Big Data Implementation for the Reaction Management in Manufacturing Systems

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Abstract— **Big Data is one of the most discussed trend themes worldwide in both research community and industrial practice. Thus, researchers as well as company representatives focus on the study of Big Data technologies and the potentials deriving from gaining and structuring data. In this paper, we firstly conduct a literature review. Then, we describe the approach to implement reaction management in manufacturing environment before we finally report on a research project aiming at applying Big Data technologies in producing companies. The project goal is to develop a real-time capable platform in consideration of industrial requirements. With the help of a Big Data platform, producing companies will be enabled to use several applications like e.g. monitoring, prognosis or reaction. By receiving appropriate measures defined in the platform, the ability of producing companies to detect and to react proactively to failures deriving in manufacturing will sustainably increase.**

Keywords—Big Data; Reaction Management; Failure Management; Complex Event Processing; Production Management

I. INTRODUCTION

The manufacturing industry faces a growing quantity of data and will experience a continuous growth of this trend [1]. Reasons are the advancing digitization of business processes as well as the integration of measuring, control and regulatory systems along with their diverse and heterogeneous data output [2][3]. IT systems support increasingly diverse processes and more and more complex cross-linkage [4][5]. Diversity and heterogeneity of data regarding e.g. human, machine and communication technologies are the greatest challenge for companies coming along with this development [6]. Data sets, which are so huge and complex that conventional data processing systems are not able to perform analysis, curation, transfer and visualization effectively, are referred to as 'Big Data'.

Data and resulting information gained in importance in the manufacturing industry during the last years [8] and enabled an intelligent cross-linkage, phrased as 'internet of things' [3][7]. This development is part of 'Industry 4.0', which is a broad term for technologies and concepts of value chain organization regarding cyber-physical systems. Regarding data in particular, the idea of Industry 4.0 is to overcome decentralized and separate data islands within company structures in support of a centralized and company-wide usage. This enables faster and more flexible responses to changes or troubles in both the production and market environment. On top of that, big data technologies even hold the potential to detect and prevent failures before they actually occur.

II. LITERATURE REVIEW

A. Complex Online Optimization

The term 'complex online optimization' comprises complex optimization problems including requirements of short response times and the inclusion of different decision making levels and planning levels. These kinds of problems occur especially when a failure emerges or is feared and the production process has to be restored to a stable state. To prevent these kinds of situations, defined buffers considering failure probabilities are traditionally integrated into the production process in an early stage [9][10]. First approaches to a dynamic adaption of productions plans do already exist, e.g. the preponing of production steps practicable in spite of failures [11] or simulation-based rescheduling [12].

These practices only refer to the actual production or even a mere machine as a decision level due to a lack of information from subsequent production steps or decision levels. The rescheduling is often executed without considering consequences for all following production steps for the very same reason. The project BigPro addresses these problems by factoring as much data as possible from different decision and planning levels into the solution process. In addition to these approaches for rescheduling within the production process, BigPro also resorts to approaches to event-based failure detection and troubleshooting of transportation failures [13].

B. Complex Event Processing

The intelligent and agile production must be able to process a vast amount of real-time data from different internal and external sources on-the-fly and to use it in order to identify relevant events. Complex Event Processing (CEP) technologies make this proceeding possible. CEP describes the direct processing of a variety of events regarding the company environment in terms of real-time data as well as the buildup of capacities to forward these to the correct recipients in line with demand [14]. On that point, events can be structured by clustering, analyzing for patterns, abstracting, adapting in different formats or prioritizing. The processing happens directly on the event streams without any storing in databases. CEP is a relatively young cross-sectional technology, being researched within the last ten years and has been increasingly gaining acceptance in the research area. Big Data entails new challenges to CEP regarding volume and diversity of the event streams and especially the connectivity of event streams revealing pattern with the objective of failure detection.

Declarative CEP technologies are not the only ones being applied and accommodated to occurring challenges within the framework of BigPro. In fact, the current CEP gets enhanced by intelligent methods of knowledge processing like 'Reasoning', creating an intelligent Complex Event Processing (iCEP). This shall correlate real-time information (events) regarding temporal, spatial and causal characteristics. iCEP provides real-time analytics for a given scope and processes events in the context of background knowledge (static or slowly developing knowledge) to discern more complex situations.

