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ScienceDirect
Procedia Manufacturing 31 (2019) 206–212
Procedia MANUFACTURING
www.elsevier.com/locate/procedia

9th Conference on Learning Factories 2019

Example of a problem-to-course life cycle in layout and process planning at the MTA SZTAKI learning factories

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Abstract

MTA SZTAKI maintains two learning, demonstration and research facilities which are both set up to host individual student projects and repeated courses likewise. While the physical setting and facility functionalities do already establish a fundamental context linking both types of activities, recent experience has shown additional potential in building up repeatable courses on the outcome of one-off projects. The paper gives an in-progress overview of a project-to-course development based on equipment designed and built around assembly problems of existing industrial products. It is expected that such interlinking of stand-alone projects and repeated courses will become a recurring part of the operation of the facilities, therefore, a roadmap of a project-to-course life cycle is proposed as a working assumption, pending gradual refinement through subsequent experience and integration of other methodologies.

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Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.

Keywords: Human–robot collaboration; layout planning; process planning; course development

1. Introduction

Collaboration of human and robotic agents in a shared work environment is anticipated to unlock new potentials of productivity by combining complementary strengths of humans and machines, but also to transform workplaces into collaborative environments [1,6]. Much of the predicted challenges will form as the evolution of human–robot collaboration (HRC) unfolds. Therefore, education has to prepare future engineers for embracing, and most probably shaping, new paradigms in industrial production [2,10,12], by (1) openness towards new problems and solutions, and

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Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.
10.1016/j.promfg.2019.03.033

(2) a sober engineering judgment with stronger reliance on critical thinking rather than established—and de-facto little questioned—patterns. Learning factories can foster such qualities by allowing a hands-on approach to learning and experimenting in a physical environment leaning on real-life backgrounds [17], but without immediate industrial constraints that would limit openness to innovation [10]. The need for the latter has already been addressed in the learning factory community, both regarding learning content [10,18], as well as methodologies to be applied in industrial practice to tackle an unknown future [20]. In *maker spaces* [10,16], the interaction of experimenting, education and training can facilitate the uptake of new challenges and solutions that may remain overlooked in a set curriculum. Many advances are related to Industry 4.0 in general [1,12,15], and various aspects of human–machine or human–robot interaction, in particular, have also received attention [1,11,14,19]. Literature points out that learning factories still offer evolution potential to chart and explore—Tisch and Metternich [21] have named several limiting dimensions and possible ways of overcoming them. Menn *et al.* [22] show how a different type of production can shift the focus of learning from process to product—the gradually unfolding interdependencies of HRC may similarly increase the importance of the *interrelation* of process and setting aspects in the morphological placement of a learning factory or just a single workstation in it (see Abele *et al.* [17] for a definition of morphological aspects).

The paper gives an in-progress view at a selected case where workstation appliance and layout design for HRC are initially carried out in an individual project, for existing commercial products. The initial outcome made the appliance and related design problems suitable for adaptation to re-use in repeatable courses, for which a roadmap is proposed as a working assumption. At the time of writing the paper, course development is still underway, hence a critical evaluation of the roadmap—in view of actual results and already known methodologies [2,5,10,12,13]—remains to be presented once first results are available. In further parts, the paper is organized as follows. Section 2 presents the initial individual design project, along with the context of the hosting sites. Section 3 positions possible course focus in the LF morphology [17], and names extensions to be added for re-use in courses, while Section 4 proposes a structured process in which a one-off project outcome can be consolidated into course infrastructure and content.

2. From problem to individual solution

Both facilities maintained by MTA SZTAKI (the Smart Factory in Budapest [8], and the Learning Factory within the premises of Széchenyi University in Győr [9]) aim to provide infrastructure, learning content and opportunities for future production engineers, with a strong emphasis on automation and human–robot collaboration. Apart from serving as a maker space for academia and industry, the sites offer two types of learning programs: (1) independent work in one-off projects (with individual problems to solve, as part of an engineering curriculum), and (2) repeatable exercises and courses based on pre-existing content subject to feedback-based refinement.

