NOVELTY OF LABORATORY MEASUREMENT TOOLS IN MULTI BUSINESS MODEL INNOVATION

PhD dissertation

By

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Curriculum Vitae

Per Valter (Nationality: Danish, Born: 1974)
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Education and academic degrees

2010 - 2013	MSc in Business and Management Research at Henley Management College.
2008 - 2010	Executive MBA - Master in Management of Technology at Technical University of Denmark.
2006 - 2006	AM36, Robots and Dynamic Agents Interfaces Design at Maersk Mc-Kinney Moller Institute.
2006 - 2006	DM18, Compiler Construction at University of Southern Denmark.
2004 - 2004	Certified SuperOffice Professional at Superoffice – Norway.
2001 - 2001	TARGIT Analysis Certified Professional at TARGIT.
1997 - 2000	Graduate in Computer Science at Vejle EDB School.

Current and recent positions held

2018 -	Assistant Professor at Aarhus BSS - Aarhus University.
2017 - 2018	Research Assistant at Aarhus BSS - Aarhus University.
2003 -	Chief Executive Officer at Valgbar ApS.
2016 - 2017	External Lecturer at University of Southern Denmark.
2013 - 2015	Vice President Consultancy at Wallmob.
2012 - 2013	External Lecturer at University of Southern Denmark.
2007 - 2015	Chief Executive Officer at BoligMap ApS.
2005 - 2006	Guest Lecturer at Aalborg University.
2000 - 2003	Chief Solutions Officer at Metza A/S.
1997 - 2000	Chief Information Officer at FirmaWeb.

Professional memberships, affiliations and office-holder positions

2017 -	Member of the Board at Fynoti ApS
2017 - 2018	Member of the Board at Thedigibusiness ApS
2013 - 2015	Member of the Board at Wallmob A/S
2013 - 2015	Member of the Board at PureLime A/S
2007 - 2015	Member of the Board at BoligMap ApS.
2000 - 2003	Member of the Board at Metza A/S.

Management and leadership experience

Per Valter has successfully been founding serval several companies and grown them to exit's stage and was awarded "Børsen Gazelle" in 2013 and 2014 for creating and leading one among the fastest growing companies in Denmark.

Scientific Projects

2017 - 2018 Biogas 2020 – A Scandinavian Biogas Network.
2017 - 2018 Experimental exploration of business model digitization
2017 - 2018 B-LAB environment attribute monitoring and control
2018 - 2019 Exploring the boundaries of human-computer interaction in a real-world setting of globally connected entrepreneurial business model environments

Publications

[1] P. Valter, P. Lindgren and R. Prasad (2017) Artificial intelligence and deep learning in a world of humans and persuasive business models. 2017 Global Wireless Summit (GWS), Cape Town, 2017, pp. 209-214.

[2] P. Valter, P. Lindgren and G. Kingo (2018) Sensing Multi Business Model Innovation via advanced sensor technology. Nordic and Baltic Journal of Information and Communications Technologies.

[3] P. Valter, P. Lindgren and R. Prasad (2018) "The consequences of artificial intelligence and deep learning in a world of persuasive business models," in IEEE Aerospace and Electronic Systems Magazine, vol. 33, no. 5-6, pp. 80-88, May-June 2018.

[4] P. Valter, P. Lindgren and R. Prasad (2018, April) Advanced Business Model Innovation Supported by Artificial Intelligence and Deep Learning. Wireless Personal Communications. 100, 1, s. 97–111.

[5] P. Lindgren, P. Valter, K. Tonchev, A. Manolova, N. Neshov, V. Poulkov (2018) Digitizing Human Behavior with wireless sensors in Biogas 2020 Technological Business Model Innovation challenges. In press; scientific journal Wireless Personal Communications.

[6] P. Valter, P. Lindgren and R. Prasad (2018) Valter's Seven Forces; a Model for Analyzing the Forces Affecting the Business Model Innovation Process. Nordic and Baltic Journal of Information and Communications Technologies.

[7] P. Lindgren, P. Valter and R. Prasad (2018) Advanced Business Model Innovation supported by Artificial Intelligence, Deep Learning, Multi Business Model Patterns and a Multi Business Model Library. In press; Wireless Personal Communications.

Teaching experience

2018 - Business Development with Information Systems at Aarhus University.
2018 - Digital Capabilities at Aarhus University.
2018 - Project Management at Aarhus University.
2018 - Virtual reality/AI Technologies (TBMI) at Aarhus University.
2017 - Digital Capabilities at Aarhus University.
2016 - Web and interactive media at University of Southern Denmark.
2015 - Digital Design and Production II at University of Southern Denmark.
2013 - Web and interactive media at University of Southern Denmark.
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2012 - Project Management (DD and Production 1) at University of Southern Denmark.
2012 - Digital methodology at University of Southern Denmark.
2011 - Media Production II at University of Southern Denmark.

