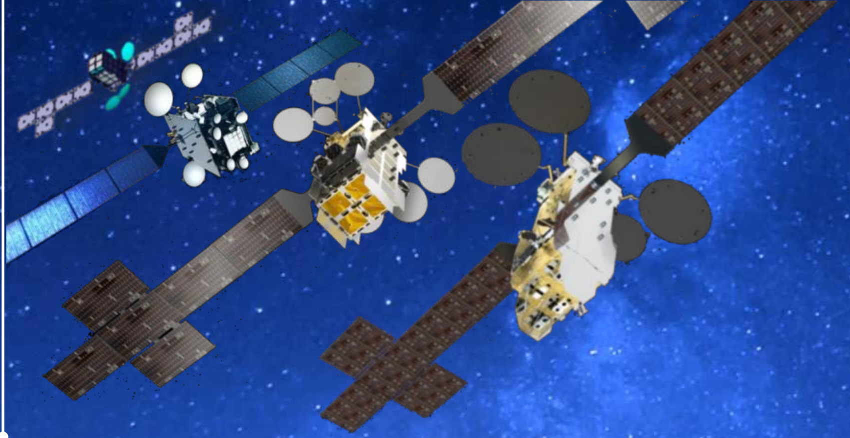

# MACHINE LEARNING FOR GNC:
## PERSPECTIVES

P. DANDRÉ

2020/10/21



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# 1 - CONTEXT

## ///WHY ?

- MORE AND MORE COMPLEX SUBSYSTEMS DIFFICULT TO BE HANDLED BY CLASSICAL GNC METHODS AND FRAMEWORK
- RECENT IMPROVEMENT IN MACHINE / DEEP LEARNING
- INCREASED ON-BOARD CPU AND FPGA CAPABILITIES OFFER NEW OPPORTUNITIES

## /// ORIGIN / OPPORTUNITIES OF MACHINE LEARNING FOR GNC

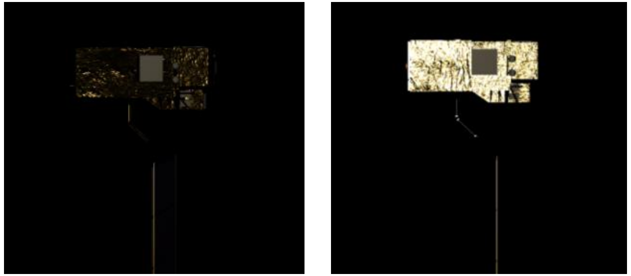
- NAVIGATION
- GUIDANCE
- CONTROL
- FDIR AND V&V

# 2 – MACHINE LEARNING OPPORTUNITIES FOR GNC

## /// NAVIGATION SOLUTION

### ORIGIN

- Large autonomy required
- Complex integration and fusion of equipments' units (LIDAR, Camera VIS/IR…) for rendezvous or landing



Impact of the illumination on Sentinel-3 model (20deg delta), mainly specular

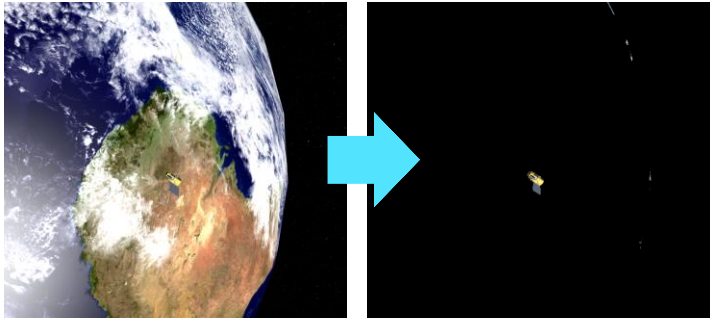
### OPPORTUNITIES

### SATELLITE BACKGROUND SEGMENTATION / EXTRACTION

- Solution for autonomous rendezvous with collaborative / non-collaborative target

### DATA FUSION OF MULTI-SPECTRAL NAVIGATION IMAGES FOR POSE ESTIMATION

- Identification of surfaces of interests (remove rotating elements)
- Recognition of profiles per images types



Satellite Segmentation with CNN (extraction from background prior Pose Estimation)



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# 2 – MACHINE LEARNING OPPORTUNITIES FOR GNC

## /// GUIDANCE SOLUTIONS

### /// ORIGIN

- **FOR AUTONOMOUS ELECTRICAL ORBIT RAISING,** ON ORBIT PROPAGATOR LIMITATIONS CAN LEAD TO SUBOPTIMAL PROPELLANT CONSUMPTION + NEED OF PERIODIC TC LINK (EXTRA-COTS)
- MANAGEMENT OF **IMMINENT COLLISION AVOIDANCE** SUCH AS DEBRIS OR NON-COLLABORATIVE SATELLITE (LEARNING FROM COLLISION AVOIDANCE FOR AUTONMOUS CARS)
- **UNPREDICTABLE** CONDITIONS (E.G. LANDING SITE DETERMINATION ON ASTEROID)

