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Using Gestures to Interact with Home Automation Systems: 
- a Socio-Technical Study on Motion Capture Technologies for Smart Homes -

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Keywords: Home Automation, Gesture Control, Usability, Pervasive Computing

Abstract

Homes and working spaces are considered significant contributors to the top percentage of energy consumption and carbon emissions worldwide (GeSI Report, 2017). Previous studies in the field of home- and building automation have demonstrated the sustainability gain brought by smart home solutions, in terms of energy-efficiency, economic savings, and enhanced living and working conditions. A major barrier, however, to the adoption of these solutions is the complexity and limited usability of user interfaces. In addition, various modes of interactions for the control and automation of residential environments are an emerging area of study within Human-Computer interaction. As a response to these challenges, this study investigates the use of gestures as a natural way of controlling and interacting with home automation systems. Using the available motion capture technology, a gesture dictionary will be defined as a set of meaning actions in free-form and in-air movements. A usability test will be conducted to measure the resulting socio-technical aspects. Lastly, the study will present the analysis and effects of gestures control for a higher up-take of smart home solutions towards designing and maintaining buildings of the future that are both user-centric and resource efficient to reduce our overall carbon footprint.

Introduction

In an article published by Eurostat regarding energy trends from data collected June of 2017, households comprise 25.4% of the final energy consumption, one of the dominant categories together with transport (33.1%), and industry (25.3%) within the European Economic region (Consumption of energy - Statistics Explained, 2017). In addition, buildings, both homes and working spaces, are culpable for the 36% of the total carbon emissions in Europe (Buildings - European Commission, no date). The European Commission is convinced that by using commercially available building automation technologies, possible reductions to energy consumption can be up to 6%, and 5% for the total carbon emissions (Buildings - European Commission, no date). Through its policies, initiatives, and research activities, the European
Union pushes its citizens to use energy more efficiently - to lower their utility bills, reduce their reliance on external suppliers of oil and gas, and help protect the environment.

The Global e-Sustainability Initiative (GeSI) suggests in its #Smarter2030 Report that ICT in households and buildings will increase comfort and reduce energy and water bills. The report adds that smart building solutions could cut up to 2.0Gt of carbon emissions from the housing sector, reducing energy consumption by 5 billion MWh, and creating revenue opportunities of another $260 billion (GeSI, 2015). The future of smart buildings relies on the concept of insight and control, from smart metering that enhances people’s awareness of their energy and resource consumption to enabling users to interact with these technologies remotely and automatically. These solutions will lead to strong sustainability impacts such energy and resource efficiency, improved processes and automation, and enhance living conditions and productivity.

Home automation technologies have been commercially available for a couple of years now, these solutions repeatedly faced market failures. Amid all the benefits, low usability can be seen as one of the prominent reasons for the high level of reluctance from customers to invest in home automation systems (HAS) (Droegehorn, Pittumbur and Porras, 2017). Other factors include high investment cost, lack of flexibility and scalability, and the variety of individual products that are not easily interoperable. However, the user interface and control are often reported to be the most unusable product due to its poor design and complex features which result in home automation technologies being inaccessible to a wide range of non-technical users (Droegehorn, Pittumbur and Porras, 2017).

As a response to these challenges, this research aims to investigate whether a natural mode of interaction would entice users towards adopting home automation systems. This investigation looks into gesture control as an intuitive way of interacting with home automation systems. A survey of motion capture sensors and its applications will be done to evaluate suitable technologies. Meaningful actions will then be defined as gestures in the context of HAS interaction and control. Lastly, a usability study will be conducted to measure the level of socio-technical aspects such as acceptability, ease of use, and gesture anthropology. The need to pursue this study arises from the need to improve the up-take of HAS thus maximizing its potentials to address economic, environmental, and usability issues.

**Review of Related Works**

This chapter will be divided into three sections dealing with the following topics: (a) home automation systems, (b) motion capture technologies, and (c) gesture interaction and usability. Each section will discuss previous studies, applications, and works that are either directly or indirectly but substantially related to this work.