Furthermore, the currently used CEP enables production systems to respond to crucial events merely just-in-time but not proactively. One of the goals of the project BigPro is to enable the very same responses to be proactive, meaning before actual failures occur. Existing approaches combine CEP technologies and deductive reasoning [15] to realize intelligent, anticipatory production systems. Those approaches are grounded on elaborate calculations requiring large computing capacities, though. Therefore, BigPro aims at more efficient approaches considering proactive failure detection.

C. CEP Pattern Management

So far, most of the approaches for real-time monitoring within the scope of production have merely focused on the direct monitoring of production processes to identify anomalies regarding the processes runtime. Some approaches, for example, aim at identifying relevant situations by integrating data from corporate applications and production machines within the same system and continuously putting real-time requests to these data [16][17].

Other approaches address the real-time analysis of the output using a combination of data from production machines (e.g. from sensors) and statistic process data (e.g. CAD models). These approaches utilize CEP technologies to identify relationship between different events and therefore potential critical situations [18]. Currently, the CEP patterns (Event Pattern) necessary for these approaches are manually created, declaratively described and can merely be identified if exact congruence is on the hand.

Meanwhile, first approaches to self-learning monitoring do exist, refining the relevant event patterns by the use of methods of the machine learning [19]. These approaches do not provide a methodical practice to identify the required event patterns, though. They rather merely point out potentially problematic situations without providing concrete reaction measures. Therefore, BigPro intends to pick up on already addressed capabilities of methodically generating event patterns and updating them throughout the whole lifecycle [20][21][22][23].

Another challenge besides the methodical creation of pattern lies in the task to broaden the event detection regarding indistinct patterns. The technology, which is necessary for this purpose, has to be developed and applied within BigPro. These methods are to be used to support real-time decision making. First basic technologies pertaining to suchlike ideas can be found on the internet, e.g. Xively (www.xively.com; data from sensors and measuring instruments can be exchanged almost in realtime as XML, JSON or RSS) or DataSift (www.datasift.com; complex processing pipelines can be defined onto social web data streams). Nevertheless, the regarding filter and processing primitives are nowhere near capable event detection solutions.

D. Caching Technologies for Big Data based on In-memory

What occurs besides the direct processing of event streams is also the need for the offline-processing of data in support of e.g. the analysis of historic data and to ensure data privacy. The usage of in-memory caching technologies is necessary for efficiently processing the huge amount of data associated with Big Data scenarios. Caching technologies enable the scaling on a node with terabyte-sized in-memory as well as the scaling over many nodes. A transparent cache functionality including request options is provided in this context.

E. FMEA Incident Management

The Failure Mode and Effects Analysis (FMEA) is an analytic procedure for a proactive systems and risks analysis. The FMEA allows to reveal existing weak spots and to initiate measures for the purposes of remedying those and preventing possibly resulting failures (preventive approach). Moreover, the FMEA facilitates the optimization of current products and processes (corrective approach). Furthermore, the FMEA serves companies to systematically bundle experience based knowledge regarding relations between failures and to provide it to the planning department for the purpose of reusing known solution possibilities [24][25]. As a consequence, the FMEA is a highly suitable method regarding the proactive failure management as addressed within the scope of BigPro.

F. Mood Monitoring and Sentiment Analysis

Meta data referred to humans like emotions and physical activity become more and more relevant in several fields of research. Human Computer Interaction (HCI) focuses the recognition and representation of emotions and their effects on the work attitude [26][27][28]. The effects of emotions on learning processes are also under examination within the scope of technology-aided learning [29][30]. Considering this, several communities try to gather and excogitate the effects of emotions on their health and life through the use of different tools. Accordingly, there are several approaches to examine the role of emotions in one's own life. Neither of these approaches considers how the monitoring of these meta data referred to humans may be able to improve the failure management if associated with other information, though. This is also in the scope of the research project BigPro.

The subject 'stress management' had also been examined during the last years, but new sensory developments have improved the options of measuring and detecting stress notably. There are several types of sensors well-suited for detecting stress at a workplace. Using biosensors, it is possible to measure various relevant parameters regarding stress. Noninvasive biosensors for example are applied on the users' skin. Among others the skin conductance, the pulse or the breathing may be measured by the use of these sensors. Besides heart frequency and heart beat rhythm, the heart rate variability is ascertained by an easily performed measurement. The latter provides information about the hearts capability to adapt to the continuously changing mental and physical challenges. Considering all these parameters, a computerized heart portrait is created and the cardio-stress-index may be calculated. These approaches concerning stress management are already tested in several areas of application. They are currently not utilized in a production environment to facilitate failure detection or rectification. Therefore, the research project BigPro ties in to these approaches and enhances them in reference to failure detection and rectification in a production environment.

