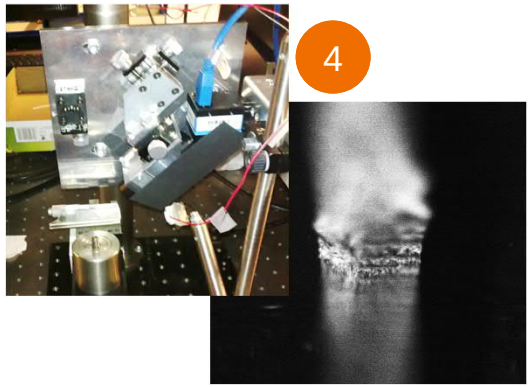
=

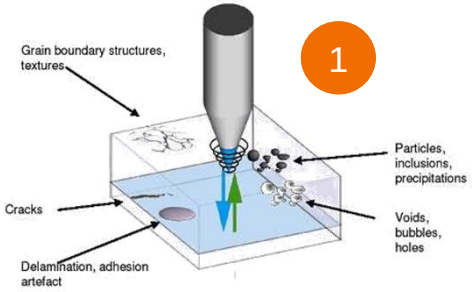
Combined dark field area from *N* LEDs

Scratch measurement

- Goal:
  - Most potential technology accurate measurement of scratches and dents (emphasis on depth)
  - Preferably a hand-held instrument

- Potential technologies:
  1. Ultrasound, acoustic microscopy (UA, SAM, C-SAM)
  2. Optical coherence tomography (OCT)
  3. Depth from focus (DFF) / Focus stacking
  4. Tilted focal plane imaging (TFPI)





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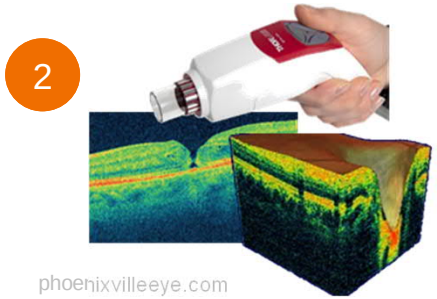

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https://www.reviewofophthalmology.com/
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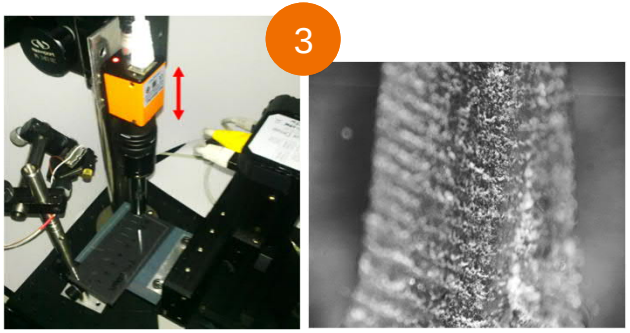


