

# A Recommendation for a Systems Engineering Process and System Architecture for UAS

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# Agenda

- 1 Introduction
- 2 State of the Art
- 3 System Engineering Process
- 4 Framework and Tools
- 5 Architecture
- 6 Conclusion and Outlook

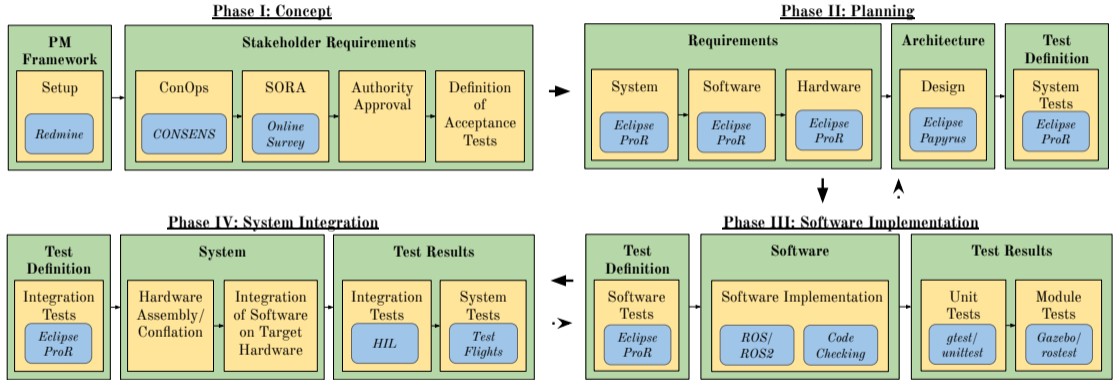
- System Engineering Process is complex and time-consuming
- Well-known methods (e.g. Waterfall, V-Model, Agile) are used across domains
- In new or rising domains, the development without a reference system is non-trivial
- We provide the development process, toolchain and architecture and our lessons learned for developing an UAV (Unmanned Aerial Vehicle)

- UAVs or UAS (Unmanned Aircraft Systems) are becoming more and more popular
- Those systems are complex and have many requirements on its software and hardware such as safety and security constraints
- Standards for UAV/ UAS are not yet available in Europe
- Expensive tooling and processes for manned aviation are used (e.g. DO-254 [1], DO-178C [2], and ARP4754A [3])
- Alternative: Open-Source Tools and a SE process suitable for UAV/ UAS



S4R drone

- E.g., Waterfall, V-Model, Agile
- DREAMS toolchain [4]
- APP4MC [5]
- And many more



S4R drone

- CONSENS [6]
- CONOPS (Concept of Operations)
- SORA [7]
- Cross-Cutting Issues
  - Traceability
  - Agile
  - Transparency
  - Iterative process

## Frameworks

- Low-Level Control
  - Pixhawk [8] (hardware) and PX4 [9] (software)
- High-Level Control
  - Robot Operating System (ROS) [10]
  - Gazebo (Simulation) [11]
- Computer Vision
  - OpenCV [12]



## Tools

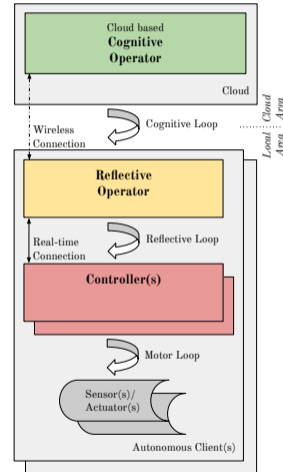
- Project Management
  - Scrum [13], Redmine [14], JIRA [15]
- Version Control
  - git [16]
- Requirements Engineering
  - CONSENS
  - Eclipse Papyrus (UML) [17]
  - Eclipse ProR [18]

## Tools

- Traceability
  - Eclipse Capra [19]
  - Polarion, MATLAB Simulink [20]
- Code Analysis and Formatting
  - cppcheck [21]
  - Flawfinder [22]
- Unit Tests
  - gtest [23]
  - unittest [24]
- Integration Tests
  - rostest [25]
  - Gazebo [11]

itemize

- Layered architecture (e.g. Strube [26])
- Operator-Controller Module (OCM) [27]



OCM based architecture

- This reference SE process including recommended frameworks and tools lowers the entrance point for other developers
- The usage of Open-Source tools is possible but not the best option for any case
- The disadvantages of those Open-Source tools could be solved by applying a consistent toolchain that spans over all development steps
- This would require interfaces capable of transferring data or models from one tool to another within the toolchain, similar to APP4MC, widely used in the automotive domain

