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Neuroscience for smart domotic environments and intelligent spaces

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ABSTRACT

Evaluative and neuroscience smart home studies focusing on users' experience inside the intelligent environment are still relatively scarce. However, neuroscience research holds potential in providing new and useful information on smart home users' experience, that can be widely exploited by parties involved in smart home development. Indeed, by applying a neuroscientific multi-method approach it is possible to measure the neurophysiological correlates (central and autonomic indices) of the person interacting with the smart environment. Our approach contemplates the study of human-smart environment interaction as a communication between two highly complex systems that mutually influence each other. For this reason, in the present short theoretical contribution, it is proposed a new approach that suggest studying this relational exchange in real-time by focusing on two distinct main phases of interaction. Specifically, within this approach much relevance is given to the investigation of the users' neurophysiological correlates while they are interacting with the smart environment, through wireless neuroscientific systems.

Keywords: neuroscience methods; smart environments; user experience; EEG; wireless systems

1. INTRODUCTION: SMART HOME AND NEUROSCIENCE APPROACH

Research in the field of home automation is mainly composed by engineering studies aimed at creating efficient, functional and ergonomic artefacts to be implemented in people with disabilities' houses, in order to improve their autonomy and quality of life. From the point of view of automation, domotics is an interdisciplinary concept that refers to the integration of the different technologies in the home through the simultaneous use of telecommunications, electronics, informatics, and electricity. Also, its purpose is to improve the quality of life of human beings (Navarro-Tuch et al., 2019).

However, in this field, research also investigated elements, factors, and functional aspects that generate the perspective associated with the concept of "smart home", both from the point of view of users and of the technology manufacturers building smart homes (Mallett, 2004). Indeed, previous literature divided types of smart home studies based on what they can tell us, and identified four different types of study: conceptual, technical, prospective, and evaluative. Technical and prospective research literature mainly focuses on concepts of control, activities, and technical security inside and of the home; while conceptual and evaluative studies strive to answer questions on relations, values, and identities (Gram-hanssen & Darby, 2016).

Between these four categories, evaluative studies are the most interesting from a social and psychological perspective, because they deepen *"how smart homes work in practice (routines, meanings, technology, and knowledge), including relational aspects and functionality*" (Gram-hanssen & Darby, 2016). These studies are few in number, however, they are important not only to assess how smart home technology works in particular contexts but also how users evaluate their relationship with the smart systems. Among the still reduced existing evaluative contributions in literature on smart home, there is also the presence of ethnographic studies aimed at understanding how families interface with the domotic environment, how they use the various devices and how they learn to exploit their potential (Woodruff, Augustin, & Foucault, 2007). In these studies, typically qualitative methods, including questionnaires and semi-interviews structured, are used to elicit users' opinions and evaluation of their experience with the complexity of the environment. These self-report methods allow researchers to explore in-depth users' explicit opinions on their lived experience with the smart home, but they do not provide direct information on the cognitive and emotional implicit evaluation of users while they are inside the study context. In line with exploitation of this methodology, there are the psychological studies of the so-called "psychology of living" that have made an important but still limited contribution on the emotional value attributed to architecture and the design of the house, focusing mainly on the strong identity traits which characterized the concept of home (Filighera & Micalizzi, 2018).

Besides these four categories of study cited above, there is also a fifth type of research directed primarily to users/occupants of smart homes. This fifth type regards neuroscience literature on home automation that nowadays is still scarce and mainly focused on the practical advanced of applying brain-controlled systems allowing people to control the environment (Aloise et al., 2011; Babiloni et al., 2009; Cincotti et al., 2010). Indeed, previously, neuroscientific tools, such as the electroencephalogram (EEG), have been used to estimate the cortical activity associated with the mental imagery of the movements of the limbs, within a domotic context. These studies use a system known as Brain-Computer Interface (BCI), which consists in recognizing patterns of electrical activity in the brain, using the advanced high-density EEG devices, capable of reducing the blurring effect generated by the electrodes on the scalp. These BCIs have the advantage of creating new communication and control channels for patients with severe motor disabilities (Babiloni et al., 2007).

Other studies focused also on the BCI graphical user interface (GUI) that may mediate the electroencephalographic signals and the control of various devices in a smart home. The user with severe motor disabilities will thus be able to control his own house by monitoring his actions on the GUI simply by means of a mouse emulator (Guruprakash, Balaganesh, Divakar, Aravinth, & Kavitha, 2016). The use of a GUI opens the question about which type of user interface is the most functional for various categories of user: indeed, nowadays even vocal user interface (VUI) is widely spread and allows users to immediately and effectively control the smart devices. For this reason, it is essential to conduct studies in the field of neuroscience that test both the functionality connected to the user-GUI relationship and the different types of GUI. Furthermore, the purpose of the BCI-GUI system is to acquire and identify the EEG signal that is related to the users' intention to use a device within the intelligent home and it is, therefore, necessary to have a unique profile for each user, to map its activation patterns.

