Technical Report

TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

Protocol for:

A Systematic Mapping Study of

Cyber-Physical Social Systems

Marta Sabou[1], Angelika Musil[1,2], Juergen Musil[1], Stefan Biffl[1]

[1]Institute of Information Systems Engineering,
TU Wien, Vienna, Austria
{marta.sabou, stefan.biffl}@tuwien.ac.at
{angelika, jmusil}@computer.org

[2]Department of Computer Science,
KU Leuven, Leuven, Belgium

Protocol for:
A Systematic Mapping Study of
Cyber-Physical Social Systems

Marta Sabou[1], Angelika Musil[1,2], Juergen Musil[1], and Stefan Biffl[1]

[1]Institute of Information Systems Engineering, TU Wien, Vienna, Austria
{marta.sabou,stefan.biffl}@tuwien.ac.at
{angelika,jmusil}@computer.org
[2] Department of Computer Science, KU Leuven, Leuven, Belgium

1   Introduction

Cyber-physical systems (CPS) are systems that span the physical and cyber-world by linking objects and process from these spaces. In a typical CPS data is collected from the physical world via sensors and computation resources from the cyber-space are used to integrate and analyze this data in order to decide on optimal feedback processes which can be put in place by physical actuators.

CPS have started to diffuse into many areas, including mission-critical public transportation, energy services, and industrial production and manufacturing processes. While CPS affect the lives of people that rely on them on a daily basis, they so far only interact with humans as passive consumers. The results of a recent study about adaptation in CPS [5] revealed an emerging trend to add an additional "social" layer in a CPS architecture to address human and social factors. This trend shows the growing recognition of the importance of the social dimension of such CPS and of the need to evolve them into *cyber-physical social systems (CPSS)* [6]. CPSS consist not only of software and raw sensing and actuating hardware, but are fundamentally grounded in the behaviour of human actors, who both generate data and make informed decisions based on data [2,1,8].

This raises new research challenges due to additional complexity introduced by social systems in terms of uncertainty due to social dynamics, privacy concerns associated with the processing of sensitive social data, and the number and heterogeneity of data sources that need to be integrated. Also the social dimension naturally arises questions of the relation between CPSS and self-organizational, crowd-powered systems and Collective Intelligence (CI) systems like what are the characteristics of the social component and to what extent does the social part have an impact on the traditional CPS architecture and system processes?

Therefore, to address the needs and challenges of stakeholders it is important to obtain a comprehensive understanding of the CPSS concept and an overview of current state of research on this topic. To achieve this goal, we use a systematic mapping study (SMS) as research method. From the study, we consolidate

existing research to provide a first definiton of this new type of cyber-physical systems and an overview of existing use cases and application scenarios of CPSS, key characteristics and architectural design, current CPSS approaches as well as existing research challenges and limitations. These findings should support future CPSS researchers and practitioners with a comprehensive overview of current state-of-the-art relevant to CPSS and current approaches for their realization as well as existing problems.

2   Research Method

To achieve the goals of this study, we use a *systematic mapping study (SMS)* as research method. To apply this research method in an unbiased, objective, and systematic way, we follow the guidelines by Kitchenham and Charters [4]. The goal of a SMS is to review a specific software engineering topic area and to classify primary research papers in that domain [3]. In contrast to a systematic literature review, a systematic mapping study is applied to review a specific software engineering topic area and classifies primary research papers in that specific domain [3]. Thus the research questions for such a study are generally broader defined and more high level to provide an overview of a certain topic [3].

Research Questions

To achieve the goal, the study aims to answer the following main research questions:

RQ 1: What is an overarching definition of CPSS?

RQ 2: What are application domains, goals and stages specific to CPSS?

RQ 3:What are main characteristics of CPSS that could be used for their classification?

RQ 4: What is the role of human and social elements in CPSS?

RQ 5: What data sources are typically used in CPSS?

RQ 6: How is data processed and distributed in CPSS?

RQ 7: What architectural approaches are applied to design and describe CPSS?

RQ 8: What are currently main research areas and topics and what are key challenges and emerging future work trends in CPSS?

The answer to these research questions aims to identify state-of-art approaches and open issues in the new research area of CPSS.

Study Process

The research method complies with a well defined sequence of steps according to a previously developed protocol. Since the protocol is a critical element of a systematic study, it is piloted by reviewing a sample of two papers. In the following, the study protocol is revised with respect to the pilot results. Once all researchers agree on the protocol, the phase of conducting the study starts by applying the search strategy and selection criteria, data extraction strategy, data analysis methods, and reporting strategy defined in the protocol.

