Swarm Intelligence Layer to Control Autonomous Agents (SWILT)

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Abstract. The project SWILT focuses on swarms of cyber-physical system (CPS)s in industrial plants (e.g., formed of products, machines, or equipment). CPSs find their application in many disciplines including Internet of Things (IoT), smart mobility, smart grids, Industry 4.0 and smart houses. Swarms of CPSs are even more complex, hard to control and program. To handle the complexity of swarms of CPSs, natural systems can serve as inspiration. Only through their interactions, a collective behaviour emerges to solve complex tasks. SWILT considers the use cases of production scheduling in industrial plants and transportation in logistics. Currently, linear optimization is a widely used approach but due to the increasing complexity it is typically performed only on a subset of the industrial plant. Thus, current methods are unable to cope with the search space of scheduling problems in large industrial plants. Since the problem sizes in these use cases are extremely large and pre-calculated schedules or transportation tables are not sufficient, the innovation is to use swarm algorithms with reactive local rules on individual agents which are able to compensate for dynamic system changes via local interactions within their vicinity.

Keywords: Cyber-physical system · Swarm Intelligence · Self Organization.

1 Project data

Acronym:	SWILT
Title:	Swarm Intelligence Layer to Control Autonomous Agents
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2 Introduction

Cyber-physical systems (CPSs) have strongly intertwined hardware and software components, and find their application in many disciplines including IoT, smart mobility, smart grids, Industry 4.0, and smart homes. In many cases, CPSs are connected to other CPSs forming a system of systems or a swarm. Such swarms of CPSs are even more complex, hard to control and program. This is reflected in the current situation of the manufacturing processes for wafers. The production of wafers is a highly dynamic process. Multiple machines need to be scheduled, and repeated (between 400 and 1,200 different stations during a waferfab). This results in an NP-hard problem when optimizing the WIP (work in progress) flow, as there are nearly 2,000 different products. Another main challenge is to integrate human work into optimized logistic processes.

SWILT focuses on swarms of CPSs in industrial plants (e.g., formed of products, machines, or equipment). To handle the complexity of swarms of CPSs, natural systems can serve as inspiration. Therein, many homogeneous and heterogeneous agents cooperate without central control, executing simple rules locally. Only through their interactions, a collective behaviour to solve complex tasks emerges. The SWILT concept embeds the local swarm rules in a three-layered architecture: L3 - autonomous agents, L2 - swarm control, where each swarm consists of a set of agents and their computation is intended to run as 5G network application, and L1 - central management (see Fig. 1).

3 Related Work

Other research activities combine the Particle Swarm Optimization (PSO) approach with other heuristics to improve its performance[15, 9]. The majority of related work on the application of swarm concepts in production scheduling build upon PSO or other swarm-based optimization algorithms. A notable exception is the work by Leitão and Barbosa [8] using swarm agents to create a self-organizing system for production scheduling. Another important contribution to controlling swarms of CPSs comes from research on swarm robotics.

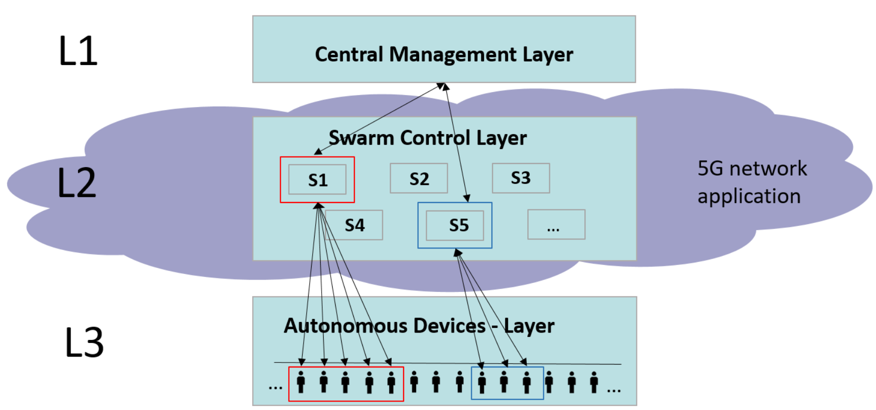

Fig. 1. The concept of applying a 5G network application.

Here, many simple small robots are coordinated in a self-organizing way following the properties of a swarm. While approaches to define an intended behaviour of a robot swarm [4, 13, 5] are inspiring for the research in this project, practical implementations of robot-swarms are mostly on an experimental basis [1, 10] or with an educational focus [7]. Overall, the state of the art shows that direct applications of swarm intelligence (other than using swarm intelligence in an optimization process), are very uncommon.

