Towards a Cubesat Autonomicity Capability Model (CACM) v2

Panel:
Autonomy Control at Work: Cars, Robots, Drones, Satellites and all other resources
(Main Features, Vision, Sensing, Trustfulness, Stability, ...)

ICAS 2020

Panel position: Autonomy @ work via Autonomicity …
an example study with CubeSats

Towards a CubeSat Autonomicity Capability Model (CACM)

Updated from Adaptive 2018

Gama, C., Sterritt, R., Wilkie, G., & Hawe, G. (2018). "Towards a Cubesat Autonomicity Capability Model A Roadmap for Autonomicity in Cubesats." Proc. The Tenth International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2018) - Barcelona, Spain., Feb 2018 (pp. 34-43). International Academy, Research, and Industry Association.
https://pure.ulster.ac.uk/en/publications/towards-a-cubesat-autonomicity-capability-model-a-roadmap-for-aut

Towards a Cubesat Autonomicity Capability Model (CACM) v2

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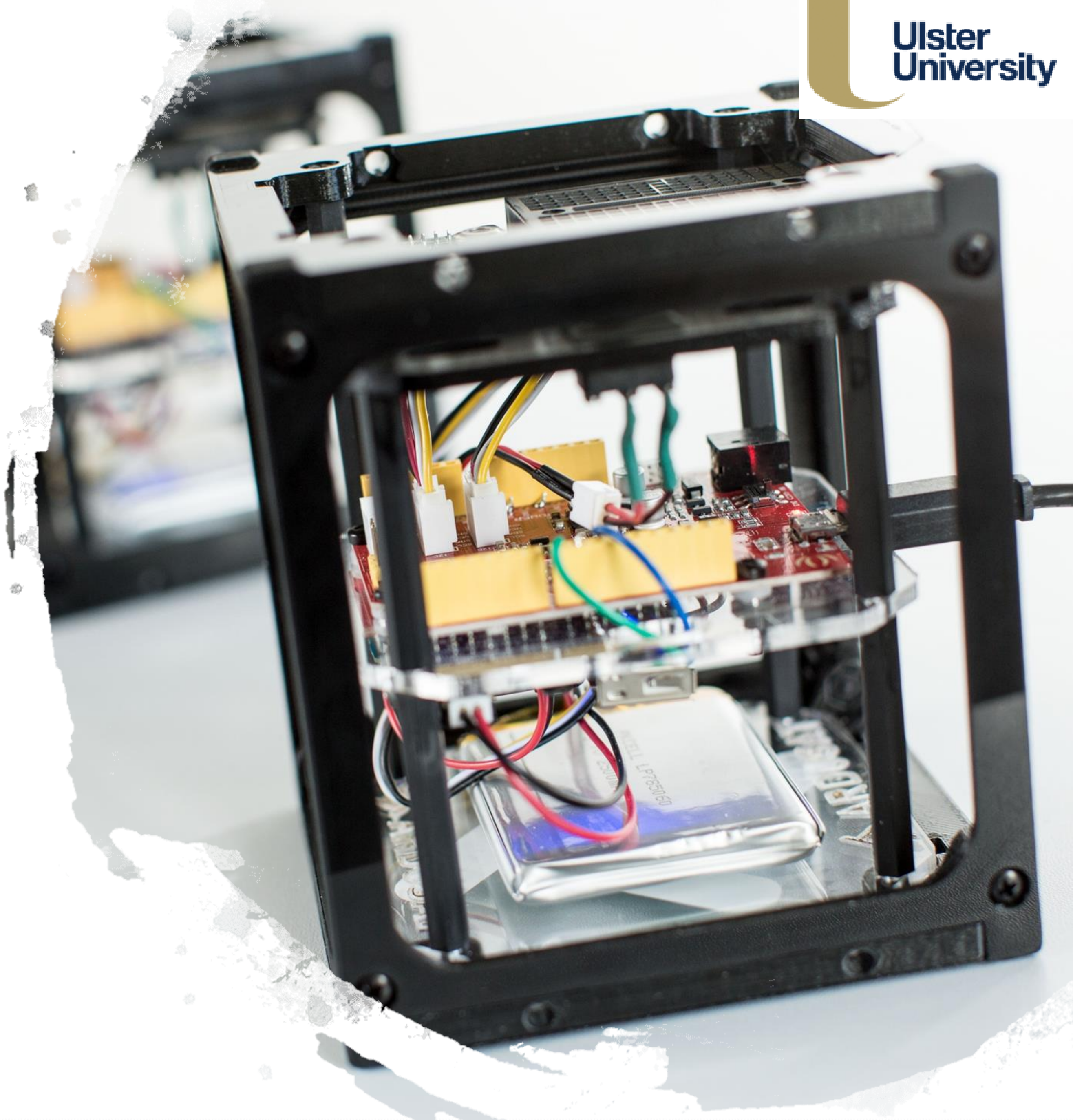