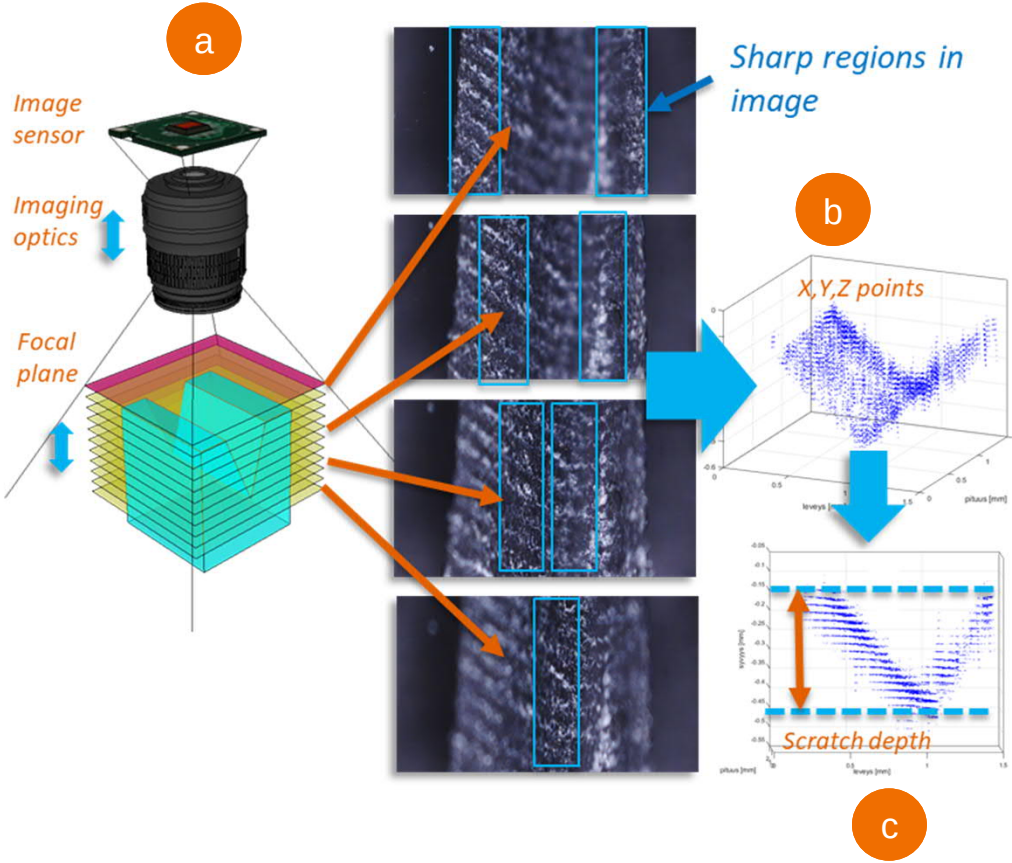
Scratch measurement

- Depth-from-focus (DFF)
  - Scratch depth estimation principle

    a) Capture defect images w/ even intervals (depth-wise)

    b) Estimate the sharpest image in the stack for each pixel position

    c) Finally, compute the depth of the defect by estimating the top and the bottom (dashed line) of the defect



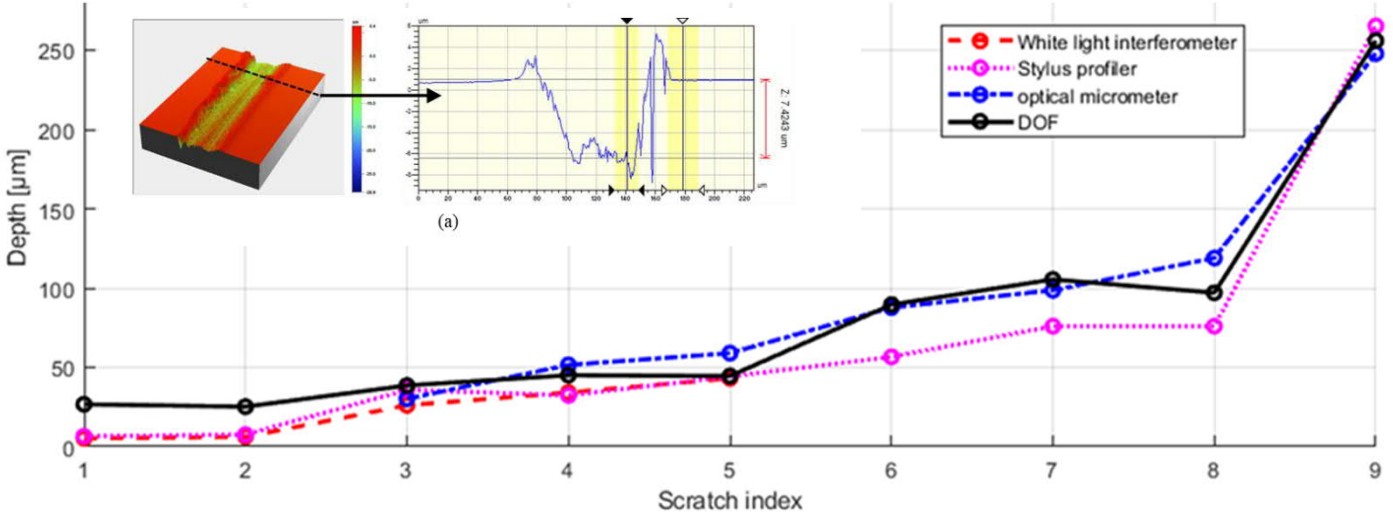
Scratch measurement

Depth-from-focus (DFF) → handheld prototype

- Handheld system for defect dimensioning
  - User friendly for “on a/c” maintenance
    - industrial digital camera
    - microscopy optics
    - a motor
    - a microcontroller
    - buttons
    - a color display as a user interface