English Abstract

Today's business environments are influenced by new competing business models and by ever-increasing technological possibilities. The trend is unlikely to change in the near future, in fact, it is likely to increase even more. Therefore, a successfully embedded continuous multi business model innovation process within a business would – without any doubt – increase the likelihood for success for that business. Thus, an improved understanding and improved measuring tools of the multi business model innovation process itself is of the utmost importance. At the beginning of this thesis a newly developed conceptual model in digital multi business model innovation is presented. The model can be used to facilitate the understanding of the relationship between business reality, business models, digitalization and humans. Therefore, the model proposed is more focused on such relationships rather than on the process itself. However, after the development and proposition of the engineering lab set-up and after the careful examination and evaluation of the laboratory measurement tools used to collect data regarding the multi business model innovation processes, another model focusing on the business model innovation process is proposed in chapter 5 - Valter's Seven Forces. Furthermore, the proposed engineering lab set-up has been empirically tested at the Scandinavia Biogas Conference 2017 in Skive where three multi business model innovation labs were empowered with the proposed engineering lab set-up. The engineering set-up collected data regarding the multi business model innovation processes in the three business model innovation laboratory environments. The data collection was conducted over a timespan of three days. Following the data collection an evaluation of the engineering lab set-up was started which fueled the improvement of the engineering lab set-up itself. This resulted in a newly proposed and improved engineering lab set-up based on the experience of the empirical data collection process. Finally, based on experience from the entire experiment, the conceptual model "Valter's Seven Forces" was developed and proposed with the aim of analyzing the business model innovation process. The Seven Forces in the conceptual model affect the probability for success of a business model innovation process. The effect from the forces can be either positive or negative depending on the situation. For instance, if the group dynamics contain conflicts and interpersonal power battles, the probability for success of the business model innovation process is affected negatively; however, if the group dynamics contain respect, collaboration and harmony, the probability for success of the business model innovation process is affected positively.

Dansk Abstrakt

Nuværende forretningsmiljøer er påvirket af nye konkurrerende forretningsmodeller og af stadigt stigende teknologiske muligheder. Denne trend ser ikke ud til at vil ændre sig i den nærmeste fremtid, tværtimod ser det ud til at den vil stige endnu mere. Derfor vil en vellykket indlejret kontinuerlig forretnings model innovationsproces i en virksomhed – uden nogen tvivl – øge sandsynligheden for succes for den virksomhed. Således er en forbedret forståelse og forbedrede måleværktøjer til måling af forretningsmodel-innovationsprocessen af stor betydning. I begyndelsen af denne afhandling præsenteres en nyudviklet konceptuel model til digital multiforretning model innovation. Modellen kan bruges til at forstærke forståelsen af forholdet mellem erhvervslivets virkelighed, forretningsmodeller, digitalisering og mennesker. Derfor er den foreslåede model mere fokuseret på sådanne relationer end på selve processen. Efter udviklingen og forslaget af den tekniske laboratorieopsætning og efter den nøje undersøgelse og evaluering af laboratoriemåleværktøjer, der anvendes til at indsamle data vedrørende multiforretningsmodel innovationsprocesserne, foreslås en anden model med fokus på innovationsprocessen for forretningsmodeller i kapitel 5 – Valter's syv kræfter. Desuden er den foreslåede tekniske laboratorieopsætning blevet testet empirisk på den Skandinaviske Biogas Konference 2017 i Skive, hvor tre multiforretningsmodel innovationslaboratorier blev opgraderet med den foreslåede tekniske laboratorieopsætning. Den foreslåede tekniske laboratorieopsætning indsamlede data omkring multiforretningsmodel innovationsprocesserne i de tre forretningsmodel-innovationslaboratoriemiljøer. Dataindsamlingen blev udført over en tidsperiode på tre dage. Efter dataindsamlingen blev der indledt en evaluering af den oprindelige foreslåede tekniske laboratorieopsætning, hvilket udmøntede sig i en proces med forbedringen af den tekniske laboratorieopsætning. Hvilket igen resulterede i et nyt forslag til en ny og forbedret teknisk laboratorieopsætning, baseret på erfaringerne med den empiriske dataindsamlingsproces. Slutligt på baggrund af erfaringer fra hele eksperimentet blev den konceptuelle model "Valter's syv kræfter " udviklet og foreslået med det formål at analysere forretningsmodel-innovationsprocessen. De syv kræfter i den konceptuelle model påvirker sandsynligheden for succes i en forretningsmodel-innovationsproces. Effekten fra kræfterne kan enten være positiv eller negativ afhængigt af situationen. For eksempel, hvis gruppedynamikken indeholder konflikter og interpersonelle magtkampe, påvirkes sandsynligheden for succesen af forretningsmodel-innovationsprocessen negativt; Men hvis gruppedynamikken indeholder respekt, samarbejde og harmoni, påvirkes sandsynligheden for succesen af forretningsmodel-innovationsprocessen positivt.