**Home Automation Systems**

Previous studies in Home Automation and Smart Homes have various definitions of these common buzz words. David, et. al (2002) defines it as “the integration of technologies and
services, applied to homes, flats, apartments, houses and small buildings with the purpose of automating them and obtaining and increasing safety and security, comfort, communication, and technical management” (David, Collete and Magdalen, 2002). In another study Malcolm (2001) put it as “one where smart technologies are installed and where those technologies facilitate automatic or user-initiated communication, involving a range of appliances, sensors, actuators and switches” (Malcolm, 2014). Martinez (2017) also referred to it as a derivative of Building Automation (BA) which is specifically implemented in homes and residential spaces (Martinez, 2017). These are the working definitions that will be used in the context of this research.

In the following chapters, the term Home Automation Systems (HAS) will be used to define the collective idea and concepts of home automation, smart homes, and domotics, which were loosely referred to in the literature and other related works. In addition, Smart Home Technologies will be the working term for all technologies, such as sensors, actuators, and similar devices that are used and integrated towards developing and implementing HAS.

**Motion Capture Technology**

The release of the LEAP Motion Controller in 2013 opened new frontiers for gesture technologies. While the industry and tech enthusiasts differ in opinion on how useful the highly publicized device was, the sale of the product – along with the new generation XBOX Kinect sensor by Microsoft, marked a step forward for commercial gestural interface use (Garber, 2013). We are interested with gestural interfaces for several reasons. Advances in technology have made gesture recognition more feasible and affordable in terms of low-cost and efficient microcontrollers, enhanced machine vision software, and state of the art 3D cameras and depth sensors (Garber, 2013).

Gesture control technologies or gestural interfaces can be categories to either perceptual or non-perceptual technologies (Karam and Schraefel, 2005; De Carvalho Correia, De Miranda and Hornung, 2013). Like how Karam & Schraefel put it, perceptual technologies are those which enables gestures to be recognized without requiring any physical contact with an input device or with any physical objects, allowing the user to communicate gesture without having to wear, hold or make physical contact with any intermediate devices (Karam and Schraefel, 2005). Non-perceptual technologies, on the other hand, are those that involves the use of artifacts such as a glove, pen, or mouse, and requires physical contact to transmit spatial or temporal information as input.

For the purpose of this study, we focus on perceptual technologies, such as the Microsoft Kinect, in terms of its ability to enable gesture recognition without the need for physical contact. Non-perceptual technologies will still be mentioned in related works as these are studied and used along-side the Microsoft Kinect. Thus, while several studies have investigated models and methods in meaningful gestures on screens, gloves, pens, and other non-perceptual technologies that require physical contact, this study focuses on defining a set of “in-air” gestures with attention to making a natural and intuitive way of interacting with home automation systems.
Although this is not an exhaustive look at literatures regarding Microsoft KINECT and the technology behind it, the survey or related works provides a practical mean to understand how the device work, and its application in research.

With the invention of Microsoft Kinect sensor, high-resolution depth and visual (RGB) sensing has become more available for widespread use (Han et al., 2013). The complimentary nature of the depth and visual information provided by the sensor opens up new frontiers to solve fundamental problems in machine vision. Though originally perceived to revolutionized entertainment as a control-free interface for XBOX, Kinect’s impact has extended far beyond the gaming industry (David, Collete and Magdalen, 2002). Many researchers have utilized the device to develop creative ways to interact with machines and perform different tasks – Microsoft calls this the “Kinect Effect.” In 2012, the tech giant released the first version of the Kinect Software Development Kit (SDK) for Windows, which undoubtedly amplified the Kinect Effect to reach more practitioners and developers from the fields of computer science, electronics engineering and robotics, thus transforming human-computer interaction in multiple industries (Zhang, 2012). The following is a survey of studies published on Microsoft Kinect technology evaluation and its applications.

The Kinect found its way outside the living room to the other places inside the house. (Panger, 2012) studied the problem of people who want to flip through recipe books, change music, or set a kitchen timer even with hands messy from cooking or baking. Another application that uses Kinect is the Ambient Wall (Kim et al., 2011), a smart home system that allows users to control the television, air conditioning, and others through an interface projected on a wall. Hands-Up (Oh et al., 2012) uses the device with a projected user interface on the ceiling surface, where users lying in bed put their hands up to control devices. (You, Tang and Wang, 2014) integrated Kinect with and Arduino creating an immersive ambient entertaining environment in automating parties. The system is responsive and sensitive to human activity such as gestures, body movement and facial expressions.