Associated with the growing importance of social media and networks the concept of sentiment analysis starts becoming an object of interest. Originally used in the context of stock markets, the term ‘sentiment analysis’ is taken to mean a general analysis of moods, emotions and personal statements regarding particular brands, issues or topics. Usually, collocation analyses are utilized for common sentimental evaluation of free texts from social media. For this purpose, the statistically defined term ‘collocation’ (according to that ‘collocation’ describes basically every co-occurrence of adjoining words within texts) is reinterpret and means ‘semantic relation’. So-called ‘collocation graphs’ depict the frequency of the co-occurrence of words or lemmata in texts (defined by a particular distance, usually three to five words). Occasionally, these are interpreted as a ‘conceptual net’ mistakenly. With a view to their methods, collocation analyses are only suited for huge text sets and therefore inapplicable to analyses of single sentences or statements. Nevertheless, this approach is used by many current software tools for sentiment analysis.

III. Reaction Management in the Production

According to the 5M method, failures in production environment may originate from human, machine, milieu, material and method or measurement [31]. The human often becomes a disturbance variable through accidental misuse of machines. Thus, machine and milieu data regarding employees are gathered and related for the purposes of the failure management in the context of BigPro. One example is that based on the communication between employees working at the assembly stations an automatic sentimental analysis of the verbal communication will be conducted. This will enable to identify deviations in the assembly process so that the corresponding employees will be informed to prevent potentially occurring failures in the process flow.

The technical requirement is that the employees will use headset during the assembly process so that the communication can be recorded and analyzed. Furthermore, machine malfunctions may adumbrate through e.g. a raised vibration level or a changing noise level. These kind of failures need to be identified with the help of the required technical equipment and provided through the integration of corresponding IT systems to the persons in charge. Disturbances regarding the environment may be identified based on e.g. temperature fluctuations or machine failures. Failures which may be detected using staff data are gathered, identified and visualized by adequate acquisition methods.

It is the duty of the reaction management to suggest and initiate suitable responses to disturbances which are detected by monitoring. Moreover, the target in the near future has to be the prediction of the disturbances as part of a failure prognosis methodology. Hereby, a differentiation between reactive and proactive proceeding is done.

In case of reactive proceeding, failures are remedied only after they actually occurred. The moment that the system detects a failure, it suggests an action which the user may affirm or disaffirm. This kind of error correction is state of the art and naturally carried out by all producing companies.

In case of proactive reaction management, looming errors and failures in the production environment won’t suddenly appear since a monitoring and prognosis of failures will sufficiently early alert the members of the production system. In order to monitor and prognosticate potential disturbances the most important aid is real-time data emerging from the running production process.

An adequate solution approach to analyze and to evaluate the captured data is the FMEA (Failure Mode and Effects Analysis). In BigPro, the FMEA is adapted to evaluate each disturbance and its causes based on a quantitative method. This ensures a weighting and prioritization of potential disturbances. To sum it up, the method provides information about the potential failure’s probability of occurrence. If the analysis underlines that the probability of occurrence is relatively high, pre-defined countermeasures will be automatically selected and initiated after a final review of the responsible employee. If the analysis reveals an unlikely or insignificant failure, the process owner gets informed about the decision, e.g. via mail or display device, and the failure is added to the failure catalogue. Latter one is also part of the research project. Thus, a universal catalogue consisting of relevant failures and appropriate countermeasures is defined in BigPro.

There are two different ways of ascertaining suitable countermeasures in both the reactive and the proactive proceeding: either by using a defined catalogue of known countermeasures or by generating countermeasures dynamically. In the first proceeding, historic data and former interventions serve as the base information to combine the countermeasures in a catalogue and to use them in the related cases. The latter proceeding will be applied if no suitable countermeasure is found in the catalogue. In that case, new countermeasures are dynamically created. This step bases on the current case of failure. In case of success, the newly defined countermeasure will be also added to the catalogue.

IV. Research Project BigPro

A. *Project Objective and Emphases*

The main objective of the research project BigPro is to generically build up a real-time capable Big Data platform enabling the usage of several applications like e.g. monitoring, prognosis or reaction. On the BigPro platform, generic data from the production level considering e.g. human, machine and material is consolidated, edited and provided to the users according to their requirements. The intention of the platform is to qualify manufacturing companies to design their production systems more resilient and reactive by the implementation of Big Data technologies and the additional integration of human and machine related data as an important success factor for a failure-free production. Thereby, a proactive failure management in production is facilitated. Failures shall be prevented preemptively by suitable measures before they actually occur. Otherwise, they are to be remedied in a partly or fully automated manner as soon as possible by triggering appropriate measures.