Scratch measurement

- Reference object w/ real scratches, measured with VTT's profilometers
  - White light interferometer Wyko NT3300
    - scanning profilometer, resolution up to 0.1nm
  - Stylus based profilometer Veeco Dektak 150
    - resolution up to 1nm
  - Optical micrometer
  - DFF (DOF)

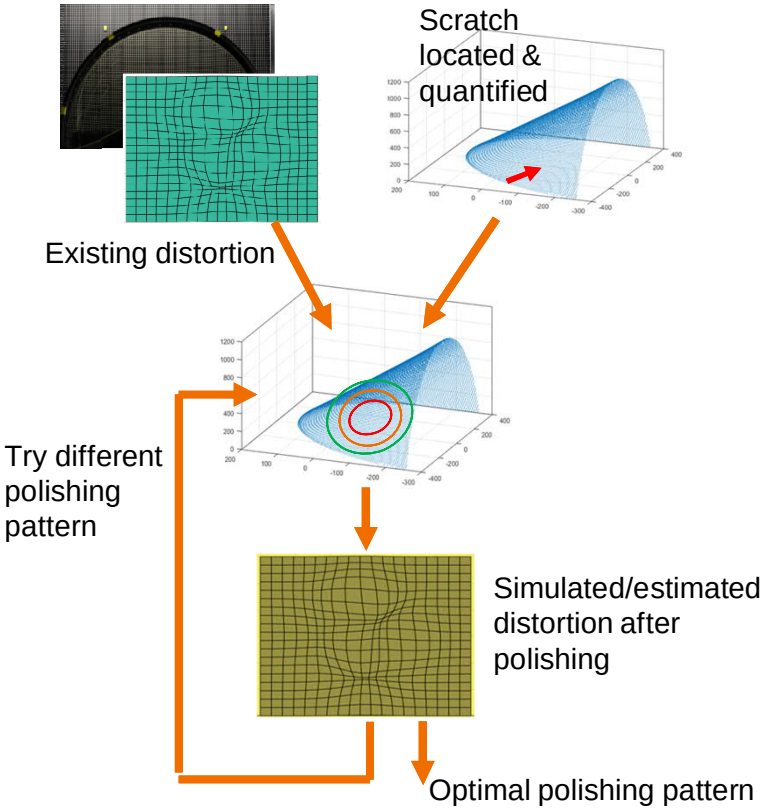


Repair simulation

Goal:Simple tool for assessing scratch repair and supporting polishing process

- Output
  - How to do the polishing in order to minimize induced distortion
  - Where to do the polishing, maintenance optimization

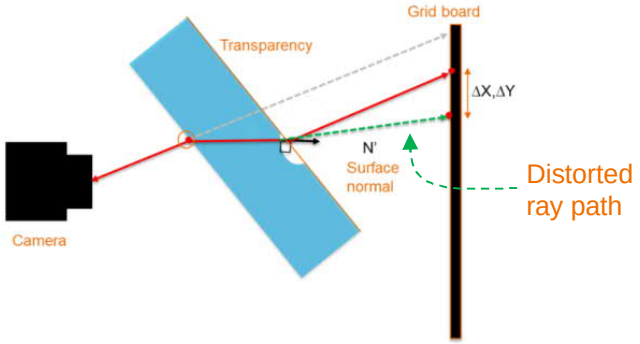
- Process
  1. Measure distortion map
  2. Locate and measure scratch/dent
  3. Try different variations of polishing “shapes
     - Choose a variation
     - Simulate new distortion map based on shape change
     - Choose one with minimal distortion