Prior Publications

The thesis has seven prior publications, six peer reviewed journal publications and one international conference papers. The conference paper [1] was presented at the 2017 Global Wireless Summit in Cape Town, South Africa where the digital multi business model innovation conceptual model was originally proposed to improve our understanding of advanced business model innovation in today's digital age. The first conference paper was presented at the 41st Wireless World Research Forum, Herning, Denmark and is published at journal of NBICT [2]. In the second journal paper [3] published in IEEE Aerospace and Electronic Systems Magazine, the digital multi business model innovation conceptual model has been described in much greater detail with its archetypes and corresponding interacting archetypes patterns. In the third journal paper [4] published in the scientific journal Wireless Personal Communications, the digital multi business model innovation conceptual model has been used to categorize various empirical cases. Also, parts of the research experiment at the Scandinavia Biogas Conference 2017 in Skive have been published in the paper [5] "Digitizing Human Behavior with wireless sensors in Biogas 2020 Technological Business Model Innovation Challenges. The latter is in-press at the scientific journal Wireless Personal Communications. Finally, the model "Valter's Seven Forces" for analyzing the business model innovation process together with some contextual information has been published in the scientific journal "Nordic and Baltic Journal of Information and Communications Technologies" [6] and the last paper "Advanced Business Model Innovation supported by Artificial Intelligence, Deep Learning, Multi Business Model Patterns and a Multi Business Model Library." are in-press at the scientific journal Wireless Personal Communications [7]. Large part of this thesis therefor consists of prior published material.

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Acknowledgments

First, I would like to give special thanks to Professor Ramjee Prasad and Professor Neeli Prasad for their kind support and assistance as my supervisors. It has been a truly joyful and pleasant learning experience, and I especially cherished all the good advice and their kind inclusion of me in the global research network CTIF Global Capsule (CGC). All the effort has been truly appreciated, and I am proud to be a member of such a fine research network.

Also, thanks go to the organizers of BioGas2020 which is a cross-border cooperation for biogas development in the area of the Øresund-Kattegat-Skagerrak. The cooperation deserves special thanks for giving me the opportunity to conduct my research experiment at the Scandinavia Biogas Conference 2017 in Skive, Denmark. Here we collected data regarding the multi business model innovation processes in three business model innovation laboratory environments. A special thanks also go to the students from Denmark, Norway and Sweden who were involved in the multi business model innovation processes in the three real-life business cases. Furthermore, thanks are also given to Thise Dairy, VEAS and Westlax for providing their real-life business challenges for the experiments.

I would like to express my acknowledgment to the International Technological University (ITU) San Jose and to CTIF Global Capsule (CGC) for inviting me as a panel speaker at the 4th CGC workshop. It was a truly inspirational event that has produced many reflections and much scientific knowledge. Also, a truly grateful thanks to the Department of Business Development and Technology, Aarhus University and Aarhus University Research Foundation that have been funding my research with research grants thus making my research economically possible.

Last but not least, I would like to give a very special thanks to my wife Edna Valter, my three daughters and my newly born baby boy for their kind understanding and support during all these long nights of work on my research and this thesis.

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Vocabulary

MBMI = Multi Business Model Innovation

BMES = Business Model Ecosystem

BM = Business Model

IS = Information System

DBM = Disruptive Business Model

BMI = Business Model Innovation

IoT = Internet of Things

TBMI = Technological Business Model Innovation

EEG = Electroencephalography

fMRI = functional Magnetic Resonance Imaging

MBM = Multi Business Model

UV4L = User space Video4Linux

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Chapter 1 - Introduction

This chapter presents my motivation to carry out the research in the area of multi business model innovation (MBMI) process. Further, it discusses the challenges and approach for a fruitful scientific dissertation. At the end of the chapter, my original contributions and scope of this thesis are presented.

1.1 Motivation

The seed for the motivation to write this thesis was planted around 1996 when the Internet was slowly beginning to attract the interest of the general public and when the Internet's journey to mainstream technology began in Denmark.

As a practitioner this was the time when the Internet and computer technology opened my eyes to a whole new world of possibilities with new and better ways to do things. It seemed quite obvious at that time that technology would have the potential to improve the non-digital business model's (BM) greatly. Retrospectively, this was when the seed for my passion to create value with technology was planted, although the journey to where I am today has given me some surprises and has required me to make corresponding adjustments.

My first rather naive impression was simply that the more understanding of the technology, the better value was created. As a consequence, the first of my technology business was founded which was a hosting business providing web and e-mail servers for businesses. However, it quite quickly became clear that the majority of the businesses did not understand at that time the new technologies such as web and e-mail. Therefore, I started to drive around Denmark as a technician for CyberCity [8] – which became Denmark's second largest Internet service provider – literally setting up Internet access and teach the use of web, mail etc. As the Business Model Ecosystem (BMES) for Internet matured, the new eCommerce Business Model trend was spotted. I believed that this was a good way of creating value with technology.

I made my first successful exit and sold my start-up hosting business. Subsequently, I made a new eCommerce business together with investors and other partners. At the same time, I started my formal technical education in computer science. The following period was a rather expensive but good learning experience since the dot com bubble busted and the unfortunate and disappointing development in the business lead to the end of the lifecycle of this business. With this new learning experience, it became utterly clear that technology alone will not create value whereas the correct and useful usage of it will. Therefore, I decided to supplement my technical background in computer science with an Executive MBA - Master in Management of Technology. Simultaneously, I start a consultancy business. The following period was economically very successful with several successful exits of businesses.

The impact of the usage of technology in my businesses was still largely limited to those specific businesses. So, with a desire to have a larger impact I began teaching first at the University of Southern Denmark in 2010 and later at Aarhus University. However, even though the potential impact of teaching others in creating value with technology is large, it is still limited to those students and their career. To have a truly worldwide impact, research on the use of technology to improve the process of measuring digital multi business model innovation must be done to generate a deeper understanding of the process itself. It is also important to determine how to implement promising improvements and how to measure its effects.

