Using gestures to interact with home automation systems

Marcel Lowell Villanueva[1, 2]*, Olaf Droegehorn[2]

[1]*Erasmus Mundus Master in Pervasive Computing and Communications for Sustainable Development*
[2]*Hochschule Harz – University of Applied Sciences, Wernigerode 38855, Germany*

*Corresponding author: E-mail: marvil-7@student.ltu.se

DOI: 10.5185/amp.2019.1443
www.vbripress.com/amp

Abstract

Homes and working spaces are considered significant contributors to the top percentage of energy consumption and carbon emissions worldwide. 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 poor 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. After a survey of available motion capture technologies (Microsoft Kinect and LEAP Motion) and studies related to both, a gesture dictionary will be defined as a set of meaning actions in free form in-air movements. A socio-technical study t will be conducted to measure the resulting aspects such as acceptability, ease-of-use, and culturability. 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. Copyright © VBRI Press.

Keywords: Home automation, gesture control, usability, pervasive computing.

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 [**1**]. In addition, buildings, both homes and working spaces, are culpable for the 36% of the total carbon emissions in Europe [**2**]. 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 [**2**]. 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 [**3**]. 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) [**4**]. 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 [**4**].

As a response to these challenges, the research aims to investigate whether a natural mode of interaction would entice users towards adopting home automation systems. The plan is to look 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 to be able to improve the up-take of HAS thus maximizing its potentials to address economic, environmental, and usability issues.

Research framework & methodology

Design science research can be seen as an embodiment of three closely related cycles of activities. 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. It is contingent on the researchers to thoroughly research and reference the knowledge base in order to guarantee that the designs produced are research contributions and not routine designs based upon the application of well-known processes. 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 thesis, action research methodology will take over the design cycle towards implementing the artifact.

Adopted from the design science research process suggested by Tran (2017) [**5**], we derive a five-stage design cycle based on the Design Science Framework [**6**] as in **Fig. 1**.

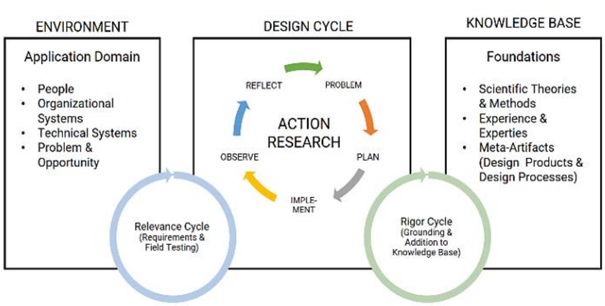

Fig. 1. Design science research framework.

The workflow will have five stages as shown in **Fig. 2**. The components of the design science research are incorporated in these stages. 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.

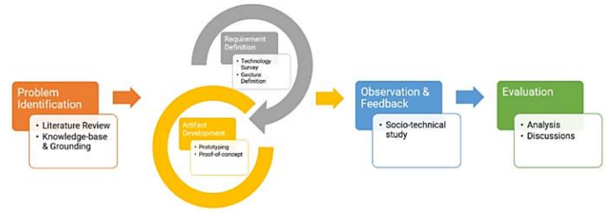

Fig. 2. Workflow based on design science research.

Review of related works

This chapter will be divided into three sections that would talk about 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 the study.

A. *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” [**7**]. In another study Malcolm (2014) 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” [**8**]. Martinez (2017) also referred to it as a derivative of Building Automation (BA) which is specifically implemented in homes and residential spaces [**9**]. 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.

B. *Motion capture technologies*

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 [**10**]. 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 [**10**].

Gesture control technologies or gestural interfaces can be categories to either perceptual or non-perceptual technologies [**9**, **10**]. 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 [**11**]. Non-perceptual technologies, on the other hand, are those that involve the use of artifacts such as a glove, pen, or mouse, and require 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 [**13**]. 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 [**14**]. 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 [**14**]. 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 [**15**] 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 [**16**], a smart home system that allows users to control the television, air conditioning, and others through an interface projected on a wall. Hands-Up [**17**] 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, *et al.* [**18**] 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, *et al.* [**19**] 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 & Lun [**20**] 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.