Overview

- Introduction
- Background Context
- Research Hypotheses
- Roadmap for Autonomicity in Cubesats
- Kill Switch – Exemplar Application
- Summary

Introduction

To investigate the applicability of autonomic computing in cubesats, and introduce a roadmap for future autonomic cubesat development (a Cubesat Autonomic Capability Model (CACM))

- Autonomous systems are also known as Unmanned Systems, Unmanned Aerial Vehicles, Unmanned Underwater Vehicles and Unmanned Ground Vehicles.
- CACM inspired by:
  - IBM 2001 autonomic computing model (incorporating 5 levels)
  - Autonomy Levels Framework (ALFUS)
  - Automotive Driving Automation Levels Model
  - Capability Maturity Model Integration

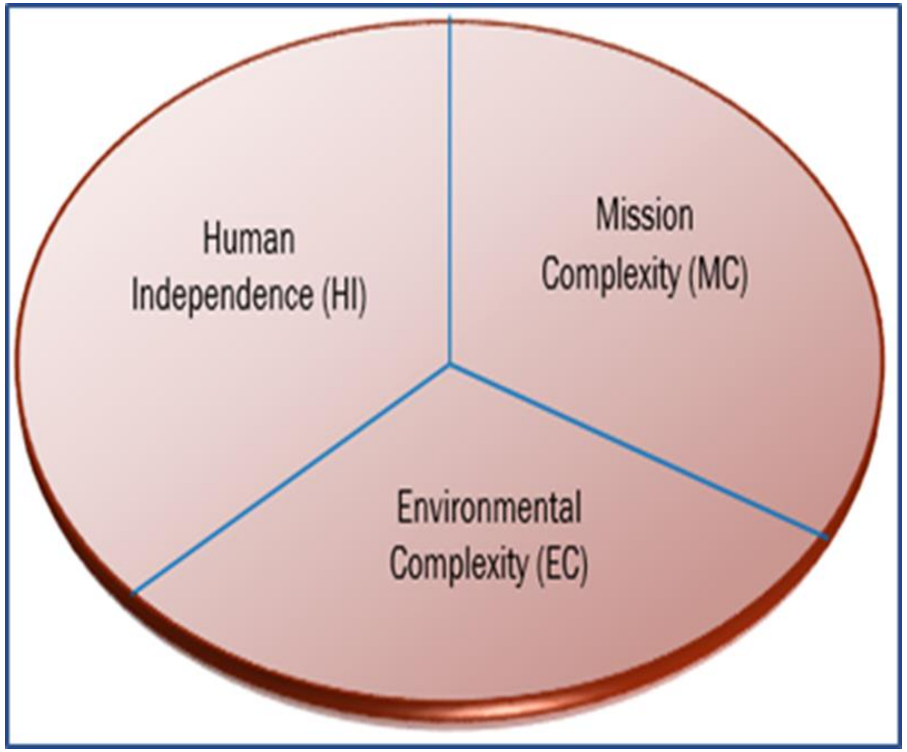
IBM 2001 Autonomic Model

Levels	Characteristics	Skills	Benefits
Level 5 Autonomic	Integrated IT components are collectively and dynamically managed by business rules and policies	IT staff focuses on enabling business needs	Business policy drives IT management Business agility
Level 4 Adaptive	IT components, individually and collectively, able to monitor, correlate, analyse and take action with minimal human intervention	IT staff manages performance against SLAs	Balanced human / system interaction IT agility and resiliency