1.2 Challenges

As discovered [9] through previously conducted research, the business environment today is highly competitive and subject to constant change, since new and continuously evolving business models are introduced and all BMs and BMES are under constant threat from disruptive BMs and disruptive BMES. Furthermore, the business environment today is subjected to increasing numbers of new technology possibilities and the inner complexity from hostile takeovers, business reorganizations, joint ventures, organizational mergers etc. [10], [11].

To manage a business within such a BMES, it is of the utmost importance not only effectively to use information systems (IS) to lead and manage the business core BMs. It is also of the utmost importance to use the information systems to create business advantages that can ensure the business a strategic place in the future BMES. Also, it is important – via this use of Information Systems – to be able to meet the new Disruptive Business Models (DBM) before they enter the BMES or even to be able to create a new BMES.

This is posing a considerable challenge for today’s management who have to deal with outdated legacy systems, incompatible systems built on different technologies with different data compliance and structure from business mergers etc. All of which makes the task increasingly harder to handle [12].

However, the increasing complexity in the BMES is only one factor that business today has to cope with. Another factor that needs to be taken into consideration is Moore’s Law [13]. According to Moore’s Law the development in technology capabilities will not only continue but will do so at an ever-increasing rapid pace. Furthermore, the implication that technological advance means that managers are having difficulty in being aware of new technologies that could be beneficial in their organizations [14] suggests that a scientific and methodologically structured approach is needed to overcome the challenges of the future.

1.3 Approach

In the process of seeking to overcome the challenges above, the first challenge was to set the broad context in which the multi business model innovation process is conducted in order to better understand the relationship between business reality, business models, digitalization and humans. Therefore, the digital multi business model innovation conceptual model in chapter 2 is proposed. With this new model to facilitate the understanding of the relationship in the context of digital business model innovation, the thesis moves forward to create the engineering set-up for measuring the multi business model innovation process within the multi business model innovation process lab. At this point, the engineering set-up is divided into three main parts. The first part is focusing on the environment in the multi business model innovation process lab and measuring CO2, temperature, humidity and pressure. The second part of the engineering set-up focuses on the group as a whole and records 360-degree videos and sound under the multi business model innovation process. Finally, the third and last part of the engineering set-up focuses on the individual and measures heart rate, emotions and personality. Then this thesis takes a double loop learning [15] approach to the digital multi business model innovation process itself and thereby narrows its focus to propose technology to measure the multi business model innovation process and to conduct empirical experiments with the propose technology in chapter 3. In chapter 4 the results of the empirical experiments are used to improve and optimize the proposed technology to measure the multi business model innovation process and thereby to enhance the tool available for businesses to understand the multi business model innovation process better. Finally, based on the experience from the process of the experiments, chapter 5 proposes the new conceptual model "Valter's Seven Forces" as a future model for analyzing the Business Model Innovation (BMI) process.

1.3.1 Problem Definition

To overcome the challenges listed in the section 1.2 Challenges, the following problem definition has been made.

Firstly, there is a need for a new digital multi business model innovation conceptual model to form the basis for a uniform approach to studying the field of digital multi business model innovation process improvement, this is a fundamental need for all the challenges in section 1.2

Secondly, there is a need for a scalable digital approach for measuring the BMI process, this need is based on that fact that the business environment today is highly competitive and subject to constant change and the resulting struggle for manger today to keep their business alive and preferably ahead of the evolution curve, this calls for a structured scalable digital approach for measuring the BMI process.

Finally, there is a need, not only for measuring the BMI process, but also for the capability to adjust and optimizing the BMI process to archive faster and better BM's with its resulting derived higher business performance, to archive such a capability there is a need for a new conceptual model to generate knowledge about the main dominating factors influencing the BMI process.

1.4 Contributions

Overall there are five main scientific contributions in this thesis. Each of the scientific contributions are closely tied together in a logical order. In the following, the scientific contributions are explicitly presented in the logical order in which they are tied together.

Firstly, this thesis is proposing the digital multi business model innovation conceptual model in chapter 2. With its archetypes and interaction archetypes patterns, the model aims to enable a more structured way of examining digital multi business models. Thereby it not only forms the basis for a uniform approach to studying the field of digital multi business model innovation process improvement, it also facilitates and supports collaboration among researchers with a more structured approach to knowledge sharing.

Secondly, the original engineering set-up in chapter 3 is developed and proposed to measure the multi business model innovation processes. The original engineering set-up consists of tools for measuring the environment force, the individual force and the group force in a business model innovation process. The original engineering set-up is capable of taking the following environment measurements: CO2 level approximately every second, temperature approximately every second, humidity approximately every second and finally pressure approximately every second. Furthermore, the original engineering set-up is capable of taking the following measurements at group level: 360-degree camera live streaming and separate live sound recording. Furthermore, the original engineering set-up is capable of taking the following measurements at individual level: personal profile with Insights® Discovery, emotion detection with the developed emotion recognition cap and heart rate of the participants with the H10 sensor.

Thirdly, the originally proposed engineering set-up is empirically tested at the Scandinavia Biogas Conference 2017 in Skive, where three multi business model innovation labs where setup and the BMI process was measured consistently over three days.