The SMS will be conducted by a group of three researchers with expertise in the areas of software engineering, human computation, data integration as well as with previous experience in performing SMS. They are supported by a group of six undergraduate students enrolled in an academic course for scientific research work. The researchers will design and guide the study and closely supervise and collaborate with the students. For each step, the students will receive detailed instructions on how to perform their tasks and data collection sheets where they should put their results for later analysis. Two researchers will define the initial study protocol which will be reviewed by the third researcher. The piloting of the protocol will be done by the students under the supervision of the researcher team in a workshop. The retrieving and selecting publications process as well as the data extraction from the selected studies will be performed by the students. After each step the results will be crosschecked by the researchers and discussed with the students. Finally, the three researchers will synthesize and analyze the data as well as write the final study report. Fig. 1 shows the overall systematic mapping study process that is planned to be applied. Detailed information about each step is provided in the following sections.

3 Search and Selection Strategy

The identification and collection of paper candidates will be done by the students. Each student will apply the search strategy on two defined databases as sources to identify potential study candidate papers. Each database will be searched by two students. The students decide whether a paper is potentially relevant based on its title and keywords, although the abstract can also be consulted in unclear cases.

Sources

Papers to include in the study must be published in established and scientifically accepted online databases. Therefore, to cover as many as possible relevant studies about CPSS, we performed searches in five of the largest scientific online databases as sources of primary studies:
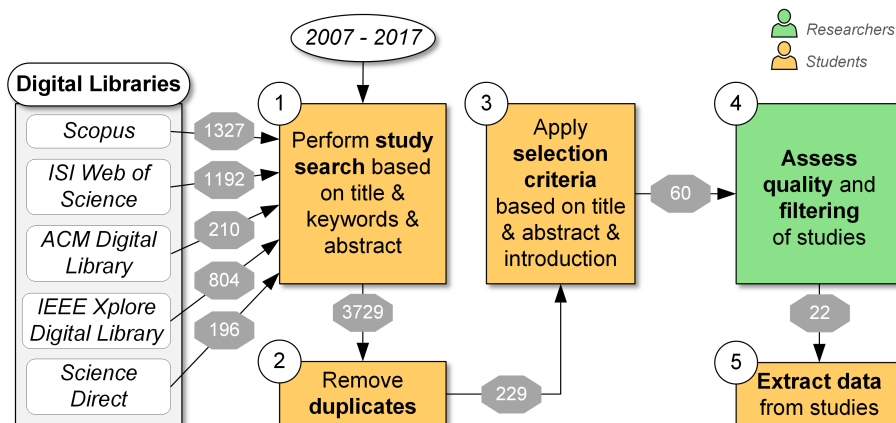
Fig. 1. Planned systematic mapping study process

- Scopus
- ISI Web of Science
- IEEE Xplore Digital Library
- ACM Digital Library
- ScienceDirect

Search Process and Documentation

To identify potential study candidates, we applied a manual search method using the following search keywords to search in paper title, keywords and abstracts in each individual database search engine:

```
( cyber  AND  physical  AND  soci∗)  OR
( cyber  AND  physical  AND  human )  OR
( cyber  AND  physical  AND  soci∗ AND  distributed )  OR
( cyber  AND  physical  AND  participatory )
```

The students will apply the search strategy to identify potential study candidates. The scope of the search includes studies from 2007 to 2017. The search results will be documented in a spreadsheet where the identified candidate papers will be collected and stored. This spreadsheet is provided by the researchers. In addition, duplicates will be removed in this process step. Each paper will be indexed by a unique reference ID and its title. Each student should keeps a search log to document search as well as any changes to the search strategy.

Selection Criteria

The identified set of candidate studies will be carefully assessed and filtered for their actual relevance to answer the research questions. Therefore, the study

goals and well-defined study selection criteria will be used to determine which studies to include or exclude. Each identified study will be assessed by two students by inspecting the title, abstract, introduction and if needed the full paper to decide in terms of the study inclusion and exclusion criteria. The selection of studies resulting from this step are cross-checked by the researchers who also assessed the quality of the papers. A study is included if it is compliant to the following inclusion criteria and does not fulfill any of the following exclusion criteria:

IC 1: Studies focusing, proposing, leveraging, or analyzing a CPSS in detail. We are looking for papers that provide at least a minimal description of a concrete system in an application scenario or use case. At least one section of the paper should describe a system.
IC 2: Studies subject to peer review [7] (e.g., journal papers, papers published as part of conference proceedings).
IC 3: Studies published since 2007.