In a more medical application, Blumrosen, *et al.* [**21**] used the Kinect as a non-wearable sensor to track human activity at home. They extracted Kinect Signatures to differentiate patients for tele-rehabilitation and kinematics therapy. Kinect was also used as a smart home aide to people with disabilities, the differently-abled, and patients with specific needs, for applications such as controlling appliances [**22**] and interpreting sign language as commands [**23**].

The LEAP Motion controller is a small peripheral that plugs into USB port and sits in a desk or table in front of a computer. Using two cameras to capture motion information and three infrared LEDs as a light sources, the system tracks the movements of hands, fingers, finger joints, and several other objects in an area of approximately 60 cm in front of, to the side of and above the device [**10**]. Compared to the Kinect which tracks large full-body movements, the LEAP Motion Controller detects small motions and can be accurate to within 0.01 millimeters.

On the more practical applications, Ameur, *et al.* [**24**] developed a comprehensive LEAP Motion database for hand gesture recognition. This was used for medical visualization while focusing on user satisfaction with movements such as click, left and right rotate, increase and decrease contrast, zooms in and out, move left and right, previous and next. As a popular case study, LEAP Motion was used to interpret sign language both in Indian Sign Language (ISL) [**25**] and American Sign Languange (ASL), including manual signs and finger-spelling [**26**] with great accuracy. In addition, a novel method to tracking movements of the human hand, Ponraj & Ren [**27**] used the LEAP Motion control with flex sensors to follow finger tips. And as a recent development that the LEAP Motion company wants to venture in, the device is introduced as a Virtual Reality (VR) or Augmented Reality (AR) controller, such as those in the virtual museum [**28**] and VR bulb switches control [**29**].

Both technologies have their own strengths and challenges in terms of the depth of technology and advancement in applications. As presented in this chapter, the survey of related works and published literature on the research viability of these devices proved exciting potential for Microsoft Kinect and LEAP Motion as gesture control technologies 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.

C. *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 (i.e. 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 [**14, 30-31**] however, the social sphere needs to be considered as well. With this in mind, Correia, *et al.* [**12**] 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 [**12**]. And as shown in **Fig. 3**, each aspect is represented by a dashed ellipse and has interactions with the three dimensions.

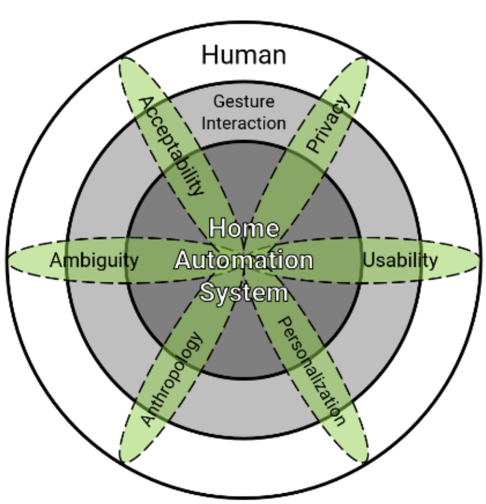

Fig. 3. Framework of socio-technical aspects for gestural interactions.

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* [**32**]. 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 [**33**] 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 [**12**]. 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.

Implementation

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, (c) Demo & Testing, and topics on the technical implementation done to purse of the goals.

A. *motion capture technologies*

Fig. 4 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.

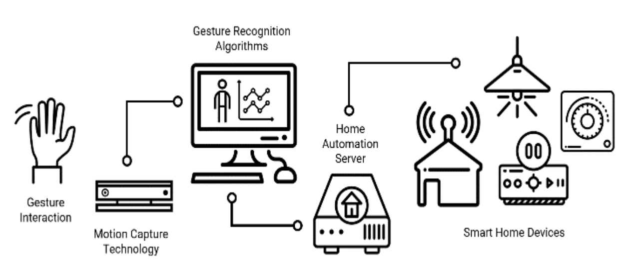

Fig. 4. System architecture diagram for HAS and gesture interaction.