Level 3 Predictive	Individual IT components and systems able to monitor, correlate and analyse the environment and recommend actions	IT staff approves and initiates actions	Reduced dependency on deep skills Faster / better decision making
Level 2 Managed	Management software in place to provide consolidation, facilitation and automation of IT tasks	IT staff analyses and takes actions	Greater system awareness Improved productivity
Level 1 Basic	Rely on system reports, product documentation, and manual actions to configure, optimize, heal and protect individual IT components	Requires extensive, highly skilled IT staff	Basic requirements addressed

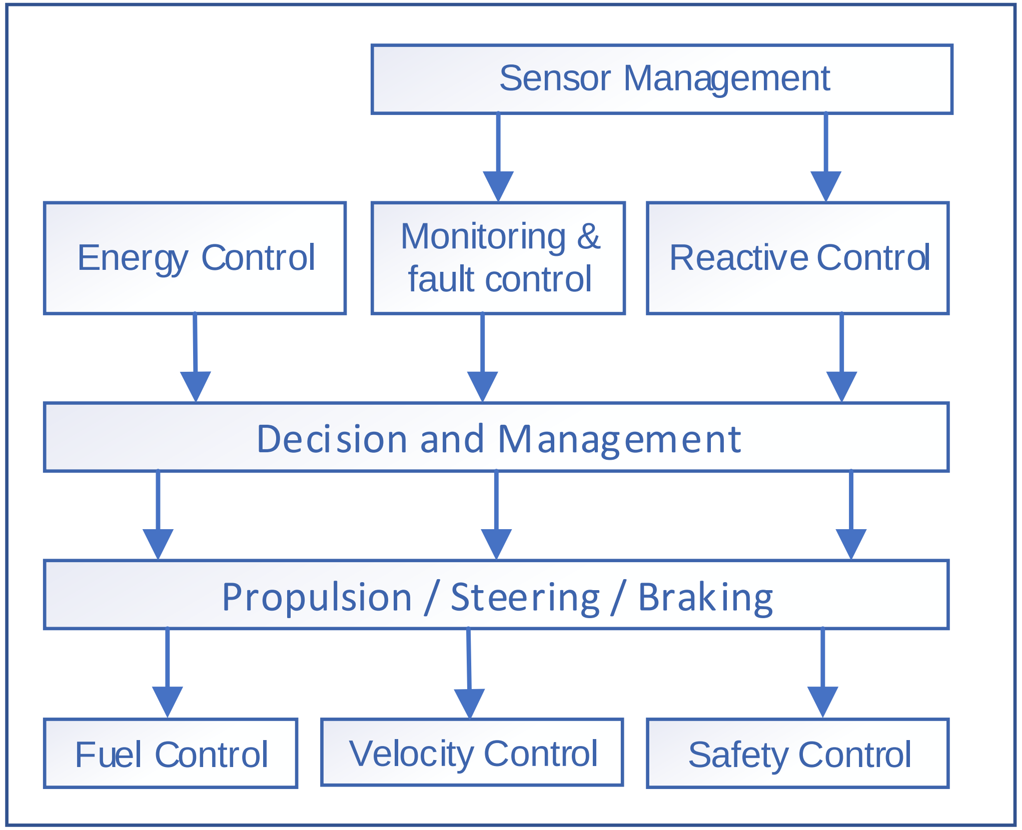
Derived from the IBM 2001 Autonomic Computing Adoption Levels

Autonomy Levels Framework

- IBM Model suitable for stationary computing systems
  - Dedicated environment – lots of processing power
- Model does not work for mobile computing: UMSs & spacecraft
- Ad-Hoc Working group developed: Autonomy Levels For Unmanned Systems (ALFUS) Framework.
- Customised version of AC to address underwater, aerial & over ground AC issues using the following categories:
  - Mission Complexity (MC)
  - Environmental Complexity (EC)
  - Human Independence (HI)