The project partners' expertise is the base to build up a BigPro platform which is capable of analyzing heterogenic and unstructured data in the sense of Big Data and processing it semantically. So, real production data from three application partners which are characterized by a different degree of automation and IT integration in their production systems, serve as data source, made up by staff data ascertained by speech processing and mood monitoring. The conjunction of all this data for the purpose of creating information is a major challenge approached by BigPro. Innovative, real-time capable means of control in production should be achieved through acquisition and analysis of the huge, heterogenic mass of data and its causal relationships.

Primary objectives include the analysis and interpretation of system statuses followed by an immediate deduction and execution of appropriate reactions. Besides sensor and system data, the employees' perception has to be analyzed automatically in real-time, too. The semantic sentiment analysis is a possibility to match staff related data and the corresponding emotional coloring with concrete events and/or processes and to utilize the information for a proactive failure management by applying CEP.

Moreover, scalable technologies for the visualization of statuses, prognoses and opportunities to react need to be created. Great importance is attached to the issues of data privacy and security. In consideration of the privacy-by-design concept, an on-site installation within the structures of the application partners has to be implemented in order to prevent that data leaves the own network.

At the same time, the platform's transferability to other domains of use is ensured by a holistic research approach. The goal is to shape the research results sector independent so that the transferability will be secured. The expertise of the participating application partners forms the groundwork to define the relevant requirements to the solutions. In particular, this is considered in form of use cases. Key figures, being specific for each application partner, are taken as a basis for the visualization of the analysis results from the platform and expanded by other key figures as appropriate. Fig. 1 represents a summarized illustration of the notified objective of the research project BigPro.

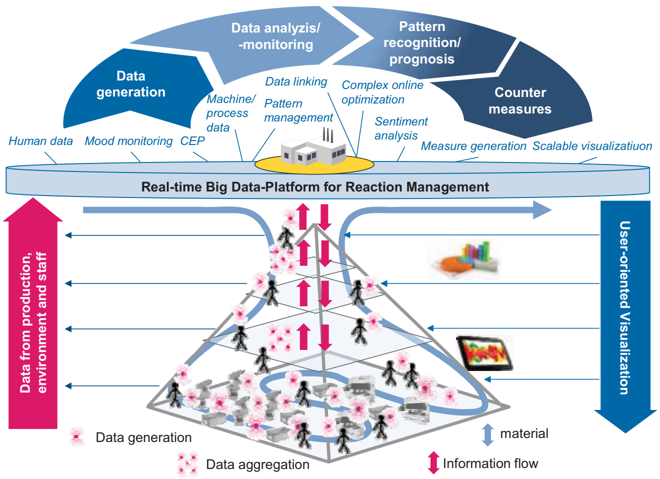

Fig. 1. Figure of the notified solution

B. Scientific and Technical Objectives

Within the scope of BigPro, data sets from different sources will be related among themselves and taken as a basis for a more effective failure management at producing companies. The main challenge is to combine and to relate the data from sensors inside the machines and from further data sources within the production environment. Therefore, the information demand and the required technical infrastructure have to be identified in the first place. The major difficulty regarding the failure detection is not only the detection of failures as early as they occur, but also the prediction and thus the prevention of each failure in a proactive manner. This requires innovative approaches regarding the processing of heterogenic data.

Another important objective of the project is the support of the user regarding creating and updating failure patterns. This currently requires a profound comprehension of the CEP technologies and is not possible to be done automatically, yet. Once the requirements for the information demand are defined and the generation of failure patterns is finished, the results will be integrated into the reaction management approach. The essential part of the reaction management is the use case specific escalation model structured into several escalation levels. These escalations levels base their decision making process on the provided real-time data. The information demand and the required information flows are regarded as imperative to identify.

Moreover, the automatic generation of concrete reaction recommendations requires complex algorithms for each escalation level respectively. These algorithms generate solutions as optimal as possible in real-time on the base of available data. Failures do not only occur in production but also in other industries. The sources of failures, suitable measures and the required basis of decision making may change due to the altered perspective. Analyses revealing the requirements on a cross-domain transfer of the research results are necessary to make most of the transferability of BigPro's outcomes.