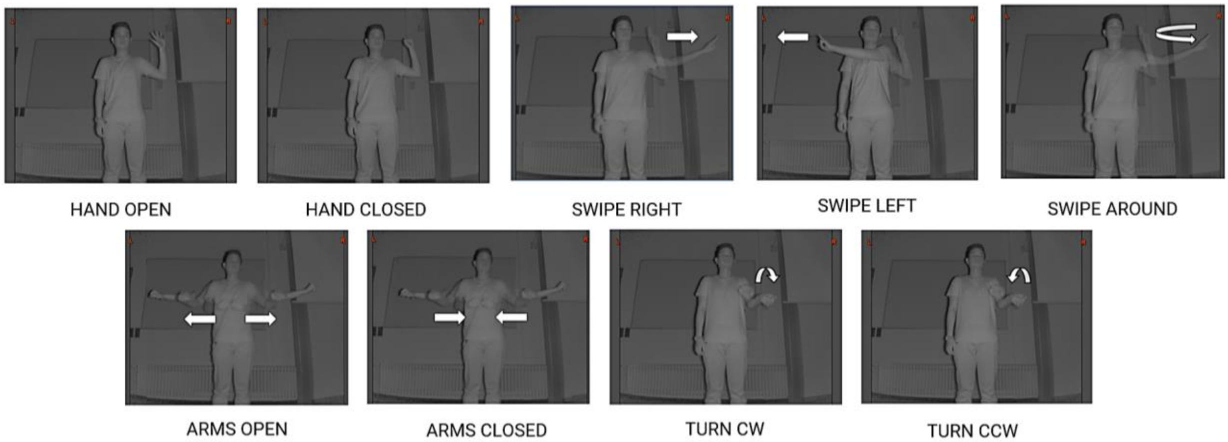

Fig. 5. Gesture dictionary visualized with Microsoft KINECT.

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 it 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.

Table 1. Gesture dictionary for HAS.

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

B. 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 **Fig. 5** and **Table I**. First was (1) data acquisition with gesture recording using the Kinect Studio v2.0 then each .xref file was run 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 Gesture Dictionary for HAS RFRP Progress (continuous gestures), then lastly creation of the (6) classification model.

C. 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 an informed consent form for minimal risks (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.

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 Gesture Dictionary for HAS 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 II** presents the Likert items and their descriptions.

After the demo run, the participants were asked for any clarifications or if they have any suggestions to further improve the study. All data were then encoded and tabulated for further analysis.

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.

Table II. Likert Items and the Socio-technical Aspects.

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

As shown in **Figs. 5-7** and **Table III**, 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 culturability 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 in to 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 H0: "Cultural background does not relate or affect opinion regarding gesture interactions for smart homes," can be denied. 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 ≥ F-critical, thus the null hypothesis H0 is not rejected.

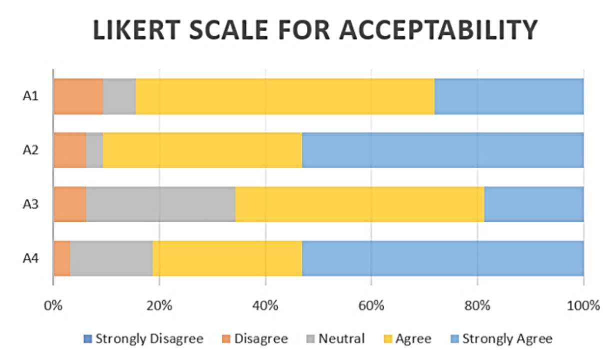

Fig. 5. Likert scale for acceptability on stacked bar (100%) graph.

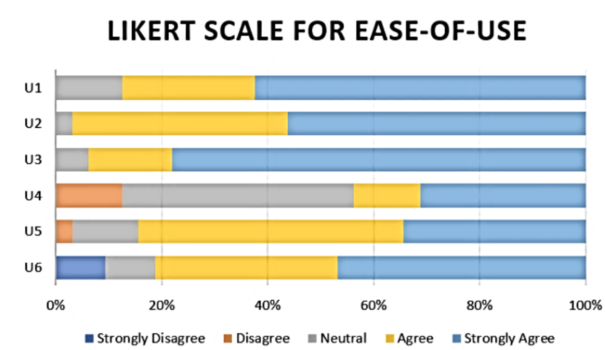

Fig. 6. Likert scale for ease-of-use on stacked bar (100%) graph.