4 SWILT Project

SWILT aims at a direct application of swarm intelligence in industrial environments. SWILT performs agent-based swarm modelling of an industrial plant on the use cases of production scheduling and transportation in logistics. Since the problem sizes in these use cases are extremely large and traditional pre-calculated schedules or transportation tables are not sufficient, the innovation is to use swarm algorithms with reactive local rules on individual agents which are able to compensate dynamic changes in their local vicinity. The project will identify a library of suitable algorithms, define a model for intra- and inter-swarm communication, and will show how to apply scenario-specific swarm intelligence algorithms and how to extend swarm approaches with human-in-the-loop concepts. To handle the complex communication within an industrial environment with a huge number of agents and sensors, SWILT will elaborate the features of 5G for handling the complex communication, such as direct device-to-device communication and explicit support for communication intelligence at the edge. The still premature communication technology promises to be an ideal match for the SWILT layer concept and swarm communications in such an Industry 4.0 application.

4.1 Goals

To apply swarm intelligence algorithms to cope with NP-hard problems, the industrial plant must be modelled as a swarm of agents, where a set of components from the same type, the same category or the same objective can be interpreted as the swarm. A swarm consists of a large number of simple agents who together pursue a specific goal based on local decisions of the agents. Since multiple components interact, the goal is to construct multiple interacting swarms. Many swarm intelligence algorithms have already been introduced in literature, but they are rarely used as local algorithms in industrial plants. In a first step, a theoretical analysis of these algorithms is performed in order to test whether they are suitable for application to swarms in industrial plants. In this analysis, the requirements of the application case and the requirements of the swarm algorithm are included. Suitable algorithms are collected, the associated boundary conditions and requirements documented and adapted to an extensible library of swarm algorithms for use in industrial plants. Such a library allows us to reuse algorithms, reproduce future results and achieve higher complexity goals. With the help of the defined library for swarm algorithms, further evaluations can be done. Another goal is to find a suitable simulation environment. Challenges here are to define a simulation that models the problem accurately enough so that solutions that are elaborated based on information from such a simulation also work in the real world, bridging the reality gap. On the one hand this calls for a rather detailed and accurate simulation model, on the other hand potential methodologies such as evolutionary methods involve a high number of simulations which requires to complete thousands of simulations in short time. Potential algorithms are implemented, tested and analysed, to evaluate the effects of swarm algorithms for both use cases. Achieving this aim gives us the ability to make concrete statements on the usage of swarm algorithms in the industrial domain. SWILT also envisages several swarms that communicate in different directions, i.e., swarm2swarm, swarm2human and swarm2central communication. A related goal is to define the best suited type or combination of communication technology. In particular, SWILT will take 5G into account and derive a communication plan according to the specific characteristics of 5G. Only with the application of 5G the SWILT swarm control layer L2 is able to run totally independent from the underlying environment, to process the data on the edge as network application and to handle the high amount of data traffic produced through the mass of agents in the use cases.

4.2 Use Cases

The first use case addresses scheduling in semiconductor production systems. This use case is of interest to the application of swarm algorithms, because calculating optimal schedules is typically out of reach for such large-scale domains. In wafer production, weekly workloads can involve around 10^5 operations on 10^3 machines. [12]

The main issues are to balance local constraints (for example, a machine might process lots in batches and thus prefer to wait until a batch is (almost) full) with competing constraints such as avoiding starvation of processing and global objectives such as maximizing throughput. In complex processes such as wafer production, a mixture of different products, dynamic changes in the system and a high number of processing steps and involved machines form a scheduling problem that due to its complexity can not be solved by exhaustive search during production.

Another use case emerges from logistics in industrial plants, where the integration of human work together with automated systems forms a major challenge. Due to limited predictability and possibly limited compliance, an optimum solution including the human factor is expected to be significantly different from a logistic schedule of a completed automated system. Here swarm system are expected to provide the necessary flexibility and adaptability to integrate human work successfully.

4.3 Methodology

The selection of algorithms and the modelling of the industrial plant are performed upon the requirements/constraint analysis from the use cases. For an initial test and analysis of these algorithms a common, easily programmable simulation environment will be established that allows for fast evaluation of algorithms and exploration of the nature of the problem. A simplified model that still covers the main characteristics can also be used as a benchmark for potential solutions where existing benchmark problems [11, 3, 14] are not specific enough. Moreover, an artificial test case also allows to be made public in order to enable a reproducible evaluation of algorithms [6]. Possible platforms for a simple simulation model are implementations in Netlogo[5], MATLAB[6], or common programming languages with extensions for complex networks such as Python[7]/NetworkX[8]. Based on the initial simulation model, possible candidates for swarm algorithms will be evaluated. Besides the general paradigm (e.g., slime mold behavior, animal swarms, or other biological systems [2]) modeling of swarm agents and the fine-tuning of algorithm parameters are issues that will be addressed.