Using Kinect as an assistive technology at home was also popular especially in terms of activity monitoring, tele-rehabilitation, and elderly care. (Lin, Hsueh and Lie, 2017) used the high-resolution RGB and depth images taken using the Kinect and applied continued deep learning models in neural networks to detect abnormal events to help users avoid injuries from falling. To promote healthier living at home, (Zhao and Lun, 2017) developed a user activity tracking system using Kinect with sensor inputs and fitness bands for health feedback. The system continuously monitors users and detect bad postures. Logs can be accessed via mobile devices to see their progress.

As presented in this section, the survey of related works and published literature regarding the research viability of such devices proved exciting potential for the Microsoft Kinect as a gesture control technology suitable for the implementation of this study. Thus, while several studies have showed the potential of motion capture sensors outside of gaming and entertainment, in areas such as tele-rehabilitation, aid for the elderly and people-with-disabilities, and digital
interactions, this study investigates on the use of the Microsoft Kinect to interact with home automation systems to attain a higher uptake for smart home technologies towards promoting sustainability.

**Gesture Interaction & Socio-Technical Aspects**

The use of gestural interaction, being frequently used in everyday social life, is considered intuitive in human communication. When addressing the naturalness of interaction (ie. intuitive, easy to learn) it is indispensable to consider social and cultural aspects of a target audience when defining a gestural vocabulary - thus meaningful gestures that do feel natural, intuitive, and easy to learn.

Developers and researchers try to provide solutions to users through complex computational means, as seen with improved accuracy, efficiency, and robustness in the case of Microsoft Kinect, aside from the technical aspects (Zhang, 2011, 2012) however, the social sphere needs to be considered as well. With this in mind, (De Carvalho Correia et al., 2014) proposed a framework to identify and discuss the challenges of different forms of interaction with technology considering socio-technical aspects in an integrated manner. The framework consists of the main dimensions: home automation systems, gesture interaction, and human. The concentric organization of these three suggests their interdependency in a triadic relationship (De Carvalho Correia, De Miranda and Hornung, 2013).

Therefore, while several studies have looked into reliability, accuracy, and efficiency in using the Microsoft Kinect for gesture recognition, this study will conduct a socio-technical study under three specific aspects to attain a level of acceptability, ease of use, and gesture anthropology and better understand the relation of gesture control and home automation systems.

- **Acceptability** – level of user’s positive response towards a new technology or innovation. This aspect will be guided by the Technology acceptance model (TAM) proposed by Davis, et. al [24]. Factors such as Perceived usefulness (PU) and Perceived ease-of-use (PEOU) will be measured to come up with the level of acceptability.
- **Usability or General ease-of-use** – measure of learnability, memorability, errors, satisfaction and overall comfort of the user towards the technology. These main topics were suggested by Nielsen [25] to understand how usability interplays with gestural interaction.
- **Culturability or Gesture Anthropology** – suggestive measure of naturalness or intrusiveness of interaction with the home automation system for people coming from different cultural or ethnological background. Researchers are still trying to understand how the gestures are influenced by culture [10]. Although this detail might seem irrelevant for the definition of gestures, it might very well influence whether a certain gesture is considered appropriate in a certain cultural context.

**Research Framework and Methodology**
A workflow methodology as shown in Figure 2 will be followed for this study. This was based on the Design Science research which is a prescriptive knowledge framework that aims to develop useful artifacts guided by three closely related cycles (Hevner et al., 2004). The relevance cycle initiates design science research with an application context that not only provides the requirements for the research as inputs but also defines acceptance criteria for the ultimate evaluation of the research results. The rigor cycle provides past knowledge to the research project to ensure its innovation. The central design cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research – for the purpose of this work, action research methodology will take over the design cycle towards implementing the artifact.