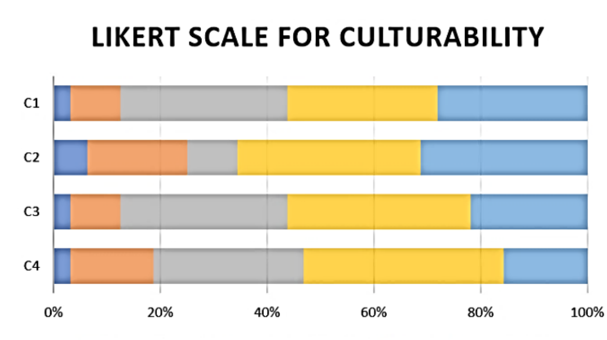

Fig. 7. Likert scale for culturability on stacked bar (100%) graph.

Table III. Statistical Results for each Likert Item.

	Likert items						
	A1	***A2***	***A3***	***A4***	***U1***	***U2***	***U3***
Mean	4.031	4.375	3.781	4.313	4.500	4.531	4.719
SD	0.861	0.833	0.832	0.859	0.718	0.567	0.581
Var	0.741	0.694	0.693	0.738	0.516	0.322	0.338
	U4	***U5***	***U6***	***C1***	***C2***	***C3***	***C4***
Mean	3.625	4.156	4.094	3.688	3.656	3.625	3.469
SD	1.070	0.767	1.201	1.091	1.285	1.040	1.047
Var	1.145	0.588	1.443	1.190	1.652	1.081	1.096

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 culturabilty. 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 with 4.125 of 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 demonstrated 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 up-take 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.

Acknowledgements

This research is part of the Erasmus Mundus Joint Master's Degree (EMJMD) in Pervasive Computing and Communications for Sustainable Development (PERRCOM) [34]. The authors are grateful to the academia, companies, and associate partners of the PERCCOM Consortium.

Author's contributions

Conceived the plan: mlv, od; Performed the expeirments: mlv; Data analysis: mlv; Wrote the paper: mlv, od.

References

1. "Energy trends - Statistics Explained," **2017**. Online.. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php?title= Energy_trends. Accessed: 21-May-2018.
2. "Buildings - European Commission." Online.. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency/ buildings. Accessed: 21-May-2018.
3. GeSI, "#SMARTer2030," **2015**. Online.. Available: http://smarter2030.gesi.org/downloads/Full_report.pdf. Accessed: 21-May-2018.
4. Droegehorn, O.; Pittumbur, M.; Poras, J.; Front-End Development for Home Automation Systems: A design approach using JavaScript Frameworks. SEEDS Conf., **2017**.
5. Tran. G.; GreenBe – A System To Capture and Visualize User's Energy - Related Activities For Facilitating Greener Energy Behavior. *SEEDS Conf.*, **2017**.
6. Hevner, A.; Scandinavian Journal of Information Systems A Three Cycle View of Design Science Research A Three Cycle View of Design Science Research. *Scand. J. Inf. Syst.*, **2007**.
7. David, P.; Collete N.; Magdalen, G.; Review of the current status of research on smart homes and other domestic assistive technologies in support of the TAHI trials Review of the current status of research on 'Smart Homes' and other domestic assistive technologies in support of TAHI trials, *Loughbrgh. Univ.*, **2002**.
8. Malcolm, J.; The Implications of Smart Home Technologies, *S. Peace, C. Holl. Incl. Hous. Ageing*, **2014**.
9. Martinez, C.; Remote control-based home automation usability evaluation, *SEEDS Conf.*, **2017**.
10. Garber, L.; Gestural Technology: Moving Interfaces in a New Direction, *Computer (Long. Beach. Calif.)*, **2013**.
11. Karam, M.; Schraefel, M.; A Taxonomy of Gestures in Human Computer Interactions, *Tech. Report, Eletronics Comput. Sci.*, **2005**.
12. De Carvalho Correia, A.; De Miranda, L.; Hornung, H.; Gesture-based interaction in domotic environments: State of the art and HCI framework inspired by the diversity, *Lect. Notes Comput. Sci.*, **2013**.
13. Han, J.; Shao, L.; Xu,D.; Shotton, J.; Enhanced computer vision with Microsoft Kinect sensor: A review, *IEEE Trans. Cybern.*, **2013**.
14. Zhang, Z.; Microsoft kinect sensor and its effect, *IEEE Multimed.*, **2012**.
15. Panger, G.; Kinect in the kitchen: testing depth camera interactions in practical home environments, *Proc. CHI 2012 Ext. Abstr.*, **2012**.
16. Kim, H.; Jeong, K.; Kim, S.; Han, T.; Ambient Wall: Smart Wall Display Interface Which Can Be Controlled By Simple Gesture for Smart Home, *SIGGRAPH Asia 2011 Sketches - SA '11*, **2011**.
17. Oh, J.; Jung, Y.; Cho, Y.; Hahm, C.; Sin, H.; Lee, J.; Hands-up: motion recognition using kinect and a ceiling to improve the convenience of human life, *Proc. CHI 2012 Ext. Abstr.*, **2012**.
18. You, Y.; Tang, T.; Wang, Y.; When arduino meets Kinect: An intelligent ambient home entertainment environment, *Proc. - 2014 6th Int. Conf. Intell. Human-Machine Syst. Cybern. IHMSC 2014*, **2014**.