### /// OPPORTUNITIES

- TRAJECTORY UNDER VARIOUS AND COMPLEX CONSTRAINTS (AVOIDANCE, TM/TC LINK…) AND MULTI-OBJECTIVE AND MULTI-AGENT OPTIMISATION
  - Guidance strategy under complex gravitational environment (microgravity, multi-bodies)
  - Autonomous orbit raising and station keeping



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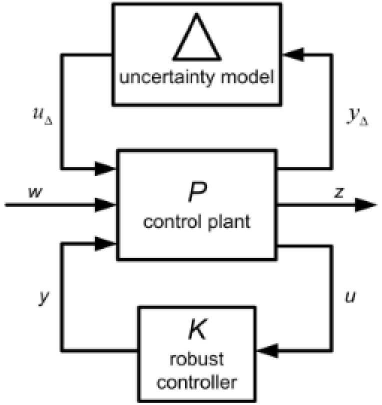
# 2 – MACHINE LEARNING OPPORTUNITIES FOR GNC

## /// CONTROL SOLUTIONS

### / CLASSICAL APPROACH: PLANT MODELLING

- POSSIBLE **non conservative** SOLUTIONS:
  - Limitations on plant modelling and robust control synthesis with **complex** systems: strong non-linear system, ageing degradation, large variations of the system features (inertia, flexible modes, unit's failure…)
    - ➢ Possible support to robust synthesis to reduce classical margins.
  - Synthesis based on predefined and limited initial conditions and uncertainty domain (predefined trajectories, predefined environment conditions )
    - ➢ Switch of control laws not suited to critical operations (rendezvous…)
- POSSIBLE **conservative** SOLUTIONS (correlated uncertainty parameters) leading to non-realistic uncertainty domain and non-optimum solution
  - ➢ Switch of control laws not suited to critical operations (rendezvous…)
  - ➢ Suitability in AOCS performances to the **real** system




Classical robust μ-synthesis

Uncertainty domain

Actual satellite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# 2 – MACHINE LEARNING OPPORTUNITIES FOR GNC

## /// FDIR SOLUTIONS

## /// ORIGIN

- DATABASE OF MORE THAN **100 000 PARAMETERS** LEADING TO **COMPLEX FINE FDIR TUNING**
- **NEED OF LARGE AUTONOMY:**
  - CONSTELLATIONS : Discriminate against false positives and anticipate faults
  - RENDEZ-VOUS : DOCKING, BERTHING, LANDING…

## /// OPPORTUNITIES

- PREVENTIVE DETECTION OF ANOMALIES / **PREDICITVE MAINTENANCE** (BEFORE FDIR TRIGGERING)
  - Improve AOCS units usage (minimize usage outside its flight domain)
  - Constellation fleet management (e.g. anticipation of satellite replacement)
- FAULT DIAGNOSTIC IMPROVEMENT (E.G. REDUCE SAFE MODE ACTIVATION)
- HAZARD DETECTION AND COLLISION AVOIDANCE FOR SAFE RDV, LANDING

# 2 – MACHINE LEARNING OPPORTUNITIES FOR GNC

## /// POSSIBLE V&V SOLUTIONS

### / SYSTEM IDENTIFICATION:

- **ORIGIN**:
  - More and more complex modelling VS Monte Carlo analysis (high nb of simulation runs): computational limitations
  - Difficulty to estimate spacecraft characteristics (CoM…)
- **OPPORTUNITIES**:
  - Modelling reduction with reduced computational load and increased confidence level
  - CoM / Inertia / Flexible mode estimation to improve manoeuvre efficiency / AOCS pointing performances

### / DETECTION OF FAULTY EQUIPMENT UNIT (E.G. **TRENDS ANALYSIS** IN AIT)

- **ORIGIN**: Huge amount of data difficult to analyse deeply
- **OPPORTUNITIES**: identify patterns (fault, deviation…)

Population coverage

| Confidence level | 68.3% | 95.4% | 99.7% |
|---|---|---|---|
| 99.9% | 25 | 199 | 3416 |
| 99.5% | 20 | 160 | 2749 |
| 99% | 18 | 143 | 2456 |
| 95% | 13 | 103 | 1756 |

Wilks formula:
Monte carlo runs number


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# 5 - CONCLUSION

/// MACHINE / DEEP LEARNING IS NOT:

- A magical tool suited for all GNC issues
- Against classical GNC methods and framework: **hybrid solutions** are possible

/// MANY POSSIBLE APPLICATIONS FOR ALL DOMAINS OF THE GNC (NAVIGATION / GUIDANCE / CONTROL / FDIR / V&V) including:

- **IMAGE PROCESSING** as first layer of navigation solutions (hybrid solutions with Kalman filtering and a posteriori verification)
- **PREVENTIVE DETECTION OF ANOMALIES** for constellations
- **SYSTEM IDENTIFICATION** in support to robust synthesis / IOT and maintenance phases support

/// GAPS:

- **FORMAL VERIFICATION** OF MACHINE LEARNING / DEEP LEARNING ALGORITHMS (BIAS VERIFICATION)
- **COMPUTATIONAL LOAD OF ON-BOARD COMPUTER** (DEEP LEARNING WITH GPU)

➢ FIRST STEP: integration on ground tools





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