Towards Adaptive Geo-Monitoring: Examining Environmental and Social Dynamics and their Relationships for Holistic Process Understanding

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1. Introduction

Beside the in-depth understanding of the fundamental concepts of space and time, an enhanced understanding of the spatio-temporal dynamics of geographic phenomena is at the core of the Geographic Information Science (GIScience) research agenda (Peuquet 1994, Goodchild 2004). Such an understanding can facilitate the examination of underlying drivers and, therefore, enable a more holistic process understanding of physical and social phenomena on different spatial and temporal scales. For instance, on a macro scale, climate change can be associated with large-scale human mobility and migration (Tacoli 2009). On a meso scale, the influence of weather conditions on people's mobility in the city might follow the same principal.

Although today's ubiquitous sensing technologies generate a comprehensive digital image of the real physical and social world, even in real-time, a better understanding of the multifaceted environmental-human interface is still needed. Such understanding would enable the quantification of the impact of environmental parameters on human behavior and, vice versa, the impact of human behavior on environmental parameters.

Therefore, the bottom-up adaptive geo-monitoring approach presented in this paper is designed to examine the spatio-temporal dynamics of both environmental and social phenomena through ubiquitous sensing and context-aware analysis in order to better understand underlying processes.

1.1 Relevant Work in a Nutshell

This research focuses on in-situ sensing technologies, particularly on environmental geo-sensor networks and mobile communication networks as large-scale sensors.

Sensors and geo-sensor networks allow for a comprehensive assessment of a variety of environmental parameters based on even "live" measurements (Resch 2012), which quantify temperature, precipitation, particulate matter etc. Distributed geo-sensor networks in combination with Geographic Information Systems (GIS) are employed to automatically generate multi-dimensional information beyond point measurements through web-based geo-processing routines and cloud computing (Yang et al. 2010). Such technologies and methods are utilized in this research to monitor the (current) state of some environmental variables, for example to generate situational awareness for decision makers (Sagl et al. in press).

With respect to human behavior analysis, one data source often used is user-generated traffic in mobile communication networks. In addition to more universal approaches (cf. González et al. 2008) a variety of contexts for analyzing such data can be identified, for instance, regular and irregular urban mobility (Sagl et al. under review), or urban planning and transportation (cf. Becker et al. 2011). However, the environmental context is rarely considered in the urban dynamics analyses. In this research the probably broadest and most representative sample is used as a proxy for the collective human behavior, namely the user-generated traffic in mobile communication networks.

The relationships between the environment and humans are multifaceted. For instance, the combination of some meteorological variables such as air temperature, solar radiation, relative humidity, or a combination of these can effect peoples' comfort conditions in outdoor urban spaces (Stathopoulos et al. 2004); poor or extreme weather conditions influence peoples physical activity (Tucker and Gilliland 2007). Vice versa, significant changes in the collective human mobility behavior can be linked with changes in the intensity of use and the choice of the transport vehicle (e.g. car, bus, train etc.). The vehicles' emissions influence e.g. the air quality along streets at different times (cf. Nicolopoulou-Stamati et al. 2005).

1.2 Research Gap and Research Question

As indicted above, the domains of environmental monitoring and collective human sensing are both well-established but rarely linked. Montgomery and Mundt (2010) describe a comprehensive but rather technical framework of how to combine and integrate various sensor data into a common platform on an almost global level. At a regional or even local level, Blaschke et al. (2011, p1762) claim: "What is really needed is a better understanding of human-environmental processes, i.e., direct measures of the impact of human activities on the environment and direct measures of environmental stressors on human functions."

One way to investigate this research gap is the ubiquitous sensing of environmental and social phenomena in combination with the power of GIScience concepts and interdisciplinary methods. The adaptive geo-monitoring framework, therefore, aims to enable the monitoring of the environmental status and the collective human behavior and the relationships between both in a more integrated and intelligent manner (cf. Sagl et al. 2011, Sagl et al. 2012).

This research is driven by the following question: How can the ubiquitous sensing of environmental and social phenomena in combination with context-aware analyses based on GIScience theory confirm known – as well as provide novel – information on environmental and collective human dynamics and potentially investigate their underlying processes?

2. The Adaptive Geo-Monitoring Approach

The bottom-up adaptive geo-monitoring approach (Fig. 1) is designed to sense, analyze, and monitor the spatio-temporal dynamics of environmental and social phenomena simultaneously across spatial and temporal scales. This can enable a more holistic process understanding. It extends the "adaptive monitoring approach" (Lindenmayer and Likens 2009) by adding the spatial dimension and the mutual context-awareness of dynamic phenomena.