19. Lin, H.; Hsueh, Y.; Lie, W.; Abnormal Event Detection Using Microsoft Kinect in a Smart Home, *Proc. - 2016 Int. Comput. Symp. ICS 2016*, **2017**.
20. Zhao W.; Lun,R.; A Kinect-based system for promoting healthier living at home, *2016 IEEE Int. Conf. Syst. Man, Cybern. SMC 2016 - Conf. Proc.*, **2017**.
21. Blumrosen, G.; Miron, Y.; Plotnik, M.; Intrator, N.; Towards a Real-Time Kinect Signature Based Human Activity Assessment at Home, *Wearable Implant. Body Sens. Networks (BSN), 2015 IEEE 12th Int. Conf.*, **2015**.
22. Iqbal, A.; Asrafuzzaman, S.; Arifin, M.; Hossain, S.; Smart Home Appliance Control System for Physically Disabled People Using Kinect and X10, **2016**.
23. Piedra-Fernandez, J.; Ojeda-Castelo, J.; Bernal-Bravo, C.; Iribarne-Martinez, L.; Sign Communication for People with Disabilities Using Kinect Technology at Home, *2016 8th Int. Conf. Games Virtual Worlds Serious Appl.*, **2016**.
24. Ameur, S.; Ben Khalifa, A.; Bouhlel, M.; A comprehensive leap motion database for hand gesture recognition, *2016 7th Int. Conf. Sci. Electron. Technol. Inf. Telecommun. SETIT 2016*, **2017**.
25. Mapari R.; Kharat, G.; Real time human pose recognition using leap motion sensor, *2015 IEEE Int. Conf. Res. Comput. Intell. Commun. Networks*, **2015**.
26. Kumar, S.; Bansal, N.; Singh, S.; Smart Interaction Using Hand Gesture Recognition, *Proc. Second Int. Conf. Inf. Commun. Technol. Compet. Strateg. - ICTCS '16*, **2016**.
27. Ponraj G.; Ren, H.; Sensor Fusion of Leap Motion Controller and Flex Sensors Using Kalman Filter for Human Finger Tracking, **2018**.
28. Dharmayansa, I.; Exploration of Prayer Tools in 3D Virtual Museum Using Leap Motion For Hand Motion Sensor," *2017 TRON Symp.*, **2017**.
29. Lu, Y.; Bulbs control in virtual reality by using leap motion somatosensory controlled switches, *Int. Conf. Adv. Commun. Technol. ICACT*, **2017**.
30. Ransalu S.; Sisil, K.; A robust vision-based hand gesture recognition system for appliance control in smart homes, *2012 IEEE Int. Conf. Signal Process. Commun. Comput. ICSPCC*, **2012**.
31. Zhang, Z.; Robust Hand Gesture Recognition Based on Finger-Earth Mover's Distance with a Commodity Depth Camera, *Hand*, **2011**.
32. Davis, F.; Bagozzi, R.; Warshaw, R.; User Acceptance of Computer Technology: A Comparison of Two Theoretical Models, *Manage. Sci.*, **1989**.
33. Nielsen, M.; Störring, M.; Moeslund, T.; Granum, E.; A Procedure for Developing Intuitive and Ergonomic Gesture Interfaces for HCI, **2004**.
34. Porras, J.; Seffah, A.; Rondeau, E.; Andersson, K.; Alexandra, K.; PERCCOM: A Master Program in Pervasive Computing and COMmunications for Sustainable Development, **2016**.

