Smart Factory Automation for Robotic Production of Satellite Formations and Constellations

Klaus Schilling

Computer Science VII: Robotics and Telematics
University Würzburg
Würzburg, Germany
e-mail: schi@informatik.uni-wuerzburg.de

***Abstract*—In space industry, the emerging mega-constellations, demanding thousands of satellites per year, dramatically change production approaches for satellites. Here, the transition from traditional human labour-intensive manufacturing of few satellites towards automated, robot-supported, flexible industry 4.0 production systems is progressing. The goal of this contribution is an outline of the production steps supported by automation, robotic manipulators and mobile robots for a flexible flow of materials. Specific requirements concern integrated production and testing capabilities to comply with the challenging space environment and to guarantee the mandatory high quality performance standards.**

Keywords-satellite production; intelligent distributed system; industry 4.0; robotics; intelligent manufacturing; flexible manufacturing; integration and testing .

I. INTRODUCTION

The sector of space technology sees currently disruptive changes often described by “New Space” or Space 4.0. The traditional large, multifunctional spacecraft in geostationary orbits are complemented by networks of hundreds of small satellites in Low Earth Orbits (LEO) [1][2]. Application areas address telecommunications (such as Starlink with about 1700 satellites or OneWeb with about 400 satellites launched) and Earth observation (such as Planet with about 400 nano-satellites of only 6 kg in orbit). There are plans for placing several thousand further satellites to provide a continuous service with low latency, in particular for Internet of Things (IoT) applications.

While traditionally less than a hundred satellites per year were manufactured in handwork, now small series production approaches are required to achieve outputs of a few thousand per year. The goal of this contribution is to address factory automation and robotic production processes to realize in a short period of time a sufficient number of satellites in orbit to offer the intended communication services. In parallel, the usual extremely high quality standards in integration and testing are to be guaranteed to support operations of the multi-satellite system with appropriate performance under harsh space environment conditions. Thus, challenges for advanced cyber-manufacturing systems result.

This contribution discusses in Section II the standardized satellite design suitable for automated production. Section III addresses the use of automation in the integration process, while Section IV has emphasis on related quality control and test approaches.

II. SATELLITE SYSTEM DESIGN

The challenges in the transition to automated production start already with design of the satellite suitable for later automated serial production. In contrast to traditional human labor and time intensive satellite manufacturing, now standardization and modularization of the satellite bus and of the satellite subsystems become key elements [3] - [5].

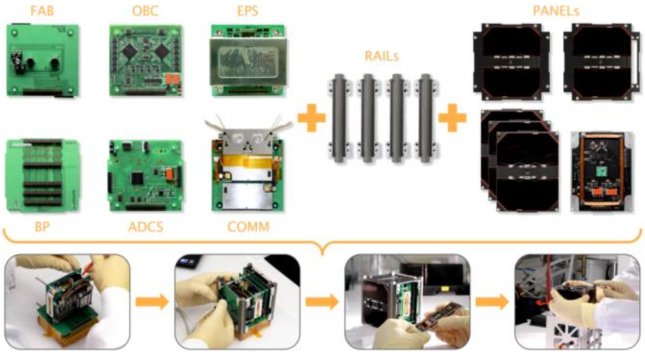

Figure 1. Modular building blocks of the satellite subsystems, supporting efficient integration onto a backplane by standardized electrical interfaces.

A digital twin accompanies the complete satellite life cycle, but in parallel modular hardware building blocks (Figure 1), too. This way, early Hardware-in-the-Loop (HiL) tests can be introduced from the beginning in order to calibrate the digital twin by real hardware performance. Typical satellite system building blocks, like subsystems for on-board data handling, communication, attitude determination and control, energy storage and distribution, are plugged by connectors on the base plate (cf. Figure 1).

ISBN: 978-1-61208-977-5

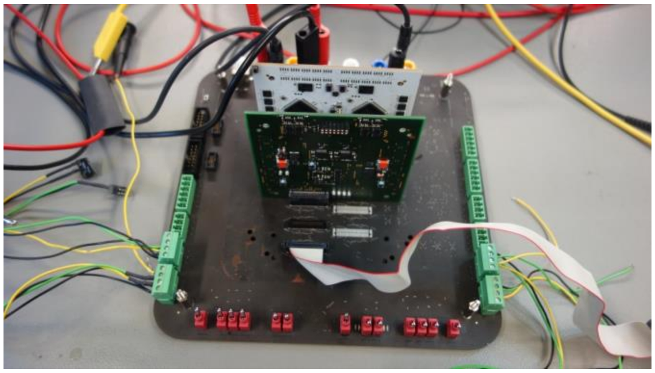

Figure 2. The UNISEC FlatSat development kit providing access for a broad range of test instruments to subsystem hardware, plugged into the base plate.