Within an Industry 4.0 excellence initiative, a demonstration and research environment was built in 2018, centered around—optionally collaborative—robot-aided product assembly at a single workstation. Motivated by industrial inquiries, the environment was required to offer: (1) versatility in adopting product sub-types and new products of comparable size and assembly complexity, (2) flexibility in task assignment to robots or humans, and (3) value stream and information connectivity to a facility context in accordance with the Industry 4.0 character of the hosting site.

In preparation, several products were examined regarding size, complexity, as well as type and interdependencies of assembly and material handling operations. Three product families were finally selected: low-voltage push-buttons, ball valves, and pneumatic power cylinders. The assembly of the selected products feature a well-defined range of operation types (fitting and insertion of elastic seals, pins, screws, and sub-assemblies, with re-orientation and grip changes as needed) which were concentrated to a robot-accessible and observable section of the workstation

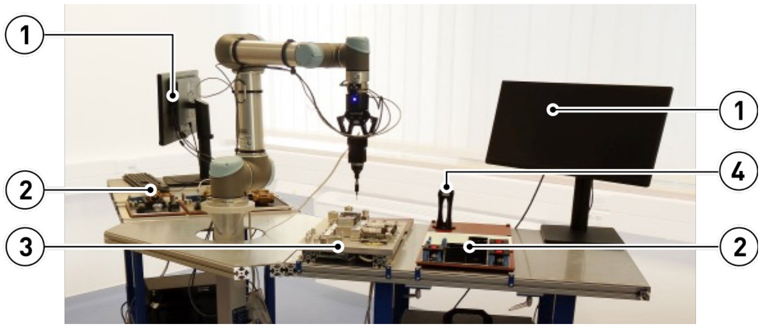

Fig. 1. HRC-enabled assembly station (1: HMI screens, 2: feeding areas, 3: core fixture, 4: tool stand).

(see Fig. 1). Further material handling and pre-assembly were assigned to other resources, or moved to peripheral areas.

As the central appliance of the workstation, a fixture features solenoid-actuated jaws and arrester pads that can be reconfigured manually during set-up. The main product components are secured in the fixture during assembly, with further parts deposited in the immediate surroundings for pre-assembly or grip change. The fixture is built to be equally accessible to the assembly robot and to human workforce, enabling multiple resource assignment choices in collaborative scenarios. The same principle is observed for tools as well—they can be fitted with adapters for dual operation. Feeding of workpieces is organized by standardized pallets. Currently, kitting and specialized pre-assembly are left to other production resources. Pallets, fixture and tools are arranged to comply with the transparency requirements of the surrounding Industry 4.0 environment. The workstation layout enables population with sensors, cameras, human–machine interface (HMI) components, and application of unique identifiers. Linking of multiple locations has become daily practice already during the elaboration of the project, as development took place at two locations simultaneously (Budapest and Győr). With designs and code shared across sites with similar physical resources, the demonstrator is a step towards cross-facility interlinking addressed in earlier publications [8,9].

Currently, the workstation has already seen use as a demonstration setup. The design of the environment was also a test of initially lifting limitations of established practice, postponing expert feedback to a later point. Automation engineers confirmed that the solution is applicable to industrial-grade equipment in a real setting, while the new potential of situation-dependent human/robot resource assignment—not part of today's engineering practice—could realistically be applied in a production context. Although systematic approaches exist [1,6,7,11], finding feasible HRC-enabled solutions to an assembly problem is still uncertain terrain—thus, it is most suitable for an individual project with room for ad-hoc response to unforeseen challenges. The outcome, however, can be re-used in repeated courses or exercises that have to comply with set requirements regarding quality and volume of knowledge involved.