The term 'adaptive' refers to, for instance, two or three spatial dimensions, zero or one temporal dimension, and *n* attribute dimensions; near real-time or "live" and post-processing workflows; aggregation and decomposition of sensor data depending on the thematic focus (e.g. air quality is a composition of particulate matter, CO_2, NO_x etc.); interpolation and extrapolation of the phenomenon of interest respecting different operational scales (e.g. diurnal and local versus seasonal and regional variability of air temperature); hybrid reasoning methods by iteratively applying the inductive and the deductive research approach.

2.1 Ubiquitous Sensing

Ubiquitous technologies, including geo-sensor networks and mobile communication networks as a large-scale sensor, are able to directly or indirectly sense environmental phenomena and the collective human behavior. In addition to the user-generated traffic in mobile communication networks, social media data from Twitter or Flickr can also be considered as proxies for the human behavior, however, rather for a specific subset.

2.2 Context-Aware Analysis

The consolidation of environmental and social sensor data on a common space-time basis enables a context-aware analysis, i.e. the analysis of one phenomenon in the context of another (e.g. human mobility in the context of the weather). Of particular interest is the evaluation of potential relations between phenomena of interest (e.g. between specific or even extreme weather conditions and the collective human mobility). This includes the use of established as well as the development of novel analysis methods and the evaluation of both.

In addition to traditional GIS analysis the context-aware analysis include, for instance: spatial interpolation (e.g. Kriging) for estimating values based on point measurements; exploratory factor analysis for reducing dimensionality and redundancy in a number of meteorological variables, e.g. to extract basic weather conditions such as "normal" or "adverse"; bivariate spectral analysis for examining significant periodical components of sensor data time series (Sagl et al. 2011); visual analytics for the interactive data exploration, e.g. for detecting spatio-temporal patterns, outliers, trends, abnormalities and singularities (Sagl et al. under review); novel statistics such as the Maximal Information Coefficient MIC for measuring the strength of the relationships between two variables, e.g. between adverse weather conditions and effective variations in collective human activity (Sagl et al. 2012).

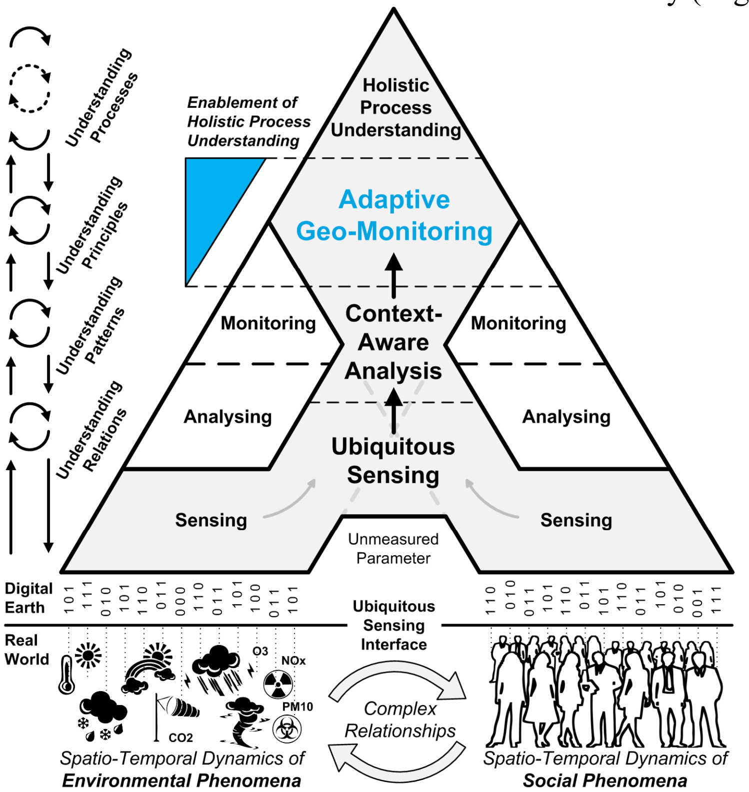

Fig. 1: The Adaptive Geo-Monitoring Approach: from the bottom-up, the spatio-temporal dynamics of real world phenomena are transferred to the digital earth via a ubiquitous sensing interface. Then, *Ubiquitous Sensing* and *Context-Aware Analysis* allow for the *Adaptive Geo-Monitoring*, which ultimately enables a *Holistic Process Understanding* of environmental and social phenomena and their complex relationships.