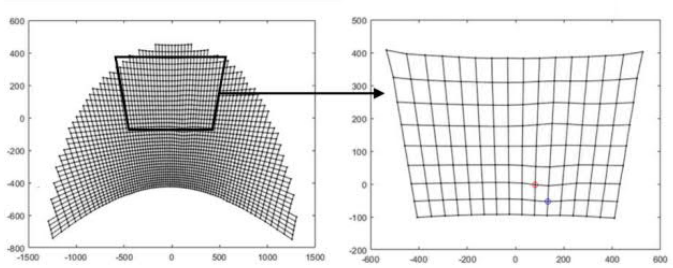
Repair simulation

Typical simulation geometry for windshield distortions

- Modeled optical layout
  - a transparent
  - ASTM-style grid board plane
  - a camera module (lens & sensor)

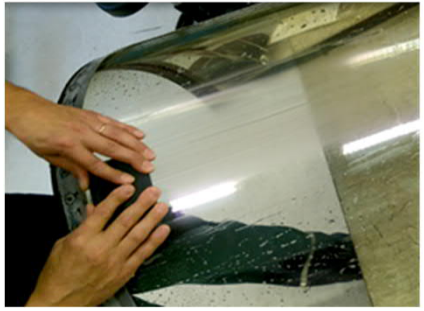


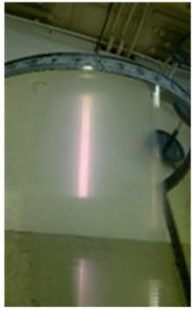
- Snell's law of refraction
- Ray tracing algorithm (camera → gridboard)
  - Model repair-induced distortion (ΔX, Δ Y) in view of surface normal N'
  - All geometry parameters adjustable
  - All transparent's distortions can be mapped to grid board images, similarly as in distortion measurements



Repair simulations were verified experimentally

Developed simulation models have been verified with real transparency repairs



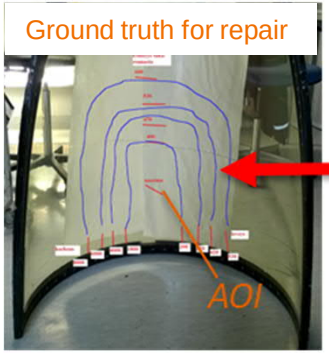


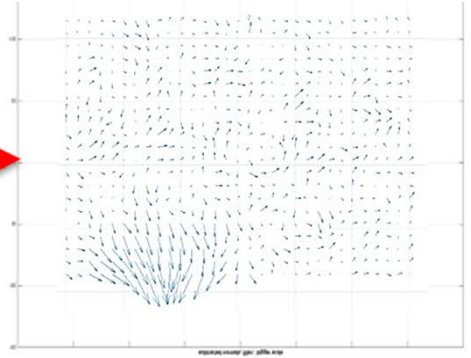
A scratch was made, measured and repaired for validating the simulation model

Reference distortion measurement (“off a/c”)

Simulated change of surface normals in AOI

Ground truth for repair





Real repair surface changes match with simulated

Summary

- Proof-of-concepts developed & fielded for FINAF F/A-18C transparencies
  - An “on a/c” optical distortion quantification system
  - An “on a/c” scratch & dent detection & quantification system
  - A repair simulation tool verified
- Benefits
  - Improved Life Cycle Support for individual transparencies
    - New products/services to Insta & Patria
    - Improved a/c availability to the FINAF
- Technology available to other a/c types & transparency manufacturers
  - VTT willing to help

Thank you!

Collaboration is the key to success

➢ Acknowledgements:

— FDF Joint Systems Centre, Combat Aircraft Section
- Funding & support throughout the years (ideas → feasibility studies → proof-of-concepts)

— Finnish Air Force
- Air Combat Center / Flight Test Section: Pilots' needs & views from cockpit
- Lapland Air Command: Transparency maintenance, repair, overhaul essentials

— Trano Oy
- Military aviators' needs & views from cockpit

— Patria Aviation
- Support in performing the repair trials & for providing related images & data

— Insta ILS
- Guidance from proof-of-concept towards productization

VTT

beyond

the obvious

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