EC 1: Studies that are written in a language other than English, or that are not available in full-text.
EC 2: Secondary studies (e.g., systematic literature reviews, systematic mapping studies, and surveys), which do not provide novel research results by their own and instead just summarize work done by other researchers.
EC 3: Studies where a CPSS is only mentioned as a side-topic, e.g., this term appears only in the title or a reference or as an example.
EC 4: Studies focusing only on CPS in general, not on CPSS specifically.

Results of selections and rejections will be crosschecked by a second reviewer and any disagreements on whether to include/exclude a study will be discussed and resolved among both students. If an agreement cannot be reached, the researcher team will look at these papers and will make the final decision. The selection results will be documented in a spreadsheet and, in case of exclusion, a rationale should be documented why a specific paper is excluded (e.g., by specifying the relevant IC/EC that determine the decision). Finally, the researchers will finalize the set of studies to be included in the data collection process and distribute the papers to the students.

4 Data Extraction

For each study remaining after the selection process, the students will independently investigate the papers assigned to them. For each paper they will extract pre-defined data based on the provided data collection sheet. The definition of pre-defined extraction forms with data items allows to survey each study in the same way (objectively) and reduces the room for bias. Before data extraction, during the protocol piloting, we will discuss each data item to be extracted to clarify the expected output and meanings of the data items to all reviewers and

Table 1. Data Extraction Form

	Data Item - Bibliographic Information
D1	Publication title
D2	Publication year
D3	Publication type (e.g., journal, conference, workshop, or book chapter)
D4	Venue (name of the publication venue of the study, e.g., conference name, book title, journal title)
D5	Affiliations of all authors
D6	Keywords provided by the authors of the publication
D7	Paper type (e.g., survey, system paper, vision paper, aspect paper, architecture paper)
D8	Paper abstract
	Data Item - Study Information
D9	CPSS definition used in the paper
D10	CPSS-related notions
D11	Application domain supported by CPSS
D12	CPSS purposes/goals
D13	Major CPSS stages/activities/processes
D14	Involved human actors and their roles
D15	Data sources and collected kind of data
D16	Mechanisms used to collect human input or data
D17	Data integration mechanisms
D18	Data analysis mechanisms
D19	Result distribution mechanisms
D20	Role of privacy and security
D21	Adaptation in CPSS
D22	Architectural design approaches
D23	Challenges of CPSS engineering
D24	Future work topics
D25	References to other CPSS

to make sure that all reviewers have the same understanding. Table 1 gives an overview of the data items that will be collected from the primary studies to answer the research questions.

First of all, the data extraction form should provide bibliographic information about the publication to be investigated: publication title, publication year, publication type, venue, author affiliations, publication keywords, study type, abstract). Besides bibliographic information, we collected data items relevant to answer our research questions, e.g., CPSS definition, application domain, CPSS purposes and goals, CPSS process steps/activities, involvement of human actors, data sources, collected data, architecture design approaches.

After discussion of the individual results for each study with the other reviewers, the collected and agreed data will be documented in a spreadsheet in a consistent manner.

5 Data Analysis & Reporting

For analyzing and interpreting the collected data with respect to the research questions, descriptive statistics have been applied. The results of the analysis describe the most interesting aspects of the data set and show frequency distributions, central tendencies as well as dispersions. The distribution density of variables are visualized in form of histograms or pie charts.

Finally, after the review is completed, the questions answered and the results consolidated, the review will be reported and disseminated. We plan to write a review report in form of a paper to be submitted in an academic software engineering journal. In addition, the review protocol, filled data extraction forms and data analysis results will be made publicly available on our website.

References

1. Cassandras, C.G.: Smart Cities as Cyber-Physical Social Systems. Engineering 2(2), 156–158 (2016)
2. Guo, W., Zhang, Y., Li, L.: The integration of CPS, CPSS, and ITS: A focus on data. Tsinghua Science and Technology 20(4), 327–335 (2015)
3. Kitchenham, B.A., Budgen, D., Pearl Brereton, O.: Using mapping studies as the basis for further research A participant-observer case study. Information and Software Technology 53(6), 638–651 (2011)
4. Kitchenham, B.A., Charters, S.: Guidelines for performing Systematic Literature Reviews in Software Engineering. Tech. Rep. Version 2.3, EBSE Technical Report, EBSE-2007-01, Software Engineering Group, School of Computer Science and Mathematics, Keele University, UK and Department of Computer Science, University of Durham, UK (Jul 2007), `https://www.cs.auckland.ac.nz/~norsaremah/2007%20Guidelines%20for%20performing%20SLR%20in%20SE%20v2.3.pdf`
5. Musil, A., Musil, J., Weyns, D., Bures, T., Muccini, H., Sharaf, M.: Patterns for Self-Adaptation in Cyber-Physical Systems. In: Biffl, S., Lüder, A., Gerhard, D. (eds.) Multi-Disciplinary Engineering for Cyber-Physical Production Systems, chap. 13, pp. 331–368. Springer International Publishing (2017)