An innovative Big Data platform capable of processing heterogenic and unstructured data almost in real-time provides the technical basis for the whole project BigPro. This fast processing facilitates a more effective and efficient failure management and makes the production flow more resilient. The collected data is analyzed by the CEP pattern detection. These patterns provide the basis of a proactive failure management indicating potential failures early on and suggesting measures. BigPro seizes on the human as an element of production and operationalizes him. Staff data in terms of speech recognition and mood monitoring is generated by the use of sensors and dashboards and gets embedded into the context of production. Thereby, an additional dimension of failure detection and rectification is created to improve the production flow. Another related sub goal is to plot failures and suggested measures in a demand actuated way and match with the information demands of particular escalation levels.

V. Conclusion

Although a lot of research work has already been conducted in the field of production management, manufacturing companies are still massively facing major challenges deriving from not expected failures. Due to increasing technical mature existing in production systems, today's manufacturing industry is also confronted with a bigger pile of data. This trend will definitively hold on in the course of the next years. To enable manufacturing companies to process this data pile sustainably, useable models and algorithms have to be developed. With the help of these models and algorithms, it will be surely easier to handle this abundance of data.

In this context, production systems need to introduce sustainable solution alternatives focusing on new technologies. Considering this, the German research project BigPro analyzes production systems and corresponding technologies to develop innovative methods to meet the increasing Big Data challenges. Therefore, a Big Data platform is developed in this research project which can realize the access of real-time production process data. This also enables the project partners to develop an approach for data pattern detection. Latter one will be used as a proactive reaction management system which is able to identify disturbances within the production system early and even prevent them before they occur. By considering and also recognizing human perception, a further dimension is taken into account in the reaction management system of BigPro. This ensures a higher quality level of production processes. Furthermore, a concept of visualizing the collected data is developed to illustrate disturbances and countermeasures user-oriented to reach the best possible support for the decision-making process.

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References

[1] Velten, C.; Janata, S. (2012): Datenexplosion in der Unternehmens-IT. Wie Big Data das Business und die IT verändert. Studie Experton Group AG, May 2012

[2] Manyika, J.; Chui, M.; Brown, B.; Bughin, J.; Dobbs, R.; Roxburgh, C.; Hung Byers, A. (2011): Big data: The next frontier for innovation, competition, and productivity. McKinsey Global Institute, May/June 2011

[3] Denner, V. (2014): Das Internet der Dinge und Dienste. Reutlinger General-Anzeiger. Aus: http://www.gea.de/nachrichten/wirtschaft/das+internet+der+dinge+und+dienste.3573003.htm, (2014-02-20)

[4] Otto, B. (2009): Stammdatenqualität: Erfolgsfaktor moderner Unternehmen. CC CDQ2, Würzburg.

[5] Zabel, U., Schubert, U., Krause, K.H.(2009): Studie zum Entwicklungsstand des Stammdatenmanagements in der deutschen Industrie.

[6] Kümmerlen, R. (2013): Big Data. 10 Fakten zur Datenanalyse. In: LOG.Kompass, 5, 2013, p. 14-15

[7] Ganschar, O. (2013): Produktionsarbeit der Zukunft - Industrie 4.0. (Spath, D., Ed.). Stuttgart: Fraunhofer-Verl. Retrieved from http://digitool.hbz-nrw.de:1801/webclient/DeliveryManager?pid=5319927&custom_att_2=simple_viewer

[8] Büst, R. (2013). Daten sind das neue Öl: Daten als Wettbewerbsvorteile in der Cloud verarbeiten. Wirtschaftsinformatik & Management, 02, p. 40–46.

[9] Hahn, D.; Lassmann, G. (1999): Produktionswirtschaft, Controlling industrieller Produktion, Bd.1+2, 3. Auflage, 1999

[10] O'Donovan, R.; Uzsoy, R.; McKay, K. N. (1999): Predictable scheduling of a single machine with breakdowns and sensitive jobs. In: International Journal of Production Research, 1999, Vol. 37, Nr. 18, p. 4217-4233

[11] Patig, S.; Thorhauer, S. (2002): Ein Planungsansatz zum Umgang mit Störungen bei der Produktion: die flexible Produktionsfeinplanung mithilfe von Planungsschritten. In: Wirtschaftsinformatik, 2002, Vol. 44, Nr. 4, p. 355-366

[12] Belz, R.; Mertens, P. (1996): Combining knowledge-based systems and simulation to solve rescheduling problems. In: Decision Support Systems, 1996, Vol. 17, p. 141-157

[13] Pulter, N.; Nimis, J.; Lockemann, P. C. (2010): Störungsmanagement in offenen, getakteten Logistiknetzen. In: KI, 2010, Vol. 24, Nr. 2, p. 131-136

[14] Luckham, D. C. (2012): Event processing for business. Hoboken, N.J: John Wiley & Sons.