However, concerning the collection and analysis of users' neurophysiological and psychophysiological (autonomic) indices within domotic contexts data are limited yet. To our knowledge, no previous research strived to understand the experience of use and the emotional experience of subjects in relation to these environments, to the artefacts that compose it and to the interfaces that allow its functioning. Consequently, it is possible to identify the presence of a literature gap, which can be filled by using the tools that neuroscience offers and that suits well also for the study of the User Experience construct.

2. Users' experience in smart domotic environments

The domotics provides us with the necessary tools to confront the problems of stress, by allowing the flexibility of the use of different technologies for the control of space and thus the alteration of the state of the subjects in the controlled space. The intention of the final development of domotics continues to be the design of a controlled space, capable of redesigning and adapting its environmental characteristics, according to the captured response of the user, or as described by Kaasinen, a user-centric view of intelligent environments (Kaasinen et al., 2013). Thus, the UX analysis of users, of products, and service becomes one of the most interesting potential implementations for neuroscience research studies and domotics market (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015).

When considering a human being navigating in a domotic environment we should conceive it as a decision-maker that is planning actions according to his own goals, that are, in the end, addressed to optimize his well-being. Indeed, the person is effectively committed in a dialogue with the smart environment, that can be intended as a complex system equipped with autonomy and the ability to predict the person's intentions. In this way, it is possible to observe the technology-mediated communication exchange that develops between these two complex systems. And it becomes highly interesting to explore the retro feedback the person receives from the environment. Embracing this view means to consider this communication exchange as a complex social interaction.

Previous studies already explored the need for an interactive ability required from smart environments for being involved in human interaction and presented a basic theory of such fundamental interactive means: the theory of Behavioral Implicit Communication (BIC; Castelfranchi, Pezzulo, & Tummolini, 2010). BIC theory states that communication in smart environments can manifest in its direct and indirect form. By adopting a direct form, the human may intentionally send a message or a signal (a concrete practical action, not symbolic gestures or mimics) to the environment itself in order to obtain collaboration. Alternatively, humans may indirectly exploit the environmental ability to observe their behaviour and to understand and anticipate humans' needs (i.e., by performing practical actions while knowing and expecting that the environment will notice and understand what we are doing and what we need). This second form goes beyond simple perception and exploits the signification ability of cognitive agents (Castelfranchi et al., 2010).

According to these authors to enable behavioral implicit communication specific social and cognitive abilities are needed and, moreover, "*we need not only to have mind-reading abilities on both sides, but we also require goals about the mind of the other agent, and we arrive to cooperation on such goals. We may consider that in BIC there are two goals/ functions meeting each other: the communicator's goal (X's behavior has the goal or function that Y "understands",* *recognizes, and comes to believe something) and the interpreter's goal (Y has the goal/function of interpreting X's behavior in order to give it a meaning)."* (Castelfranchi et al., 2010). Thus, between humans and the environment not only a form of communication is established, but even a complex form of cooperation, which owns all the features of a relational pattern. This is not new, because majority of communication for cooperation and coordination in situated and embodied agent used reciprocal perception of behaviour, and humans and smart home interactions can be established mainly thanks to a ritualized BIC behaviour (Castelfranchi et al., 2010). What is new is that for making smart environments as more user-friendly as possible, it becomes crucial to deepen *how and if* users perceive and engage in this communication in a functional to the purposes of cooperation with the environment way.

Given these premises, from a human-centered point of view, we can mainly focus on three aspects of research investigation: (i) human communication towards the environment and (ii) human reaction to the environmental actions, and (iii) we can explore the most functional ways humans can implement for interacting with the environment. To do so, new research paradigms are needed, and neuroscience holds potential and methods for providing these new insights on users' experience in smart domotic environments. Accordingly, in the next paragraph it will be described shortly what neuroscience types of study can tell us about the complex relationship between users and smart home.

3. Why can neuroscience methods tell us something about the relationship between users and smart home?

Within this framework, neuroscience methods and tools can be employed for increasing the knowledge on the interaction between novel technologies and users' well-being, as well as on a variety of topics in the field of home automation such as human's perception of smart environments, emotional users' experience interacting with domotics, humans' perception of control over the environment and consequent sense of frustration related to an inefficient answer of the environment, perception of the environment as an extension of the human body, the age and gender digital divide, and possible dysfunctional implications due to technology misuse (e.g., addiction, as previously observed for other technological platforms; Milani, Camisasca, Caravita, Ionio, Miragoli, Di Blasio, 2015; Milani et al., 2018).