UNISEC Europe provided an advanced electrical interface definition [6] suitable for very small satellites including CubeSats. All data and power lines are physically placed in the backplane. This replaces the usual harness. Advantages of the proposed bus are robust and rapid development, integration and testing of the satellite as well as simple maintenance, extension and replacement of subsystems in the complete satellite lifecycle, from development (in a flat-sat configuration) to flight model realization (cf. Figure 2). When the satellite is in orbit, the FlatSat serves as Electrical Ground Support Equipment (EGSE), to analyze anomalies observed in satellite operations.

III. AUTOMATION IN SATELLITE INTEGRATION

There is automation already employed at the level of components and subsystems. For example, in Figure 3, the gluing of solar cells on the side panels for power generation is presented. Here, by a pneumatic end-effector, the fragile solar cells have to be placed very accurately on the side panel position to be fixed by adhesive and subsequently electrically contacted. This delicate process is handled by a force-controlled two arm robot. Software continuously monitors the health status of solar cells as well as the status of the adhesive. In particular, if a solar cell breaks during manipulation, quick reaction is necessary to avoid gluing a faulty part and thus producing a defect side panel.

Figure 3. Robotic assembly of a satellite solar array.

The automation level in satellite integration has to be adapted according to the design complexity and the number of satellites. For traditional production of just small quantities, human labor will do the integration. With increasing quantities, human-robot collaboration increases efficiency and reliability (cf. Figure 4), finally leading to fully automated processing for large quantities (cf. Figure 5). Here, robots with force control are employed to guarantee the safety of the human collaborator.

Figure 4. Human-cooperation at Zentrum for Telematics, Würzburg, to jointly integrate and test satellites. The robot acts as a third arm and contributes high precision motion capabilities.

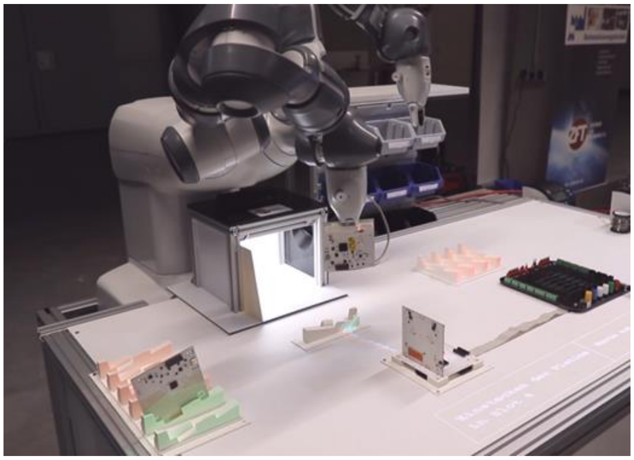

Figure 5. Fully automated integration: here, after optical quality check in the illuminated box, the robot arm moves the board to plug it into the baseplate.

In the fully automated mode (cf. Figure 5), the completed component and subsystem boards are picked by the robot from the storage area, and, after satisfactory quality checks, the integration into the base plate is performed. It uses smart

ISBN: 978-1-61208-977-5

force control of the robot to enable the very sensitive plug-in of connectors without destroying the baseplate and nevertheless providing a solid connection to tolerate the high vibration level at rocket launch.

IV. INTEGRATED SPACE ENVIRONMENT TESTING

After each integration step tests are applied to assure performance. Often, for more extensive space environment tests, the integrated parts have to be transported from the robotic work cell (cf. Figure 5) to a dedicated test area for assessment of vibration, radiation or motion and pointing capabilities. This transport is autonomously realized by mobile robots to the target facility (cf. Figure 6). Coordination by information exchange via communication links in the production environment is essential between the involved machines. In addition, results are to be transferred to the factory's process planning system in order to potentially initialize a re-planning process in case of anomalies.