3. Adaptation for re-use in courses

The above environment was selected as basis for project-oriented courses, mainly in higher education, as it is anticipated to provide sufficient degrees of freedom to explore, with the autonomy characteristic to the hands-on approaches of learning factories [10,12,13]. In the learning factory morphology [17], course topics will be identified as (1) assembly of a mature product, with (2) possible factory life cycle stages spanning (partial) factory concept, process planning, and assembly, (3) in a manual or partially automated process. Setting aspects depend partly on targeted process characteristics and partly on the nature of the implemented environment, the main focus being (1) a physical environment with digital support, (2,3) forming a life-size single work place, with (4) modularity and universality in (5) layout selection options. IT support can be implemented both preceding, and succeeding operations. Making the above presented workstation and appliances suitable for course support will include an extension in three main dimensions: (1) diversity of options available in a decision space, (2) an enriched set of infrastructural building blocks made suitable for (re-)use in repeated courses, and (3) collection of problem scenarios and connecting points to wider narratives on the level of multiple interdependent operations or an entire factory [1,4,11].

Addition of equipment options—The workstation arrangement was developed for a given set of products, with well-defined limits in geometry, material and assembly operations. Nevertheless, even these constraints leave room for new product subtypes or alternative components. Given that no commercial production is taking place, an amount of variant components sufficient for a course can be procured with rapid prototyping. The same holds for specialized gripper adapters or fixture extensions—also these can be designed and built if it falls within the selected scope of the course. Modular actuator and jaw components, and extended sensor population alternatives, will considerably enlarge the available decision space for layout design. Additional material delivery options can also be introduced based on resources already available on site [9], e.g., to offer multiple choices for structured delivery vs. bin picking.

Re-usable infrastructural building blocks—The typical volume of courses limits the effort that can realistically be exerted by a student team. Layout and process design "from the ground up" certainly transcend these limits—therefore, a set of hardware and software building blocks, "cleanly" pre-implemented functionalities and solution schemes have to be provided. Likewise, composite layout or process design primitives may facilitate the students in recognizing and experiencing important design principles if the former are not suggestive of closing in on just a few of many feasible alternatives. In the current example, the development of robust demonstration software for the one-shot initial project is still underway, but is already carried out with didactic re-use in mind. Also planned is a repository of past successful solutions to support incremental development of workstation infrastructure and course content.

Problem scenarios and narratives—Course content gains meaning in a narrative that integrates the setting of the specific problem with its place in a production network or life-cycle context. An explanation behind a specific problem serves both as motivation, and as orientation in assessing alternatives and finding perspectives that correspond to course evaluation criteria. A problem narrative also guides the institution hosting the course, giving a structured view at the sub-tasks that can be selected for elaboration in a given instance of the course, with the rest of the sub-problems provided as "pre-compiled" functional components or fixed conditions. Currently, three main contexts and associated morphological characteristics are targeted: (1) appliance design, (2) layout and process planning, and (3) linking with virtual or remote sites and replication of the solution across multiple sites.

4. Suggested roadmap for further course building and refinement

While adaptation of the equipment and elaboration of a course offering are still underway, it is already expected that such interlinking of individual projects and courses will regularly reoccur, and the incremental improvement stimulated by course outcomes will also initiate further individual projects. The prospect of a repetition of the given development case suggests the creation of a more abstract roadmap that can integrate insight from subsequent cases. As a working assumption, a first outline is proposed here within the scope of the facilities mentioned before [8,9], with dedicated phases of feedback and evaluation, as well as possibilities for loops of iterative improvement. It is important to stress that the roadmap is yet to be validated by actual development cycles, and is certain to undergo considerable changes as more insight emerges and methodologies from other sources are adopted [2,5,10,12,13]. As shown in Fig. 2 in a simplified way, the proposed phases of the development life cycle are as follows:

Phase 1: initial project—In our current case, the starter project integrated three aspects into a functional solution: (1) appliance design and construction, (2) design and implementation of software functionalities, and (3) integrated

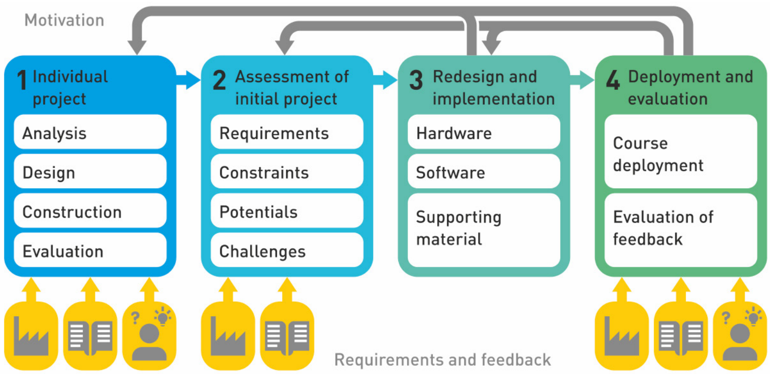

Fig. 2. Roadmap proposed for the development of courses based on the outcomes of individual projects.