2.3 Limitations

This approach has several limitations and constraints. First of all, the relationships between environmental and social dynamics, which are highly complex and multifaceted, are approximated based on the assumption of linearity – several aspects of these relationships are as yet unknown. Further, the (collective) human behavior is influenced by a variety of factors. Environmental conditions, especially the weather, are potentially one of these influencing factors, but as yet to an unknown degree.

3. Proposed Contribution

The adaptive geo-monitoring approach presented provides novel capabilities for the examination of physical and social phenomena through ubiquitous sensing and context-aware analysis. The approach is rooted in GIScience theory and allows for monitoring the spatio-temporal dynamics of geographic phenomena and the evaluation of their inherent relationships. It can thus enable a more holistic process understanding of physical and social phenomena. The recent publications with respect to context-aware analysis demonstrate the feasibility of implementing this approach in order to answer the research question.

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References

Becker, R. A., Caceres, R., Hanson, K., Loh, J. M., Urbanek, S., Varshavsky, A. and Volinsky, C., 2011, A Tale of One City: Using Cellular Network Data for Urban Planning, *IEEE PERVASIVE computing,* 10(4), 18-26.

Blaschke, T., Hay, G. J., Weng, Q. and Resch, B., 2011, Collective Sensing: Integrating Geospatial Technologies to Understand Urban Systems—An Overview, *Remote Sensing,* 3(8), 1743-1776.

González, M. C., Hidalgo, C. A. and Barabási, A.-L., 2008, Understanding individual human mobility patterns, *Nature,* 453(5), 779-782.

Goodchild, M. F., 2004, GIScience, Geography, Form, and Process, *Annals of the Association of American Geographers,* 94(4), 709-714.

Lindenmayer, D. B. and Likens, G. E., 2009, Adaptive monitoring: a new paradigm for long-term research and monitoring, *Trends in Ecology & Evolution,* 24(9), 482-486.

Montgomery, K. and Mundt, C., 2010, A new paradigm for integrated environmental monitoring, in *Proceedings of the 1st International Conference and Exhibition on Computing for Geospatial Research*, Washington, D.C., 1823888: ACM, 1-7.

Nicolopoulou-Stamati, P., Hens, L. and Howard, V., 2005, *Environmental health impacts of transport and mobility,* Springer Verlag Dordrecht, The Netherlands.

Peuquet, D. J., 1994, It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems, *Annals of the Association of American Geographers,* 84(3), 441-461.

Resch, B., 2012, *Live Geography - Standardised Geo-sensor Webs for Real-time Monitoring in Urban Environments,* Dissertations in Geographic Information Science, Heidelberg, Germany: Akademische Verlagsgesellschaft AKA GmbH.

Sagl, G., Beinat, E., Resch, B. and Blaschke, T., 2011, *Integrated Geo-Sensing: a Case Study on the Relationships between Weather Conditions and Mobile Phone Usage in Northern Italy,* First IEEE International Conference on Spatial Data Mining and Geographical Knowledge Services (ICSDM 2011) Fuzhou, China: 208-213.

Sagl, G., Blaschke, T., Beinat, E. and Resch, B., 2012, Ubiquitous Geo-Sensing for Context-Aware Analysis: Exploring Relationships between Environmental and Human Dynamics, *Sensors,* 12(7), 9835-9857.

Sagl, G., Loidl, M. and Beinat, E., under review, A Visual Analytics Approach for Extracting Spatio-Temporal Urban Mobility Information from Mobile Network Traffic, *ISPRS International Journal of Geo-Information*.

Sagl, G., Resch, B., Mittlboeck, M., Hochwimmer, B., Lippautz, M. and Roth, C., in press, Standardised Geo-Sensor Webs and Web-Based Geo-Processing for Near Real-Time Situational Awareness in Emergency Management, *International Journal of Business Continuity and Risk Management*.

Stathopoulos, T., Wu, H. and Zacharias, J., 2004, Outdoor human comfort in an urban climate, *Building and Environment,* 39(3), 297-305.

Tacoli, C., 2009, Crisis or adaptation? Migration and climate change in a context of high mobility, *Environment and Urbanization,* 21(2), 513-525.

Tucker, P. and Gilliland, J., 2007, The effect of season and weather on physical activity: A systematic review, *Public Health,* 121(12), 909-922.

Yang, C., Raskin, R., Goodchild, M. and Gahegan, M., 2010, Geospatial Cyberinfrastructure: Past, present and future, *Computers, Environment and Urban Systems,* 34(4), 264-277.