Fourthly, the originally proposed engineering set-up is improved based on the experience generated while conducting the empirical tests at the Scandinavia Biogas Conference 2017. As an example, the emotion recognition process has been moved from a cloud service provider to a locally built service.

Finally, based on the experience gained from the hole experiments, the newly developed conceptual model "Valter's Seven Forces" is proposed in chapter 5 as a future model for analyzing the BMI process.

All the scientific contributions of conceptual models, engineering set-ups with empirical tests, enable researchers worldwide to conduct future research with a higher level of understanding about the forces in the BMI process and offer a scalable digital approach for measuring the BMI process.

1.5 Contents of this Dissertation

Figure 1.1 presents an overview of the dissertation. This thesis is organized as follows:

- in chapter 1 the introduction to the thesis has been made;
- in chapter 2 the proposed digital multi business model innovation conceptual model is presented;
- in chapter 3 the research experiment is described;
- in chapter 4 the results of the experiment are analyzed, and improvements to the measurement tools are proposed;
- in chapter 5 the findings are discussed and the conceptual model "Valter's Seven Forces" is proposed;
- and finally, in chapter 6 the conclusions and future research are discussed.

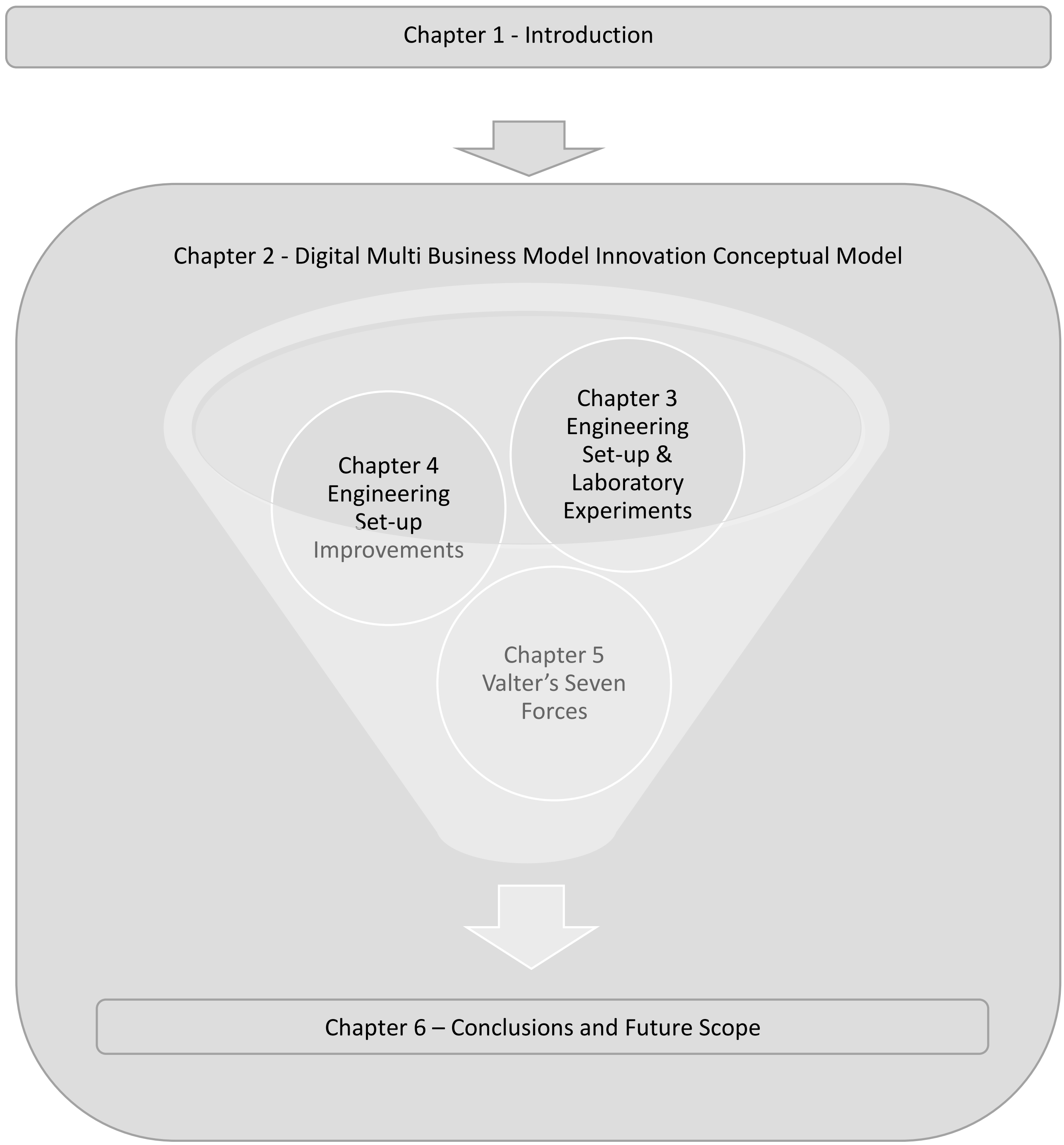


Figure.: 1.1 Model Overview of Contents of the Dissertation

Chapter 2 - Digital Multi Business Model Innovation Conceptual Model

In this chapter, a conceptual model in digital multi business model innovation is presented, this model can be used to facilitate the understanding around the relationships between the business reality, business model, digitalization and humans, the model proposed have it focus directed more towards these relationships rather than the process itself, in chapter 5 the model Valter's Seven Forces with its focus on the business model innovation process are proposed.