layout and process planning. Given that HRC capability was targeted, care was taken to keep degrees of freedom in design and implementation as little obstructed as possible by prevailing attitudes and established practices. For this reason, direct industrial feedback was postponed to the point where tangible results were available for practical tests.

Phase 2: assessment of the initial project—Potential course narratives are identified in possibilities revealed during the first evaluation, also observing needs of targeted learning factory user groups. The outcomes determine where additional degrees of freedom are needed, and what functionalities and parallel choices have to be made available to course participants. This results in a requirements specification of extensions to full-fledged course material.

Phase 3: redesign and implementation of supporting capabilities—The aforementioned extensions are specified in detail and implemented. These can be (1) additional hardware components for layout alternatives, (2) software components, elements of machine behavior, or process building blocks, and (3) supplementary material to guide participants. Implementation can be carried out either as routine development, or as new individual projects. An integrated assessment takes place at the end of this phase, before live deployment of course material.

Phase 4: course deployment and repetitive evaluation—The deployment of a course or exercise must include the provision of student and expert feedback channels from (1) the students taking the course, (2) staff running the course, and (3) optionally, industrial experts observing the execution or the outcome of the course. Lessons learned from a given course instance can prompt refinement in a reiteration of Phase 3, or initiate new independent projects as in Phase 1. By inspiring individual projects, the interaction of one-shot projects and repeatable courses comes full circle.

At present, course development based on the assembly case has passed Phase 1 and much of Phase 2, demonstrating the feasibility of these steps. The remainder of the process is currently understood as a draft, reflecting views gained from past didactic and technical experience. Integration of the workstation and associated courses into a larger ecosystem is undergoing examination, primarily regarding (1) integration into the complex scenarios proposed for the facility in Győr [9] and (2) possible linking with other locations and distribution across several interoperable sites [8].

5. Conclusion and outlook

The paper presented a demonstration setting capable of human–robot collaboration for assembly, and its continued development for use in learning factory courses. The workstation layout, consisting of a central fixture, a robot, and peripheral feeding and pre-assembly locations, was designed by a student team in an individual project.

Work was distributed over multiple locations with interchangeable capacities. The outcomes demonstrated that feasible design decisions can be taken under temporary removal of binding industrial constraints, giving more opportunities for exploration of uncharted problem domains. Experience with the demonstration environment have motivated its re-use in regular courses, primarily in the Industry 4.0 learning factory in Győr. To this end, a multi-stage process is envisaged, integrating technical extension and course content development with repeated evaluation and iterative enhancement. Currently, a first cycle of the roadmap has not yet been completed, therefore, the proposed approach is still pending full validation. In parallel to ongoing work, the inclusion of the assembly setup into a larger Industry 4.0 environment, as well as linking with other facilities and extended work across several sites are under assessment.

Acknowledgements

The authors would like to thank the staff of the Department of Manufacturing Science and Engineering of the Budapest University of Technology and Economics for their substantial contribution to the construction of workstation equipment. Research in this paper has been supported by the GINOP-2.3.2-15-2016-00002 grant on an "Industry 4.0 research and innovation center of excellence", and by the European Commission through the H2020 project EPIC (https://www.centre-epic.eu/) under grant No. 739592.