Autonomy in the Automotive Industry



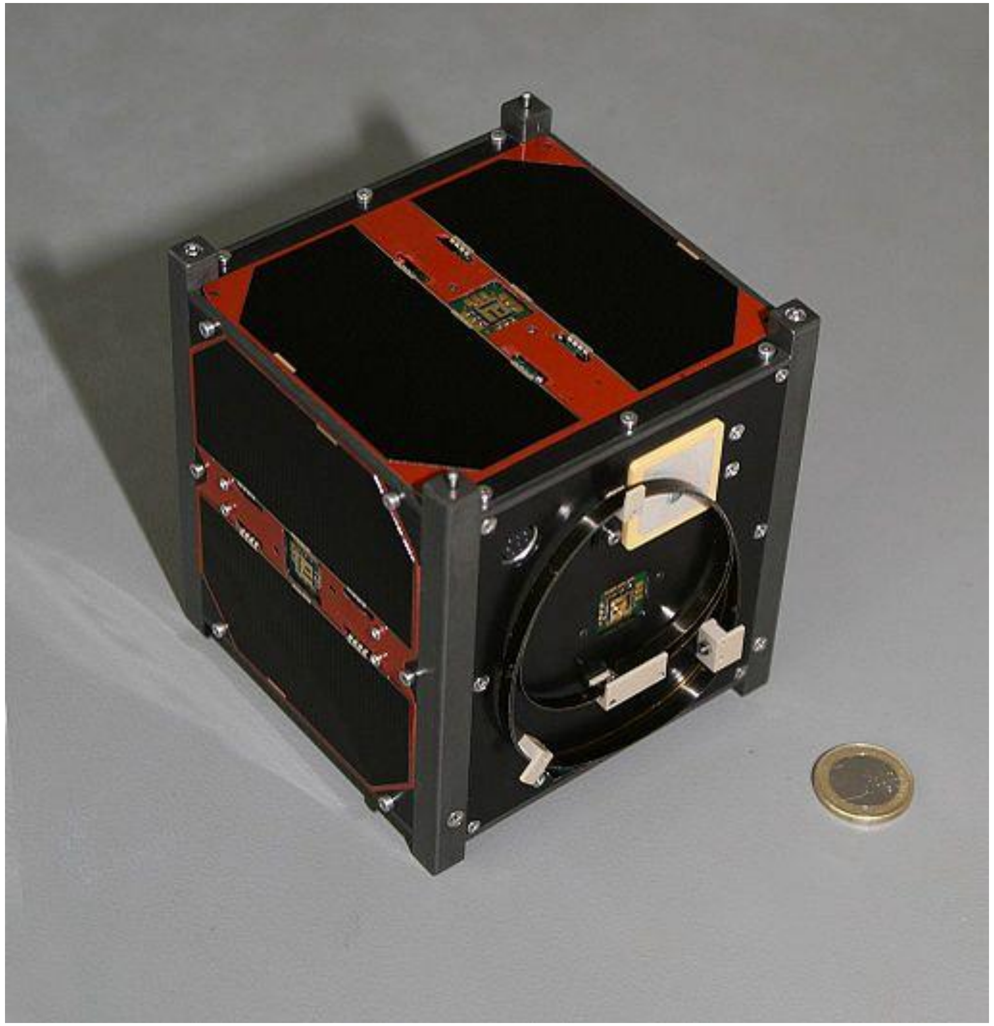
An adapted modular architecture of an autonomous car

- Working on self-driving cars
- Autonomous cars control: steering wheel, acceleration, brakes, gears & clutch
- Autonomy still a major problem
  - An autonomous car failed every 3 hours in California in 2016
  - DMV published 2,500 autonomic cars failed in 2016
- Autonomic cars mimic a human driver
  - they use live streaming of sensory values to understand the current situation

Capability Maturity Model Integration (CMMI)