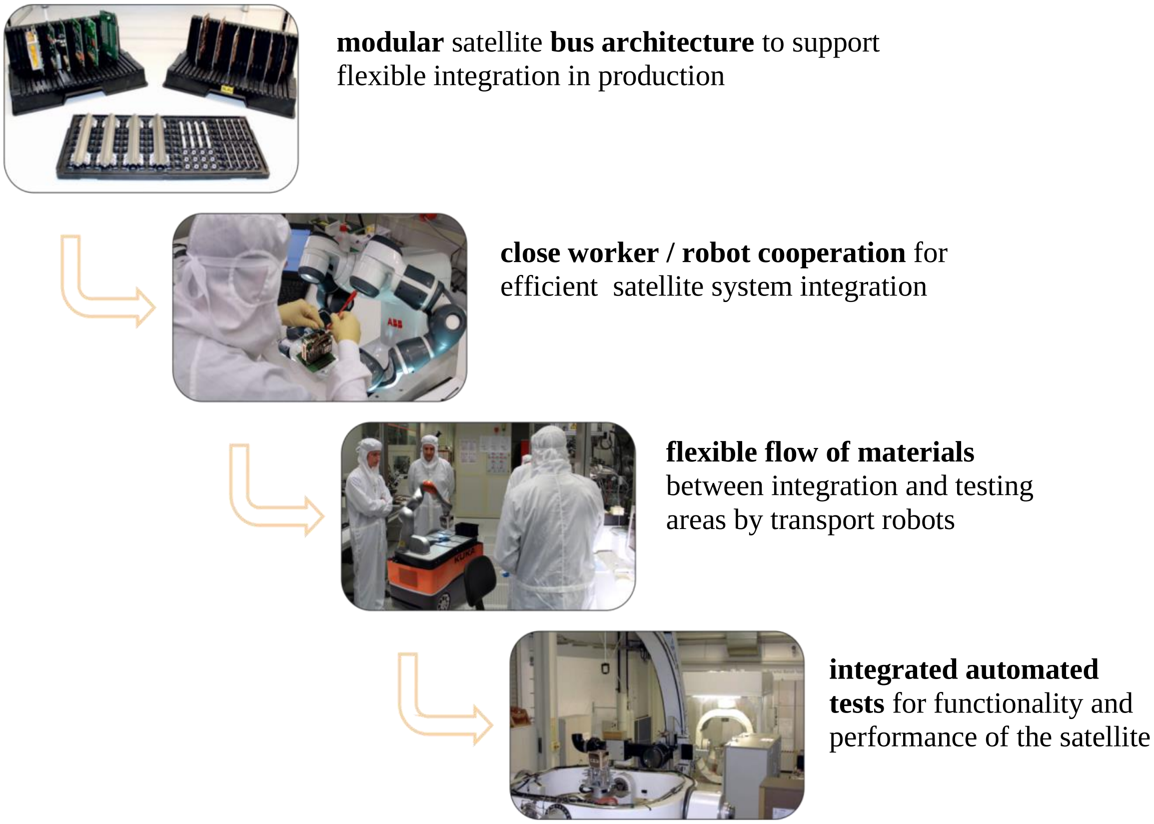

Figure 6. Process flow in satellite integration with integrated space environment testing.

Related advanced robotics and automation approaches were implemented at the Center for Telematics in Würzburg as demonstrator plant, using the example of nano-satellites. Care was taken that the applied methods are scalable to larger satellites, too. Satellites assembled this way were already placed successfully in orbit (NetSat mission launched 2020 [7]).

Similar approaches are, therefore, considered in research studies as basis for future in-orbit assembly [8]. The limitations in volume and mass by the rocket shroud often lead to very complicated designs to fold bulky parts, like deployables or arrays, for the delivery into orbit. It is always a critical and failure prone operation to unfold after deployment from the rocket. It would, therefore, be much easier to transfer the components and then finally integrate them by similar robotics to complete satellites in orbit.

V. CONCLUSION

The planned mega-constellations demand thousands of satellites to be produced in a short timeframe. This cannot be achieved by traditional satellite manufacturing. Therefore, modern consumer mass production technologies, like industry 4.0, are analyzed for transfer and adaptation to small series suitable for space environments. An approach based on modularization and standardization of satellite subsystems and components was developed and tested for nano-satellites. It demonstrated the potential of modern automation and robotics technologies in order to increase efficiency in satellite assembly.

This technology demonstrator for integrated assembly and test proved first principles and processes for efficient automated production. Suitability to comply with the challenges of the harsh space environment was demonstrated in orbit at the NetSat mission launched September 2020. Future developments will now be practiced for production of larger quantities of small satellites for telecommunication and Earth observation applications.

ACKNOWLEDGMENT

The financial support for the project “Adaptive Production” within the “Digital Production” Program of the Bavarian Ministry of Economics is acknowledged, as well as the contributions from all motivated collaborators in this project.

REFERENCES

[1] Acatech, Recommendations for Implementing the Strategic Initiative Industry 4.0 - Final report of the Industrie 4.0 working group, April 2013.

https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/ [accessed May 2022]

[2] Euroconsult, „Prospects for the small satellite market, 7th edition“, 2021.

https://digital-platform.euroconsult-ec.com/product/prospects-for-the-small-satellite-market/ [accessed May 2022]

[3] E. Hand, “Startup Liftoff”, Science Vol. 348, Issue 6231, pp. 172 – 177, 2015.

[4] N. Jones, “Mini satellites prove their scientific power”, Nature 508, pp. 300 – 301, 2014.

[5] K. Schilling and M. Dowling, “Disruptive Technology potential of Small Satellites”, The 4S Conference Proceedings, paper 320, 2016.

[6] UNISEC Europe; CubeSat Subsystem Interface Definition, 2015.

http://unisec-europe.eu/standards/bus/ [accessed May 2022]

[7] J. Scharnagl, F. Kempf, S. Dombrovski, and K. Schilling, “NetSat – Challenges of a Formation Composed of 4 Nano-Satellites”, *72th International Astronautical Congress, Dubai*, IAC-21-B4.7.8, 2021

[8] F. Kempf et al., “AI-In-Orbit-Factory – AI approaches for adaptive robotic in-orbit manufacturing of modular satellites”, *72nd International Astronautical Congress, Dubai*, IAC-21- D1.1.2, 2021.

ISBN: 978-1-61208-977-5