The workflow will have five stages where components of the design science research are incorporated. First, problem identification which include literature review corresponds to knowledge-base and grounding from the Rigor Cycle. Requirement Definition (from Relevance Cycle) will include technology survey and gesture definition while Artifact Development (Design Cycle) encompassed proof-of-concept and prototyping. To complete the Design Cycle, we move to Observation & Feedback with the usability testing; and Evaluation with the analysis and discussion towards a coherent conclusion of the research.

**Research Methods**

![Figure 1. Workflow methodology based on design science framework](image)

This chapter will discuss stages 2 to 4 of the research workflow. As such, it will be further divided into three other sections: (a) Microsoft Kinect & Artifact development, (b) Gesture Recognition & Machine Learning, and (c) Demo & Testing. This section will tackle topics regarding the technical implementation done towards the puruse of the research goals.

**Microsoft Kinect & Artifact Development**

Figure 3 below describes how the perceived system would work. The gesture will be taken in by the Kinect sensor, the input feed will go into the gesture recognition algorithms for detection and labelling, then controls will be sent out to the home automation server through a web socket. This then will control the corresponding smart home device as commanded by the gesture.
The Microsoft Kinect offers high-quality skeletal tracking and recognition. The sensor consists of a color camera (RGB), depth sensor with infrared (IR) camera and projector, and a built-in microphone array. It can track up to six bodies simultaneously with 25 skeletal joints each, and three recognized hand states: open (palms out), closed (clenched fist), and lasso (2 fingers). The Kinect Windows SDK was used to develop C# software for the use of this study. In addition, the Kinect Studio v2.0, and Visual Gesture Builder were utilized for motion capture and labelling. Home Assistant and FHEM were used as open-source HAS platform and server while HomeMatic actuators were integrated for the smart home devices.

**Machine Learning & Gesture Recognition**

The gesture recognition process followed the Machine Learning approach that is divided into six steps for all nine gestures presented in Figure 4 and Table 1. First was (1) data acquisition with gesture recording using the Kinect Studio v2.0 then each raw input file in xref format was ran through (2) pre-processing for compression and optimization. Now using the Visual Gesture Builder, (3) features were extracted after proper labelling, (4) training and test sets were separated with training sets were put into (5) post processing with two active algorithms: AdaBoost Trigger (discrete gestures) and RFRP Progress (continuous gestures), then lastly creation of the (6) classification model.

**Demo & Testing**

After the prototype was ready for demo, a testing schedule was prepared, and prospective participants were invited. To help look into capturability and gesture anthropology, a mix of local and international students were invited to participate in the demo and testing. In the end, 32 students, from 12 countries, volunteered to participate. The participants were provided with an informed consent form for minimal risk (classroom activities/projects involving human participants) to ensure that their health, safety, and protection are assured in the activity. It also ensures that their information will be protected under the “General Data Protection Regulation” (GDPR EU 2016/679) of the European Union.
Figure 3. Gesture dictionary visualized with Microsoft Kinect

Table 1. Gesture Dictionary for HAS

<table>
<thead>
<tr>
<th>Gesture</th>
<th>Description</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAND OPEN</td>
<td>Open hand near the head</td>
<td>Turn on the lights</td>
</tr>
<tr>
<td>HAND CLOSED</td>
<td>Clenched fist near the head</td>
<td>Turn off the lights</td>
</tr>
<tr>
<td>SWIPE RIGHT</td>
<td>Lasso (2 fingers) near the head, swiping to the right</td>
<td>Next song/item</td>
</tr>
<tr>
<td>SWIPE LEFT</td>
<td>Lasso (2 fingers) near the head, swiping to the left</td>
<td>Previous song/item</td>
</tr>
<tr>
<td>ARMS OPEN</td>
<td>Both fists clenched in front of the body, extending from center outwards</td>
<td>Open curtains</td>
</tr>
<tr>
<td>ARMS CLOSED</td>
<td>Both fists clenched, abdominal level away from the boy, moving towards the center</td>
<td>Close curtains</td>
</tr>
<tr>
<td>TURN CW</td>
<td>Clenched fist at arm level, turn wrist clockwise (to the right)</td>
<td>Heater value up</td>
</tr>
<tr>
<td>TURN CCW</td>
<td>Clenched fist at arm level, turn wrist counter-clockwise (to the left)</td>
<td>Heater value down</td>
</tr>
<tr>
<td>SWIPE AROUND</td>
<td>Lasso (2 fingers) near the head, make a circular movement horizontally</td>
<td>Toggle everything</td>
</tr>
</tbody>
</table>