- Industry best practices model – roadmap giving guidance for improvement specifically in the area of software engineering via a layered approach
- CMMI has associate appraisal tools and training materials, which help motivate, inspire and support software engineers - Successful example
- The models contain 16 process areas which are essential to software engineering (e.g. Organisational Training, Project Planning) – **what are the equivalent areas in the satellite domain?**
- Each process area decomposes into goals and practices – **can equivalent areas in the satellite domain decompose similarly?**

Cubesats



An example of a 1U cubesat

- Cubesats are microsatellites / nanosatellites that came out of a collaborative endeavour between California Polytechnic State University and Stanford University in 1999.
- Original goal: develop skills for creating LEO satellites with a limited number of scientific instruments on-board.
- Form factors: 1U (10cm x 10cm x 10cm), 2U, 3U, etc.
- No standardized autonomic features
- Becoming mainstream in test environments

Research Hypothesis 1

- An autonomic capability model can be used as a tool to educate and motivate cubesat developers on the relevance and areas of application of autonomicity in space missions.
- Follow the
  - IBM 2001 maturity model
  - Automotive Industry Autonomic Model
  - CMMI structure levels
- Develop a CACM that can form the basis for specifying autonomic features of relevance to future cubesat missions

Research Hypothesis 2

- An autonomic and apoptotic solution can address the needs of cubesats in complying with the requirements associated with space debris and will act as a suitable demonstrator to illustrate the architecture of the CACM.

- Using the tenets of the CACM, cubesats can be designed to comply with the international requirement to clean-up space debris by de-orbiting cubesats at the end of their mission or by executing the kill-switch if a cubesat develops irrecoverable error condition(s) before the end of its mission.

Roadmap for Autonomicity in Cubesats – Inspiration from Existing Models

- Cubesats are designed from the ground up for specific missions
- Mission type and goals determine size and capabilities
- Current research shows there is a lack of autonomicity in cubesats
- A proposed draft Cubesat Autonomic Capability Model (CACM) with 5 levels

Roadmap for Autonomicity in Cubesats

CUBESAT AUTONOMIC CAPABILITY MODEL (CACM)	
AC Level	Autonomic Cubesat Level Description
AC1 **Cubesat Managed from Ground Station**	Mission type is fixed – the cubesat mission parameters are hard coded. Limited on-board capability – No propulsion Always transmitting telemetry data Constellation: Participation if for information only – cannot be manoeuvred.
AC2 **Ground Station (GS) & Cubesat Shared Control**	Basic autonomicity – cubesat reports it health status to the Ground Station Default functions: Apoptotic feature, minimal propulsion Mission is pre-scheduled, mission operations on-board. Transmits data to ground station on a schedule. Constellation: Ground Station can manoeuvre cubesat.
AC3 **Single Cubesat Full Autonomic Control**	Single Cubesat Full Autonomicity – GS can intervene if deemed necessary Mission is pre-scheduled, mission operations on-board. Transmits data to ground station on line of sight Kill switch autonomously (apoptotic) executed and or by ground station. Mission goals can be adapted mid-mission
AC4 **Basic Constellation Management**	ONLY applies to Constellations Constellation cubesat missions implement Self-CHOP Execution of goal-oriented mission operations on-board. Individual members have to be at AC Level 3 - Autonomic internal systems operations. Send health status to ground station and constellation. Allows ground station to veto kill-switch execution.
AC5 **Full Autonomic Constellation Management**	ONLY applies to Constellations Goal-oriented mission operations on-board. Can self-re-initialize OS and internal systems – no human intervention Sends health status to ground stations. Only receives new mission from ground station. Kill switch notification with error details Ground Station can always intervene as and when necessary

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Roadmap for Autonomicity in Cubesats – CACM Functional Areas

Equivalent to CMMI process areas in our evolving CACM are Functional Areas:

- Mission Control (MC)
- Communication and Data Transmission (C&DT)
- Health Monitoring (HM)
- Ground Station (GS)
- Management
- Launch and Deployment (L&D)
- Electric Power Supply (EPS)
- Attitude Determination and Control System (ADCS)
- Orbit Determination and Control (ODC)
- Position Control (PC)
- Scientific Instrumentation (SI)
- Kill Switch (KS)
- De-Orbit Control
- Constellation

Space Debris

Space debris is one possible exemplar application area which would be drawn from the cubesat autonomic capability model.