The added value of neuroscientific techniques is that they allow exploring the detailed implicit neurophysiological mechanisms of subjects while they are located in these environments. In the contextualized situation it becomes possible to explore the cognitive and emotional responses of the subject in real-time in a highly ecological way. As mentioned before, classical paper-and-pencil self-report questionnaires and scales either qualitative semi-structured interviews are extremely useful for obtaining in-depth information on the users' lived experience in the environment, but they provide only the explicit and conscious level of information. While neurophysiological tools can give information related to the implicit neural and psychophysiological responses deriving from human cognitive elaboration processing and emotional processes. In addition, modern wireless systems allow to monitor human brain activity and psychophysiological indices and have great potential in helping us understand the functioning of our brain-and-body system.

For example, non-invasive surface EEG is the dominant modality for studying brain dynamics and performance in real-life interaction of humans with their environment. To take full advantage of surface EEG recordings, EEG technology must be advanced to a level that it can be used in daily life activities. EEG systems have been transformed from stationary and wired systems used mostly in clinical practice, to intelligent wearable, wireless, convenient and comfortable lifestyle solutions that provide high signal quality (Mihajlovic, Grundlehner, Vullers, & Penders, 2015).

This tool provides information deriving from the central nervous system and among non-invasive daily life brain activity monitoring modalities, EEG is the only one that uses sensors and mounting capabilities such that it can be worn during free locomotion. It is superior to functional Near Infrared spectroscopy (fNIRS) in terms of temporal resolution and brain areas that can be monitored and to other imaging methods, such as functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET) and Magnetoencephalography (MEG), because they have low temporal resolution or are impractical to be adapted for daily life recording. On the other hand, a limitation of EEG application is that it is noise prone when used in daily life applications and physiological signals may be carefully analysed, with systematic and well-established artifacts removal techniques (Sweeney, Ward, & McLoone, 2012). Nonetheless, one big advantage of wireless EEG systems is that it may be easily integrated with other wireless systems monitoring the autonomic nervous system and supplying, respectively, the body autonomic signals (such as the heart rate and the electrodermal activity - measured by biofeedback systems), and the ocular behaviour (gaze plot and fixation times - measurable by portable eye-tracking systems) of the person that is navigating and living a real-life ecological situation.

Thus, within the context of smart home, our approach will be oriented to explore the complex neurophysiological correlates (central and autonomic) of the users' experience by separating the interaction with the smart environment in two distinct phases:

(i) the phase before the input of the home automation command;
(ii) the phase after the input of the home automation command.

The first phase will be related to the anticipation of command input and will reflect cognitive mechanisms related to decision-making, planning and action preparation employed by the user. While the second phase regards the output derived from the command (usually coinciding with the activation of a scenario), related to the effects that the environment is returning to the user. These last outcomes may have an impact on user's emotional status, on his sensory experience and environmental fruition.

In order to deeply explore the neurophysiological correlates of these two phases, a neuroscientific multimethod approach could be useful and has already been demonstrated effective for analysing complex processes (i.e., emotions - Balconi, Grippa, & Vanutelli, 2015) in a variety of conditions and on multiple clinical samples (i.e., before- and after-decision analysis - Balconi, Angioletti, Siri, Meucci, & Pezzoli, 2018). The application of a neuroscientific multi-methodology will allow to obtain a more holistic perspective of the relationship that is established through human-smart environment interaction.

To conclude, smart home studies focusing on users' experience inside the environment are still relatively scarce and neuroscience can provide useful information on smart home users' experience that can be exploited by parties involved in smart home development. Indeed, information derived from neuroscientific studies can help in designing new human-centered domotic environments fitting in a more streamlined way with humans' intentions, in this way environments can require low-effort and can be rendered more usable, responsive, svelte and efficient. Moreover, to know how specific populations (clinical or healthy samples) react at the neurophysiological level to the interaction with smart environments may help implementing *ad hoc* smart systems for these subgroups. It is also possible that different types of user interface (GUI or VUI) may have an impact on human-environment relationship and neuroscience may help testing these aspects. Finally, to deepen how people implicitly react to smart environments may help improving the weaknesses of users' experience inside these smart spaces.

References

Aloise, F., Schettini, F., Aricò, P., Leotta, F., Salinari, S., Mattia, D., … Cincotti, F. (2011). Toward domotic appliances control through a self-paced P300-based BCI. In *Biosignals - Proceedings of the International Conference on Bio-Inspired Systems and Signal Processing* (pp. 239–244).