- [1] V. Hilderman and T. Baghi, *Avionics certification: a complete guide to DO-178 (software), DO-254 (hardware)*. Avionics Communications, 2007.
- [2] L. Rierson, *Developing safety-critical software: a practical guide for aviation software and DO-178C compliance*. CRC Press, 2017.
- [3] S. International. (2020), Guidelines for Development of Civil Aircraft and Systems - ARP4754A, [Online]. Available: <https://www.sae.org/standards/content/arp4754a/> (visited on 09/09/2020).
- [4] S. Barner, A. Diewald, J. Migge, A. Syed, G. Fohler, M. Faugère, and D. G. Pérez, “Dreams toolchain: Model-driven engineering of mixed-criticality systems,” in *2017 ACM/IEEE 20th International Conference on Model Driven Engineering Languages and Systems (MODELS)*, 2017, pp. 259–269.
- [5] L. Krawczyk, C. Wolff, and D. Fruhner, “Automated distribution of software to multi-core hardware in model based embedded systems development,” in *Communications in Computer and Information Science*, vol. 538, 2015, pp. 320–329, ISBN: 9783319247694. DOI: 10.1007/978-3-319-24770-0\_28. [Online]. Available: [http://link.springer.com/10.1007/978-3-319-24770-0\\_28](http://link.springer.com/10.1007/978-3-319-24770-0_28).
- [6] J. Gausemeier, U. Frank, J. Donoth, and S. Kahl, “Specification technique for the description of self-optimizing mechatronic systems,” *Research in Engineering Design*, vol. 20, no. 4, pp. 201–223, Nov. 2009.
- [7] “Jarus guidelines on specific operations risk assessment (sora),”, 2019. [Online]. Available: [http://jarus-rpas.org/sites/jarus-rpas.org/files/jar\\_doc\\_06\\_jarus\\_sora\\_v2.0.pdf](http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v2.0.pdf).

- [8] L. Meier, P. Tanskanen, F. Fraundorfer, and M. Pollefeys, "Pixhawk: A system for autonomous flight using onboard computer vision," in *2011 IEEE International Conference on Robotics and Automation*, 2011, pp. 2992–2997.
- [9] L. Meier, D. Honegger, and M. Pollefeys, "PX4: A node-based multithreaded open source robotics framework for deeply embedded platforms," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, ISSN: 1050-4729, May 2015, pp. 6235–6240. DOI: 10.1109/ICRA.2015.7140074.
- [10] M. Quigley, K. Conley, B. P. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, and A. Y. Ng, "ROS: An open-source robot operating system," in *ICRA Workshop on Open Source Software*, 2009. [Online]. Available: <http://www.ros.org> (visited on 04/24/2018).
- [11] N. Koenig and A. Howard, "Design and use paradigms for gazebo, an open-source multi-robot simulator," in *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No.04CH37566)*, vol. 3, Sep. 2004, 2149–2154 vol.3. DOI: 10.1109/IROS.2004.1389727.
- [12] G. Bradski and A. Kaehler, *Learning OpenCV: Computer vision with the OpenCV library.* " O'Reilly Media, Inc.", 2008.
- [13] K. Schwaber and M. Beedle, *Agile software development with Scrum.* Prentice Hall Upper Saddle River, 2002, vol. 1.
- [14] A. Lesyuk, *Mastering Redmine.* Packt Publishing Ltd, 2013.
- [15] H. M. Sarkan, T. P. S. Ahmad, and A. A. Bakar, "Using jira and redmine in requirement development for agile methodology," in *2011 Malaysian Conference in Software Engineering*, IEEE, 2011, pp. 408–413.
- [16] J. Loeliger and M. McCullough, *Version Control with Git: Powerful tools and techniques for collaborative software development.* " O'Reilly Media, Inc.", 2012.

- [17] S. Gérard, C. Dumoulin, P. Tessier, and B. Selic, "Papyrus: A uml2 tool for domain-specific language modeling," in *Dagstuhl Workshop on Model-Based Engineering of Embedded Real-Time Systems*. 2007, pp. 361–368.
- [18] M. Jastram, "The pror approach: Traceability of requirements and system descriptions," PhD thesis, 2012.
- [19] S. Maro and J.-P. Steghöfer, "Capra: A configurable and extendable traceability management tool," in *2016 IEEE 24th International Requirements Engineering Conference (RE)*, IEEE, 2016, pp. 407–408.
- [20] K. Schmiechen, M. Hochstrasser, J. Rhein, C. Schropp, and F. Holzapfel, "Traceable and model-based requirements derivation, simulation, and validation using matlab simulink and polarion requirements," in *AIAA Scitech 2019 Forum*, 2019, p. 0500.
- [21] D. Marjamäki, *Cppcheck: A tool for static c/c++ code analysis*, 2013. [Online]. Available: <http://cppcheck.sourceforge.net>.
- [22] D. Wheeler. (2006), Flawfinder home page, [Online]. Available: <http://www.dwheeler.com/flawfinder>.
- [23] A. Sen, "A quick introduction to the google c++ testing framework," *IBM DeveloperWorks*, vol. 20, pp. 1–10, 2010.
- [24] A. Pajankar, *Python Unit Test Automation: Practical Techniques for Python Developers and Testers*. Apress, 2017.
- [25] Open Source Robotics Foundation and others, "Rostest," 2019. [Online]. Available: <http://wiki.ros.org/rostopic>.
- [26] G. Strube, "Modelling Motivation and Action Control in Cognitive Systems," *Mind Modelling*, no. January 1998, pp. 98–108, 1998.
- [27] R. Naumann, *Modellierung und Verarbeitung vernetzter intelligenter mechatronischer Systeme*, Fortschritt. VDI-Verl., 2000, p. 180, ISBN: 3-18-331820-2.

# Thanks for the attention!

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