For the demo, each participant was asked to interact with the motion capture prototype, answer the questions regarding usability, and provide feedback regarding their experience of the technology. For this, a structured questionnaire was prepared to observe three socio-technical aspects to help us understand gesture interactions for home automation systems. The questions are formulated to be Likert items with under three Likert scales corresponding to acceptability, ease-of-use, and culturability. Table 2 presents the Likert items and their descriptions.

After the demo run, the participants were asked for any clarifications and if they have any suggestion to improve the study. All data were then encoded and tabulated for further analysis.
### Table 2. Likert Items for the Socio-Technical Study

<table>
<thead>
<tr>
<th>NO.</th>
<th>ITEM</th>
<th>HEURISTICS</th>
<th>ASPECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Gesture control will improve my overall experience with smart homes.</td>
<td>Perceived usefulness</td>
<td>Acceptability</td>
</tr>
<tr>
<td>A2</td>
<td>Gesture control will make interacting with smart homes easier.</td>
<td>Perceived ease-of-use</td>
<td>Acceptability</td>
</tr>
<tr>
<td>A3</td>
<td>I will easily get used to smart home interactions with the help of gestures.</td>
<td>Attitude towards using the technology</td>
<td>Acceptability</td>
</tr>
<tr>
<td>A4</td>
<td>Gestures will be a typical way of interacting with technology in the future.</td>
<td>Behavior towards intention of use</td>
<td>Acceptability</td>
</tr>
<tr>
<td>U1</td>
<td>The gestures are generally easy to remember.</td>
<td>Memorability</td>
<td>Usability</td>
</tr>
<tr>
<td>U2</td>
<td>Most gestures are easy to learn because to correspond well with the commands.</td>
<td>Learnability</td>
<td>Usability</td>
</tr>
<tr>
<td>U3</td>
<td>The gestures are generally very complex and complicated to perform.</td>
<td>Efficiency</td>
<td>Usability</td>
</tr>
<tr>
<td>U4</td>
<td>It is easy to make errors or mistakes with the current set of gestures.</td>
<td>Error</td>
<td>Usability</td>
</tr>
<tr>
<td>U5</td>
<td>I am generally satisfied with the gestures used for smart home interaction.</td>
<td>Satisfaction</td>
<td>Usability</td>
</tr>
<tr>
<td>U6</td>
<td>Most gestures are straining to the arms and hands.</td>
<td>Comfort</td>
<td>Usability</td>
</tr>
<tr>
<td>C1</td>
<td>Using gesture is a natural way of interacting with smart home technologies.</td>
<td>Intuitiveness</td>
<td>Culturability</td>
</tr>
<tr>
<td>C2</td>
<td>My culture is known to use (hand/body) gestures as part of everyday communications.</td>
<td>Gesture use</td>
<td>Culturability</td>
</tr>
<tr>
<td>C3</td>
<td>These gestures reflect possible interactions of people from where I am from.</td>
<td>Gesture anthropology</td>
<td>Culturability</td>
</tr>
<tr>
<td>C4</td>
<td>My cultural background is known to be very accepting of new technologies/innovations.</td>
<td>Openness to innovation</td>
<td>Culturability</td>
</tr>
<tr>
<td>S1</td>
<td>Compared to other media (voice command and remote controls), I am open to using gestures to interact with smart homes.</td>
<td>Comparison to other available mode of interactions</td>
<td>(Summary/Debriefing)</td>
</tr>
<tr>
<td>S2</td>
<td>I would buy (or invest to) smart home devices to control my home.</td>
<td>Perceived investment</td>
<td>(Summary/Debriefing)</td>
</tr>
<tr>
<td>S3</td>
<td>I would but (or invest to) gesture technologies to interact with my smart home.</td>
<td>Perceived investment</td>
<td>(Summary/Debriefing)</td>
</tr>
</tbody>
</table>

### Results and Findings

There was a total of 32 participants for the demo and testing, of which 87.5% are aged 18-26, and 9.4% aged 27-35 years old. Regarding the participants’ current living situation: 65.6% are living with roommates or in shared flats, 21.9% live by themselves, and 12.5% live with their families. It is also significant to mention that even only 31.3% of the participants have access to smart home devices, from 68.8% who does not, 95.7% of which are interested in such devices, the remaining 4.3% are just not interested or rather highly critical.