Babiloni, F., Cincotti, F., Marciani, M., Salinari, S., Astolfi, L., Aloise, F., … Mattia, D. (2009). On the use of Brain–Computer Interfaces outside scientific laboratories: Toward an application in domotic environments. *International Review of Neurobiology*, *86*, 133–146. doi: 10.1016/S0074-7742(09)86010-8

Babiloni, F., Cincotti, F., Marciani, M., Salinari, S., Astolfi, L., Tocci, A., … Mattia, D. (2007). The estimation of cortical activity for brain-computer interface: Applications in a domotic context. *Computational Intelligence and Neuroscience*, *2007,* 1-7. doi: 10.1155/2007/91651

Balconi, M., Angioletti, L., Siri, C., Meucci, N., & Pezzoli, G. (2018). Gambling behavior in Parkinson's Disease: Impulsivity, reward mechanism and cortical brain oscillations. *Psychiatry Research*, *270*, 974–980. doi: 10.1016/j.psychres.2018.03.041

Balconi, M., Grippa, E., & Vanutelli, M. E. (2015). What hemodynamic (fNIRS), electrophysiological (EEG) and autonomic integrated measures can tell us about emotional processing. *Brain and Cognition*, *95*, 67–76. doi: 10.1016/j.bandc.2015.02.001

Castelfranchi, C., Pezzulo, G., & Tummolini, L. (2010). Behavioral implicit communication (BIC): Communicating with smart environments via our practical behavior and its traces. *International Journal of Ambient Computing and Intelligence*, *2*(1), 1–12. doi: 10.4018/jaci.2010010101

Cincotti, F., Mattia, D., Aloise, F., Bufalari, S., Schalk, G., Oriolo, G., … Babiloni, F. (2010). Non invasive Brain-Computer Interface system: towards its application as assistive technology. *Brain Research Bulletin*, *75*(6), 796–803. doi: 10.1016/j.brainresbull.2008.01.007.Non

Filighera, T., & Micalizzi, A. (2018). *Psicologia dell'abitare: marketing, architettura e neuroscienze per lo sviluppo di nuovi modelli abitativi*. (Franco Angeli, Ed.). Milano, Italia.

Gram-hanssen, K., & Darby, S. J. (2016). "Home is where the smart is"? Evaluating smart home research and approaches against the concept of home. *Energy Research & Social Science*, *37*, 94–101. doi: 10.1016/j.erss.2017.09.037

Guruprakash, S., Balaganesh, R., Divakar, M., Aravinth, K., & Kavitha, S. (2016). Brain controlled home automation. *International Journal of Advanced Research in Biology Engineering Science and Technology*, *2*(10), 430–436.

Kaasinen, E., Kymäläinen, T., Niemelä, M., Olsson, T., Kanerva, M., & Ikonen, V. (2013). A user-centric view of intelligent environments: User expectations, user experience and user role in building intelligent environments. *Computers*, *2*(1), 1–33. doi: 10.3390/computers2010001

Mallett, S. (2004). Understanding home: A critical review of the literature. *Sociological Review*, *52*(1), 62–89. doi: 10.1111/j.1467-954X.2004.00442.x

Mihajlovic, V., Grundlehner, B., Vullers, R., & Penders, J. (2015). Wearable, wireless EEG solutions in daily life applications: What are we missing? *IEEE Journal of Biomedical and Health Informatics*, *19*(1), 6–21. doi: 10.1109/JBHI.2014.2328317

Milani, L., Camisasca, E., Caravita, S.C.S., Ionio, C., Miragoli, S., & Di Blasio, P. (2015). Violent video games and children's aggressive behaviours: An Italian study. *SAGE Open*, *5*(3), 1-9. doi: 10.1177/2158244015599428

Milani, L., La Torre, G., Fiore, M., Grumi, S., Gentile, D.A., Ferrante, M., Miccoli, S., & Di Blasio, P. (2018). Internet Gaming Addiction in Adolescence: risk factors and maladjustment correlates. *International Journal of Mental Health & Addiction*, *16*(4), 888-904. doi: 10.1007/s11469-017-9750-2

Navarro-Tuch, S. A., Lopez-Aguilar, A. A., Bustamante-Bello, M. R., Molina, A., Izquierdo-Reyes, J., & Curiel Ramirez, L. A. (2019). Emotional domotics: a system and experimental model development for UX implementations. *International Journal on Interactive Design and Manufacturing*, 1-5 doi: 10.1007/s12008-019-00598-z

Sweeney, K. T., Ward, T. E., & McLoone, S. F. (2012). Artifact removal in physiological signals-practices and possibilities. *IEEE Transactions on Information Technology in Biomedicine*, *16*(3), 488–500. doi: 10.1109/TITB.2012.2188536

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2015). Smart homes and their users: a systematic analysis and key challenges. *Personal and Ubiquitous Computing*, *19*(2), 463–476. doi: 10.1007/s00779-014-0813-0

Woodruff, A., Augustin, S., & Foucault, B. (2007). Sabbath Day home automation: "It's like mixing technology and religion." In *Proceedings of the SIGCHI conference on Human factors in computing systems, ACM Press* (pp. 527–536). doi: 10.1145/1240624.1240710