- Cubesats and other small space debris - becoming a danger to larger satellites and to other cubesats
  - LEO collisions probability very high
  - 25year satellite orbit life span not adhered to by some space agencies
- NASA Orbital Debris Program Office - advocates for the removal of at least 5 large debris objects per year & mitigate Kessler Syndrome
- ESA to use cubesats to create In Orbit Demonstrations (IOD) for Active Debris Removal (ADR) technologies
- Issues: debris ownership & responsibility
  - Space weaponization - Prevention of an Arms Race in Outer Space (PAROS)

Space Debris

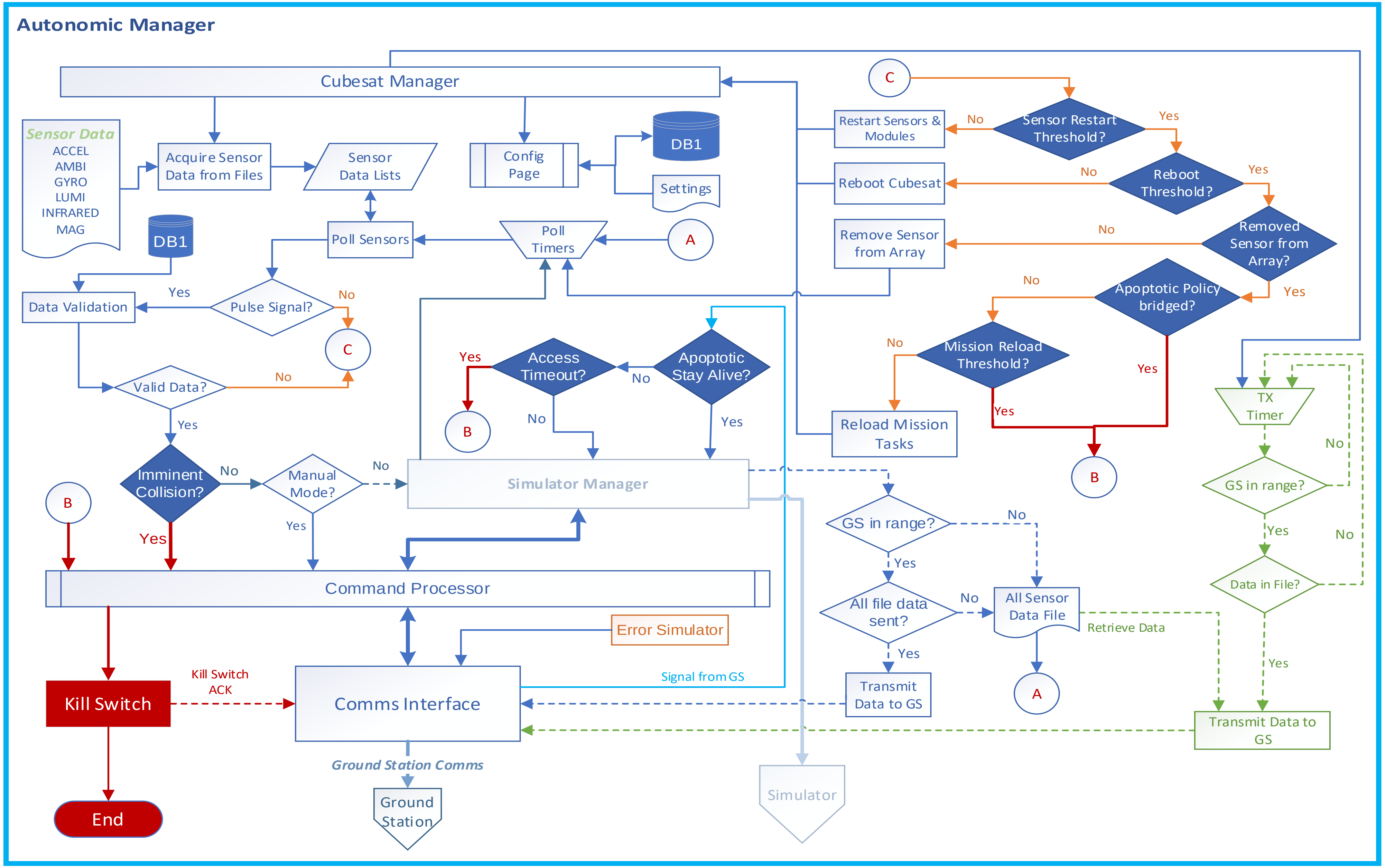
- Europe has debris mitigation standards:
- Outer Space Treaty: *The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind... Outer space shall be free for exploration and use by all States... There shall be freedom of scientific investigation in outer space*
- Treaty also refers to “harmful contamination” – high velocity debris
- Space companies opt to adhere to the treaty – not enforceable