In parallel, a detailed concept for the data abstraction and communication will be defined in form of a catalogue including the requirements and constraints of the use cases. The concept will also take characteristics of communication technologies into account, e.g., from the upcoming 5G standard, in order to select the most appropriate technologies for intra- and inter-swarm communication.

Based on the use cases and requirements, test scenarios and experiments are performed to test different swarm intelligence algorithms and the communication framework. In particular, tests and analysis are related to i) the applied algorithms, ii) their convergence to a defined goal (related to requirements/constraints), iii) the quality of inter- and intra-swarm communication (data abstraction layers). The resulting algorithms will be evaluated quantitatively in a simulation based on the selected performance metrics. In addition, the solutions will be reviewed by domain experts in order to assess their applicability in a real productive setup.

5 Conclusion and Future Work

This paper introduced the SWILT project and laid out the basic design concepts that are pursued by the project. The novelty of the SWILT project is the application of swarm algorithms as a solution for coordination and scheduling problems beyond the common application of swarm algorithms for optimization. Thus the swarm members will be identified from hardware and software elements that are already available in the CPS. Within SWILT, example use cases are production scheduling in semiconductor manufacturing and transportation problems in industrial plants that take human operators into account. The main contribution of SWILT, besides application in the specific use cases will be the provision of a general architecture supporting multi-swarm systems with communication models within and between swarms and to provide means for the management of such swarm systems.

[5] https://ccl.northwestern.edu/netlogo/
[6] https://www.mathworks.com/products/matlab.html/
[7] https://www.python.org/
[8] https://networkx.github.io/

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References

1. Arvin, F., Murray, J., Zhang, C., Yue, S.: Colias: An autonomous micro robot for swarm robotic applications. International Journal of Advanced Robotic Systems **11** (2014)
2. Camazine, S., Deneubourg, J.L., Franks, N.R., Sneyd, J., Theraulez, G., Bonabeau, E.: Self-organization in biological systems. Princton University Press (2001)
3. Demirkol, E., Mehta, S., Uzsoy, R.: Benchmarks for shop scheduling problems. European Journal of Operational Research **109**(1), 137–141 (1998)
4. Dorigo, M., Trianni, V., Sahin, E., Groß, R., Labella, T.H., Baldassarre, G., Nolfi, S., Deneubourg, J.L., Mondada, F., Floreano, D., Gambardella, L.M.: Evolving self-organizing behaviours for a swarm-bot. autonomous robots. Autonomous Robots p. 17:223 (2004)
5. Elmenreich, W., D'Souza, R., Bettstetter, C., de Meer, H.: A survey of models and design methods for self-organizing networked systems. In: W. Elmenreich, R. D'Souza, C.B., de Meer, H. (eds.) In Proceedings of the Fourth International Workshop on Self-Organizing Systems. vol. LNCS 5918, p. 3749. Springer Verlag. (2009)
6. Elmenreich, W., Moll, P., Theuermann, S., Lux, M.: Making computer science results reproducible - a case study using gradle and docker. PeerJ Preprints **6** (2018)
7. Jdeed, M., Zhevzhyk, S., Steinkellner, F., Elmenreich, W.: Spiderino – A low-cost robot for swarm research and educational purposes. In: 2017 13th Workshop on intelligent solutions in embedded system. pp. 35–39. IEEE (2017)
8. Leitão, P., Barbosa, J.: Adaptive scheduling based on self-organized holonic swarm of schedulers. IEEE 23rd International Symposium on Industrial Electronics (ISIE) pp. 1706–1711 (2014)
9. Liu, B., Wang, L., Jin, Y.H., Tang, F., Huang, D.X.: Improved particle swarm optimization combined with chaos. Chaos, Solitons & Fractals **25**(5), 1261–1271 (2005)
10. Rubenstein, M., Ahler, C., Nagpal, R.: A low cost scalable robot system for collective behaviours. In Proceedings of the IEEE International Conference on Robotics and Automation pp. 3293–3298 (2012)
11. Taillard, E.: Benchmarks for basic scheduling problems. European Journal of Operational Research **64**(2), 278–285 (1993)
12. Teppan, E.C.: Dispatching rules revisited – a large scale job shop scheduling experiment. In: IEEE Symposium Series on Computational Intelligence (SSCI). pp. 561–568. IEEE (2018)
13. Trianni, V.: Evolutionary Swarm Robotics, vol. 108. Springer-Verlag Berlin Heidelberg, 1 edn. (2008)
14. Zhang, R., Wu, C.: A hybrid approach to large-scale job shop scheduling. Applied Intelligence **32**(1), 47–59 (2010)
15. Zhao, F., Zhu, A., Ren, Z., Yang, Y.: Integration of process planning and production scheduling based on a hybrid PSO and SA algorithm. International Conference on Mechatronics and Automation, Luoyang, Henan pp. 2290–2295 (2006)