2.1 Introduction

Applications of sensors, wireless and persuasive technologies in our everyday life have increased and developed exponentially [16]. Increasingly over the last 5–10 years, business and researchers are once again standing at "the foot of the mountain" while new technology is "racing" ahead. While practitioners are playing with the technologies, business and researchers are still struggling to decide what to do and where to start climbing the mountain next? They are wondering:

How and where to embed the technologies into their business models?

How to use them in their communication with their customers, employees and network partners?

How and where do the new technologies fit together with the business model?

In other words, there is a knowledge gap in the business world and in the business model innovation community surrounding the new technologies and the way to use them. There is a strong need to understand the impact that such technologies are having now and the potential impact they will have on future business models and on BMI.

How does business ensure a structured and long-term improvement of the BMI process?

How does business measure success of the BMI process?

A conceptual framework model can potentially be used to organize the concepts to enable businesses and researchers to digest the information and to take advantage of the new technologies in their future experimental work with BMI.

However, it is essential that our business communities agree on a common and standard business model language first [16], [17], [18], [19], [20]. Table 2.1 presents the benefits that a commonly agreed-upon language would provide to the discussion of business models and to the advancement of our knowledge of business models and the practice of BMI. The table is adapted from Lindgren, 2016 [21]

Overall benefit categories	Benefits in detail.
Interoperability in BMI	Ability of devices and BMs to work and innovate together relied on BMs complying with standard language of BM
Support of government policies and legislation in BMI	Standards, IPR and Patents of BMs could play a central role e.g. in the global and regional BMES policy. Standards, IPR and Patents are frequently referenced by regulators and legislators to protect user and business interests and to support government policies
Increase in interdisciplinary business modelling across vertical and horizontal BMES	Increase in interdisciplinary business modelling across vertical and horizontal BMES due to possibility to "talk" together across BMES, Businesses, BM and thereby competences and background
Increase in BMI Technology development	- would provide a solid foundation upon which to innovate new BMI technologies, new learning and new knowledge on BM and BMI to enhance and advance existing BMI practices
Provide economies of scale in BMI	- would provide business to being able to "produce" and "innovate" "large bats" and invest in "mass production" of BMs
Encourage BMI and more BMI	Standards allow a business to develop their BMI further
Increase awareness of technical developments and initiatives within BMI and BMI technologies	- provides platform for increasing awareness - would provide a greater variety of accessible BMs to consumers
User, Consumer, network and "things" choice of BM and BMI would be easier to adapt	- provide the foundation for new features and options, thus contributing to the enhancement of daily BMI, user-driven BMI and interdisciplinary BMI
Safety and reliability in BMI	- would help ensure safety, reliability and business care. As a result, users, customers, network, competences and businesses in general would perceive standardized BM language as more dependable. This in turn would raise stakeholder's confidence, sales and the take-up of new technologies and business models for BMI

Advance BMI	- would provide a solid foundation for research, learning and new knowledge on BM and BMI to enhance and advance existing BMI practices

Table.: 2.1. Overall benefit categories of a commonly accepted and agreed upon BM language adapted from Lindgren 2016 [21]

Very few people have realized and accepted that business models do not function and will not function in the future purely in the realm of products, services, value chain functions, and organizational systems. Nor do they realize that business models do not and will not function only on behalf of and with humans. Business models are now becoming – and will in the future – be based on a mix of human and machine interactions. Additionally, machines are expected to take over more of the innovation in the business model, not just routine and incremental BMI but also radical and disruptive BMI [2]. Businesses do not realize that BMI must be carried out very differently from the previously accepted norms, forms, and types of BMI, called here "stage-gate types of BMI innovation models". Stage-gate BMI is a process. Ideas are reviewed at the stages gates and decisions to go forward or not are made along the way to full implementation.

Future BMI will be much more dynamic, agile, and particularly complex [22]. BMI will probably be quite disruptive to previous BMs, made in big leaps, and driven by groups of users and customers. Furthermore, BMI will not be based primarily on a single or closed business model in the future [23], [24], but rather on multi-business models and on open business models. BMI with single business models will be less effective and less efficient and will not provide businesses with enough competitive advantage. The proposed conceptual model in this chapter is a first attempt at creating a conceptualized overview of the knowledge, insight, and possibilities that lie within the digitalization of the business model and business model innovation concept.

Although the process of BMI is of outmost importance for today's organization, many fear this evolution because they cannot or do not "see" and "sense" the real potential of such complex BMIs that will be embedded with and supported by new and persuasive technologies.