As shown in Figure 5, we can pinpoint the Likert item that performed best for each aspect. A2 that suggests perceived ease-of-use has the highest mean of 4.375 for acceptability. U3 which is about efficiency got 4.71875, highest for usability aspect. And C2 which talks about gesture use got 3.656, for the capturability aspect. We can also compute for the global mean for each Likert
scale that corresponds to the suggestive level of each socio-technical aspect. Acceptability garnered a score of 4.125, ease-of-use with 4.271, and culturability with 3.609, out of 5.0.

Aside from descriptive analysis, we can also apply inferential statistics to look into the data gathered from the demo/testing. As a special case, we put together data for participants coming from the same country. There are seven (7) data points each for Germany, Spain, France. For this, analysis of variance (ANOVA) will be applied to see if the hypothesis $H_0$: “Cultural background does not relate or affect opinion regarding gesture interactions for smart homes,” can be denied.

**Figure 4. Results of the three socio-technical aspects in Likert scale**

ANOVA is a collection of statistical models and their associated procedures used to analyze the differences among group means. The total variation or sum of squares, variation within the group, variation between the group, and degrees of freedom are computed to calculate for an F value that will be used for an F-test along the F-distribution curve. As a standard, we choose an F-critical point as a function of the degrees of freedom which is $F_{critical}(2,18)$ for $10\% = 2.62$. Comparing all F-values derived from all the 17 Likert items, no values were $\geq F_{critical}$, thus the null hypothesis $H_0$ is not rejected.

Lastly, we compute for Cronbach’s Alpha (or coefficient alpha) which is a measure of internal consistency or how closely related a set of items are as a group to have an idea whether the Likert items play consistently in the questionnaire as whole. For sets with more than 10 items, an alpha value greater 0.70 displays a highly consistent and well sort out data. Given the 17 Likert items in the questionnaire, we calculated a Cronbach’s Alpha value of 0.85.
Discussions

In studying gestural interaction for technologies such as home automation systems, it is important to not only look into technical issues such as accuracy, efficiency and robustness, but also to socio-technical aspects such as acceptability, ease-of-use, and culturability. The positive feedbacks coming from volunteer participants help shed a light to better understand gestures and motion capture technologies for the control of smart home devices.

With participants mostly from the young adult generation which are seen as very technologically adept and the would-be homemakers in the near future, the realization of smart homes into everyday life is far from imagination. The acceptance level is relatively agreeable, 4.125 out of 5.0 with adopting the perceived usefulness of this technology. Under the usability aspect, heuristics such as learnability, memorability, and efficiency for the gesture dictionary, performed well with scores all more than 4.50, thus suggests naturalness and intuitiveness. Culturability or gesture anthropology however is a field that needs more investigation. With the ANOVA conducted for all Likert items, the null hypothesis which proposed that cultural difference does not relate to gesture interactions opinion was not rejected brought by values lower that the F-critical (2,18).

Conclusion

Indeed, the power over living a more sustainable lifestyle is in our hands. This study implemented a proposed home automation system using Microsoft Kinect as a prospective motion capture sensor for the specific context of the research. A gesture dictionary was also defined as meaning gestures with corresponding control commands for smart home devices. These gestures were tested and demonstration for the socio-technical study were aspects such as acceptability, ease-of-use, and culturability were measured for the sample population. A positive feedback from the heuristics suggests that gesture interactions for home automation systems are indeed categorically natural and intuitive. The study then responds to the challenge of improving the uptake of HAS thus maximizing its potentials towards designing and maintaining buildings of the future that are both user-centric and resource efficient to reduce our overall carbon footprint.

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