[15] Anicic, D; Rudolph, S.; Fodor, P.; Stojanovic, N. (2012): Real-Time Complex Event Recognition and Reasoning – A Logic Programming Approach. In: Applied Artificial Intelligence, Vol. 26, Special Issue on Event Recognition, 2012.

[16] Cammert et al. (2006): Stream Processing in Production-to-Business Software

[17] Grauer et al. (2010): An Approach for Real-Time Control of Enterprise Processes in Manufacturing using a Rule-Based System, Multikonferenz Wirtschaftsinformatik, 2010, p. 1511—1522.

[18] Vijayaraghavan (2009): MTConnect for realtime monitoring and analysis of manufacturing enterprises. In: Proceedings of the international conference on digital enterprise technology, 2009.

[19] Metz, D., Karadgi, S., Müller, U., Grauer, M. (2012): Self-learning monitoring and control of manufacturing processes based on rule induction and event processing. In: 4th International Conference on Information, Process, and Knowledge Management (eKNOW 2012), 2012, p. 88-92

[20] Stojanovic, N.; Stojanovic, L; Anicic, D.; Ma, J.; Sen, S.; Stühmer, R. (2011a): Semantic Complex Event Reasoning - Beyond Complex Event Processing. In: Foundations for the Web of Information and Services, Springer Berlin Heidelberg, 2011

[21] Stojanovic, N.; Milenovic, D.; Xu, Y.; Stojanovic, L.; Anicic, D.; Studer, R. (2011b): An intelligent event-driven approach for efficient energy consumption in commercial buildings: smart office Use-Case. In: Proceedings of the 5th ACM international conference on Distributed event-based system. 2011, p. 303-312

[22] Anicic, D; Fodor, P.; Rudolph, S.; Stojanovic, N. (2011): EP-SPARQL: a unified language for event processing and stream reasoning. In: Proceedings of the Twentieth International World Wide Web Conference, 2011, p. 635-644

[23] Sen, S., Stojanovic, N., Stojanovic, L. (2010): GRUVe: a methodology for complex event pattern life cycle management. In: Proceedings of the 22nd International Conference on Advanced Information Systems Engineering (CAiSE), Lecture Notes in Computer Science, Vol. 6051, Springer, Berlin, 2010

[24] Deutsche Gesellschaft für Qualität e.V.: FMEA - Fehlermöglichkeits- und Einflussanalyse. DGQ-Band 13-11, 5. Auflage, 2012

[25] Werdich, M. (2012): FMEA - Einführung und Moderation. Durch systematische Entwicklung zur übersichtlichen Risikominimierung (inkl. Methoden im Umfeld). 2. Auflage, Springer Vieweg, 2012

[26] Church, K.; Hoggan, E.; Nuria, O. (2010): A study of mobile mood awareness and communication through MobiMood. In: Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, 2010. p. 128-137

[27] Sundström, P.; Ståhl, A.; Höök, K. (2007): In situ informants exploring an emotional mobile messaging system in their everyday practice. In: Int. J. Hum.-Comput. Stud., 2007, Nr. 65, p. 388-403

[28] Healey, J.; Nachman, L.; Subramanian, S.; Shahabdeen, J.; Morris, M. (2010): Out of the lab and into the fray: Towards modeling emotion in everyday life. In: Pervasive Computing, 2010, p. 156-173

[29] Robin, K.; Karina, O. (2006): Emotions in HCI - An Affective E-Learning System. In: Computer, 2006, p. 105 - 106

[30] Fessl A.; Rivera-Pelayo V.; Pammer V.; Braun S. (2012): Mood Tracking in Virtual Meetings. In: Ravenscroft A, Lindstaedt SN, Delgado Kloos C, Hernández Leo D (Hrsg.) 21st Century Learning for 21st Century Skills - 7th European Conference of Technology Enhanced Learning, EC-TEL 2012, Saarbrücken, Germany, September 18-21, 2012. Proceedings Springer, p. 377–382

[31] Kamiske, G. F. (2011): Qualitätsmanagement von A bis Z. (Brauer, J.-P., Ed.). München: Hanser.