2.2 Theoretical Background

BMI—both closed and open BMI [24], [25]—has been and still is a hot and popular topic for businesses and academia to discuss. One indication of the increasing interest in this concept is the dramatic increase in the number of publications referring to the concept since the late 1990s and early 2000s [21]. The total number of scholarly publications containing the keywords "BM" amounted to 383 in 1995; it skyrocketed to 3,850 in 2000; to 11,500 in 2005; and to 22,000 published items in 2011 [21] However the previous discussion of business models was not related to business models embedded with persuasive and sensing technologies. Persuasive technology has been defined as: “Technologies designed to influence human beliefs and behaviors”. The definition inspired by B. J. Fogg [26] encompasses machines or business model technologies designed to influence human beliefs and behaviors that can be transferred to the business model and to the BMI “arena” As if business models are designed to influence the “beliefs” and “behaviors” of humans, things, and business models. In other words, humans and machines interact with each other and thereby exert influence and persuasion. More research on persuasive technology related to humans, things and business model behavior change will provide us with more insight into how persuasive business models (business models embedded with persuasive technologies) can be designed and innovated. From an advanced BMI perspective, this brings in a new agenda for the way in which a business should create, capture, deliver, receive, and consume the business model's values [21]. Businesses therefore need to change their BMI approach now. They need to move away from simple ideation of the business model and simple strategizing with yesterday's BMI frameworks and take “one step up” to match the level of “the technologist” and take advantage of or appreciate the real potential of the new technologies for their business model. Business must realize that persuasive business models are a reality now; and while you are reading this thesis, they are being rolled out at high speed. Consequently, a business must accept and realize that business models can act and “persuade” anywhere, anytime, with anybody and anything. They may not be able to do so in an advanced way yet, but soon they will be able to, and fast. It is therefore highly urgent that the business community change their previous BMI mindset—while persuasive technology still grows to maturity—and quickly develop a deeper understanding of the way in which businesses models really work and can work, their construction, and their overwhelming potential when embedded with advanced sensor and persuasive technologies.

The new technology itself provides us with “a helping hand” on this journey of operating as well as of innovating business models. However, we need to agree first on a standard business model and BMI language, otherwise it will be very difficult to communicate about business models, or to perform BMI.

2.3 Conceptual Model Overview

The conceptual model proposed in this article (Figure 2.1) was adapted from Valter, Lindgren, and Prasad, 2017 [16] and examines the business model through the lens of different possible BMI interactions.

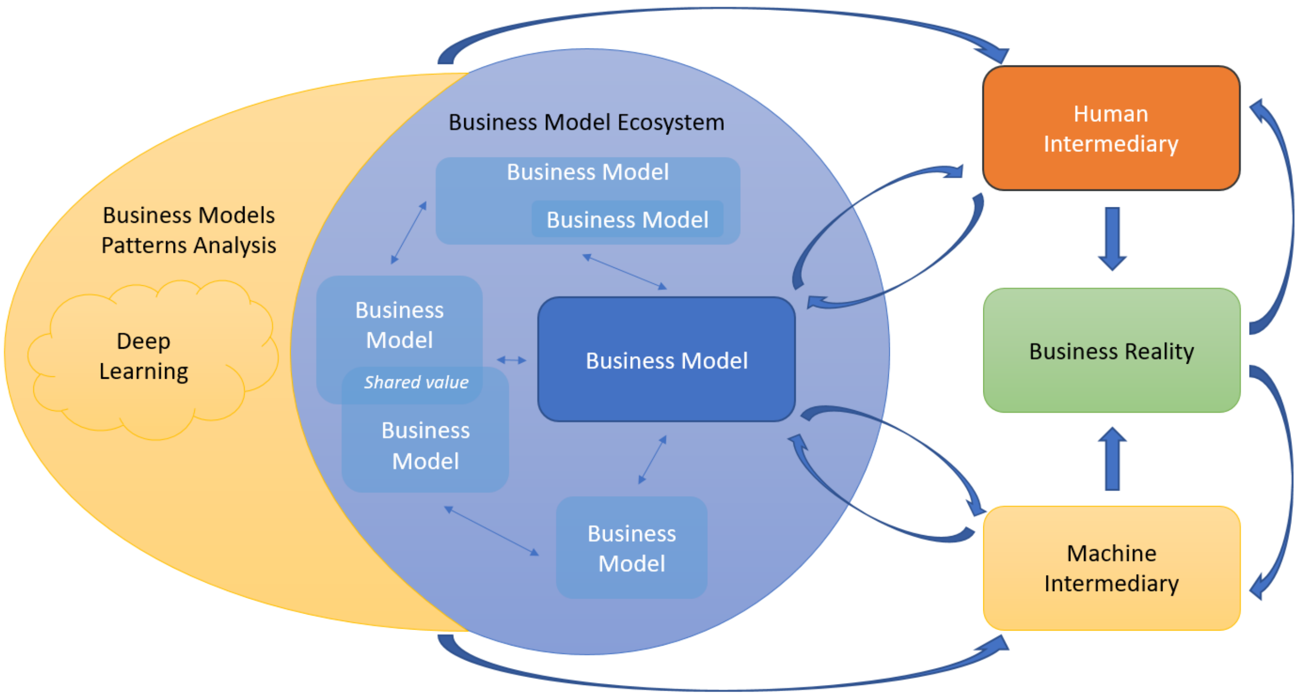


Figure.: 2.1 Conceptual Model Overview

The model consists of four main parts: The Human Intermediary; the Machine Intermediary; Business Models Patterns Analysis, and the Business Model Ecosystem [27]. The purpose of the conceptual model is to provide an overview in combination with deeper knowledge of and insight into the possibilities that emerge with the digitization of the business model concept. Therefore, when the term business model is used, it refers to a digital representative of the business model. Even though it would be possible to use parts of the conceptual model on non-digital representative business models, the conceptual model is based on a digital representation of business models.