References

[1] F. Ansaria, S. Erol, W. Sihn, Rethinking Human–Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning? Procedia Manufacturing 23 (2018) 117–122.
[2] T. Bauernhansl, M. Tzempetonidou, T. Rossmeissl, E. Groß, J. Siegert, Requirements for designing a cyber-physical system for competence development, Procedia Manufacturing 23 (2018): 201–206.
[3] H. ElMaraghy, M. Moussa, W. ElMaraghy, M. Abbas, Integrated product/system design and planning for new product family in a changeable learning factory, Procedia Manufacturing 9 (2017): 65–72.
[4] J. Enke, R. Glass, J. Metternich, Introducing a maturity model for learning factories, Procedia Manufacturing 9 (2017): 1–8.
[5] J. Enke, J. Metternich, D. Bentz, P-J. Klaes, Systematic learning factory improvement based on maturity level assessment, Procedia Manufacturing 23 (2018): 51–56.
[6] L. Johannsmeier, S. Haddadin, A hierarchical human–robot interaction-planning framework for task allocation in collaborative industrial assembly processes, IEEE Robotics and Automation Letters 2 (2017): 41–48.
[7] K.N. Kaipa, C.W. Morato, S.K. Gupta, Design of Hybrid Cells to Facilitate Safe and Efficient Human–Robot Collaboration During Assembly Operations, Journal of Computing and Information Science in Engineering 18, No. 3 (2018): 031004.
[8] Zs. Kemény, R. Beregi, J. Nacsa, R. Glawar, W. Sihn, Expanding production perspectives by collaborating learning factories—perceived needs and possibilities, Procedia Manufacturing 23 (2018) 111–116.
[9] Zs. Kemény, R. Beregi, J. Nacsa, Cs. Kardos, D. Horváth, Human–robot collaboration in the MTA SZTAKI learning factory facility at Győr, Procedia Manufacturing 23 (2018): 105–110.
[10] K. Lensing, J. Friedhoff, Designing a curriculum for the Internet-of-Things-Laboratory to foster creativity and a maker mindset within varying target groups, Procedia Manufacturing 23 (2018): 231–236.
[11] F. Ranz, T. Komenda, G. Reisinger, P. Hold, V. Hummel, W. Sihn, A Morphology of Human–Robot Collaboration Systems for Industrial Assembly, Procedia CIRP 72 (2018): 99–104.
[12] B. Schallock, C. Rybski, R. Jochem, H. Kohl, Learning Factory for Industry 4.0 to provide future skills beyond technical training, Procedia Manufacturing 23 (2018): 27–32.
[13] N. Tvenge, O. Ogorodnyk, Development of evaluation tools for learning factories in manufacturing education, Procedia Manufacturing 23 (2018): 33–38.
[14] F. Ranz, V. Hummel, W. Sihn, Capability-based task allocation in human–robot collaboration. Procedia Manufacturing 9 (2017): 182–189.
[15] H. Stern, T. Becker, Development of a Model for the Integration of Human Factors in Cyber-physical Production Systems. Procedia Manufacturing 9 (2017): 151–158.
[16] M.B. Jensen, C.C.S. Semb, S. Vindal, M. Steinert, State of the Art of Makerspaces—Success Criteria When Designing Makerspaces for Norwegian Industrial Companies. Procedia CIRP 54 (2016): 65–70.
[17] E. Abele, J. Metternich, M. Tisch, G. Chryssolouris, W. Sihn, H. ElMaraghy, V. Hummel, F. Ranz, Learning factories for research, education, and training. Procedia CIRP 32 Supplement C (2015):1–6.
[18] M. Lanz, A. Lobov, K. Katajisto, P. Mäkelä, A concept and local implementation for industry–academy collaboration and life-long learning. Procedia Manufacturing 23 (2018): 189–194.

[19] E. Groß, J. Siegert, T. Bauernhansl, Different competence areas of workers in combination with technical assistance as an enabler for mass personalization products. Procedia Manufacturing 23 (2018): 195–200.
[20] H. Karre, M. Hammer, C. Raumsauer, Learn how to cope with volatility in operations at Graz University of Technology's LEAD Factory. Procedia Manufacturing 23 (2018): 15–20.
[21] M. Tisch, J. Metternich, Potentials and limits of learning factories in research, innovation transfer, education, and training. Procedia Manufacturing 9 (2017): 89–96.
[22] J.P. Menn, F. Sieckmann, H. Kohl, G. Seliger, Learning process planning for special machinery assembly. Procedia Manufacturing 23 (2018): 75–80.