Kill Switch – Exemplar Application

- Functional area: designed to address the space debris problem of defunct satellites remaining in active orbit for many years after their missions have ended
- All cubesats should implement a form of kill switch – deorbit cubesat to burn up in the atmosphere or graveyard orbit
- Highest autonomic level for a single cubesat is Level 3
- Levels 4 & 5 require a constellation configuration

Kill Switch – Exemplar Application

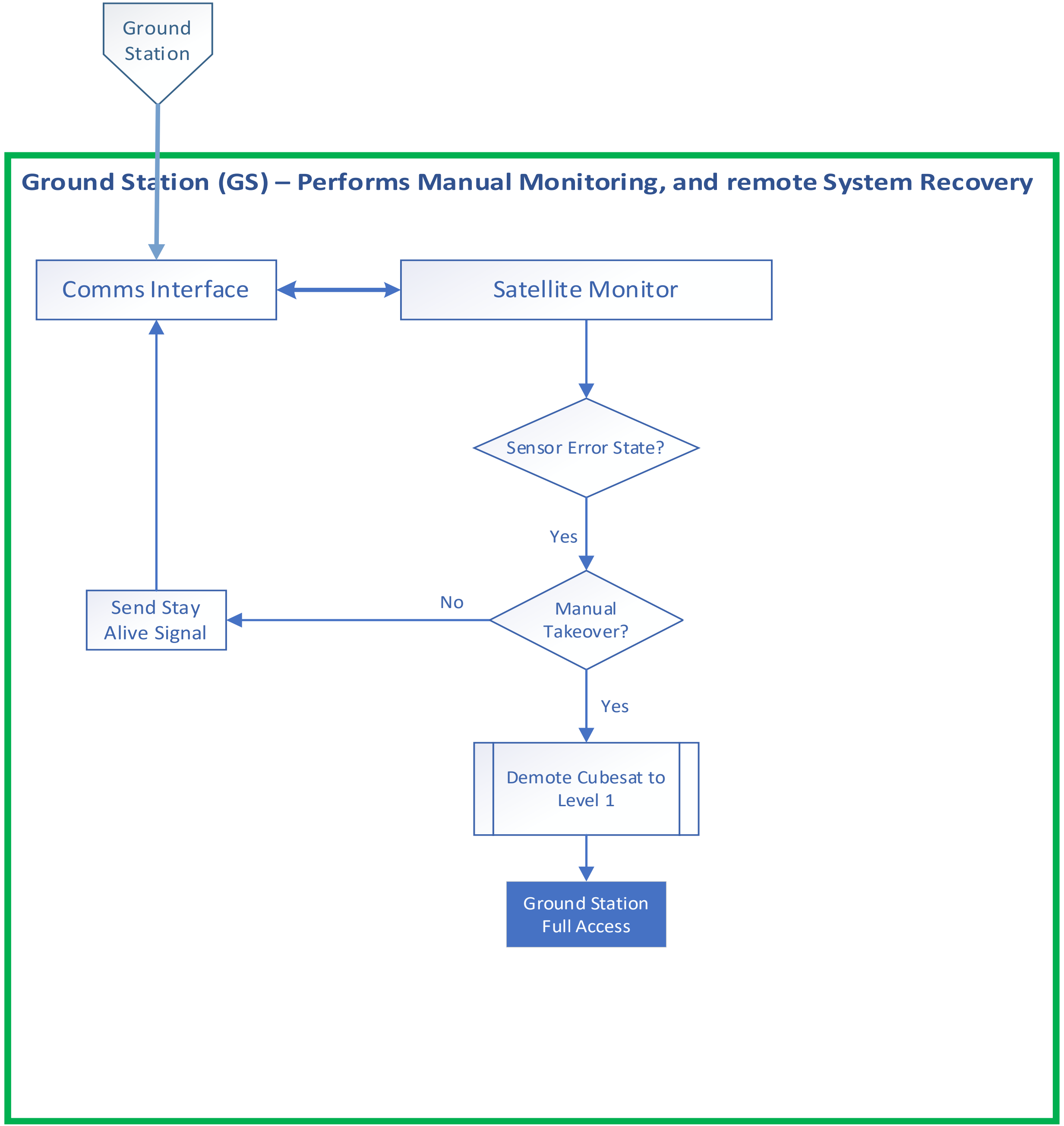
Cubesat Autonomic Capability Model Level 3