6. Wang, F.Y.: The Emergence of Intelligent Enterprises: From CPS to CPSS. IEEE Intelligent Systems 25(4), 85–88 (2010)
7. Wohlin, C., Runeson, P., Höst, M., Ohlsson, M.C., Regnell, B., Wesslén, A.: Experimentation in Software Engineering. Springer Berlin Heidelberg (2012)
8. Xiong, G., Zhu, F., Liu, X., Dong, X., Huang, W., Chen, S., Zhao, K.: Cyber-physical-social System in Intelligent Transportation. IEEE/CAA Journal of Automatica Sinica 2(3), 320–333 (2015)

Appendix: Included Primary Studies

Table 2: Final list of primary studies included in the systematic mapping study

Title	Year	Source
Parallel driving in CPSS: a unified approach for transport automation and vehicle intelligence	2017	`http://ieeexplore.ieee.org/abstract/document/8039015/`
Cyber-physical-social system in intelligent transportation	2015	`http://ieeexplore.ieee.org/abstract/document/7152667/`
An ontological ubiquitous city information platform provided with Cyber-Physical-Social-Systems	2016	`http://ieeexplore.ieee.org/abstract/document/7444746/`
Dynamic Social Structure of Things: A Contextual Approach in CPSS	2015	`http://ieeexplore.ieee.org/abstract/document/7045423/`
A CPSS Approach for Emergency Evacuation in Building Fires	2014	`http://ieeexplore.ieee.org/abstract/document/6871708/`
A Real-time Complex Event Discovery Platform for Cyber-Physical-Social Systems	2014	`https://dl.acm.org/citation.cfm?id=2578755`
A System-Level Modeling and Design for Cyber-Physical-Social Systems	2016	`https://dl.acm.org/citation.cfm?id=2834119`
Incorporating Social Sensors and CPS Nodes for Personalized Production under Social Manufacturing Environment	2016	`https://www.sciencedirect.com/science/article/pii/S2212827116310496`
A framework to design a human-centred adaptive manufacturing system for aging workers	2017	`https://www.sciencedirect.com/science/article/pii/S1474034616301392`
Consumer-Centered Energy System for Electric Vehicles and the Smart Grid	2016	`http://ieeexplore.ieee.org/abstract/document/7478506/`
Butler, Not Servant: A Human-Centric Smart Home Energy Management System	2017	`http://ieeexplore.ieee.org/abstract/document/7841467/`

A Non-Intrusive Cyber Physical Social Sensing Solution to People Behavior Tracking: Mechanism, Prototype, and Field Experiments	2017	`http://www.mdpi.com/` `1424-8220/17/1/143/htm`
Driver Assistant in Automotive Socio-cyberphysical System Reference Model and Case Study	2016	`http://www.scitepress.org/` `Papers/2016/58752/`
An Assistive Navigation Framework for the Visually Impaired	2015	`http://ieeexplore.ieee.org/` `abstract/document/7010003/`
Online communities for agent collaboration in cyber-physical-social systems	2015	`http://ceur-ws.org/Vol-1420/` `wois-paper2.pdf`
Vita: A crowdsensing-oriented mobile cyber-physical system	2013	`http://ieeexplore.ieee.org/` `abstract/document/6558754/`
Participatory cyber physical system in public transport application	2011	`http://ieeexplore.ieee.org/` `abstract/document/6123523/`

Human-centred assembly: a case study for an anthropocentric cyber-physical system	2014	`https://www.sciencedirect.`
		`com/science/article/pii/`
		`S2212017314001534`

Closing the Loop - From Citizen Sensing to Citizen Actuation	2013	`http://ieeexplore.ieee.org/` `abstract/document/6611338/`

An Open Framework for Exploratory Visual Analysis of Geospatial Data for Winter Road Management	2013	`https://link.springer.`
		`com/chapter/10.1007%`
		`2F978-3-642-40140-4_6`

A Study for Human Centric Cyber Physical System Based Sensing - Toward Safe and Secure Urban Life -	2013	`https://link.springer.`
		`com/chapter/10.1007/`
		`978-3-642-40140-4_7`

Socio-cyberphysical System for Proactive Driver Support	2015	`http://ieeexplore.ieee.org/` `abstract/document/7347782/`