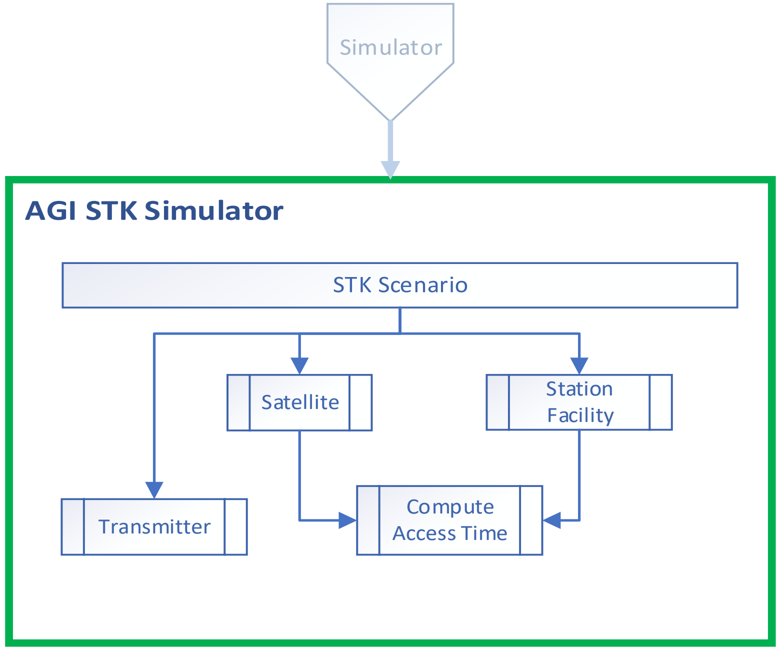


Exemplar Kill Switch application at CACM Level 3.

This is the highest level a single cubesat can implement.

Kill Switch – Exemplar Application





Exemplar Kill Switch application at CACM Level 3.

The Ground Station part is optional, only used as and when necessary

Summary

- Reviewed:
  - Autonomic Computing – defined by IBM in 2001
  - ALFUS Model
  - Autonomy in the automotive industry
  - CMMI
- Proposed and presented a brief summary of an autonomic capability model geared towards advancing cubesats and their functionality
- Further development of the CACM is being carried out in conjunction with developing an exemplar application.
- Exemplar application will be a feedback mechanism to improve the CACM

Can you help this PhD Study and give feedback?

- Please go to:
- https://www.surveymonkey.com/r/G8XH6RJ
- https://gama-c.wixsite.com/smartsats/intro
- MANY THANKS.