2.4 Human Intermediary Business Model Interaction

The first part of the conceptual model is the human intermediary section. In this section, all interactions between the business reality and the business model that are facilitated by human beings are represented. In Figure 2.2, the human intermediary business model interaction is marked with red arrows within the red circle.

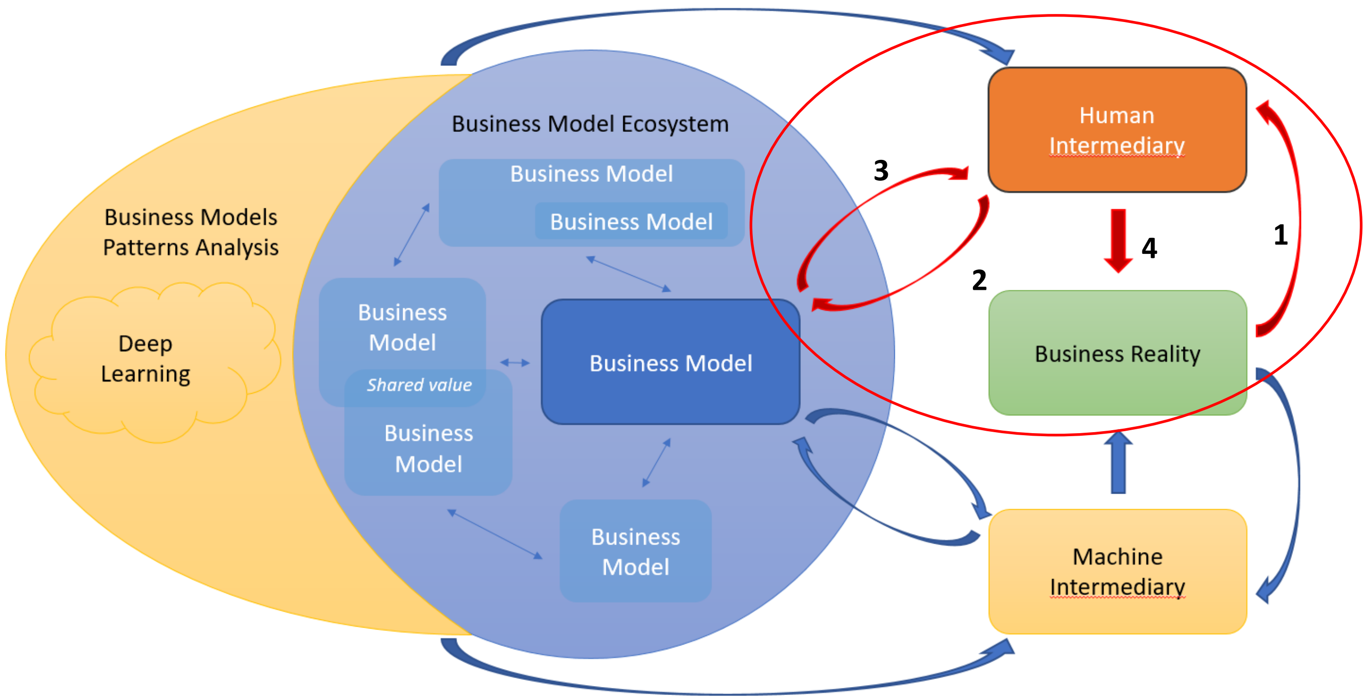


Figure 2.2.: Human Intermediary Business Model Interaction.

2.4.1 Archetypes in Human Intermediary Business Model Section

Each of the four archetypes in the human intermediary business model section are described separately and in detail in table 2.2.

Archetypes in Human Intermediary Business Model Section.	Description
2.4.1.1 Archetype one 	A person observes the business reality, the conceptual model clearly distinguishes between the actual business reality and a business model as a representation of the business reality. It is important to emphasize that the interpretation of the observed business reality can easily vary based on the interpretant area of expertise.

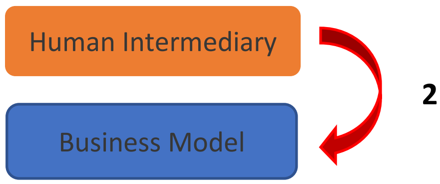
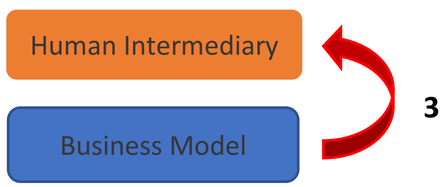
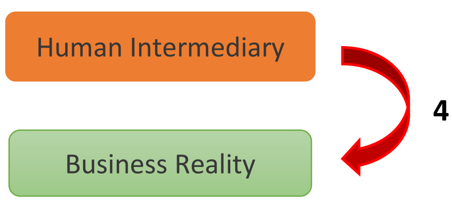
2.4.1.2 Archetype two 	A person updates the model with his understanding of the business reality. It is important to emphasize that the business model is not limited to one person's understanding of the business reality but could also represent the understanding of different people with different areas of expertise.
2.4.1.3 Archetype three 	A person's interpretation of the business model can provide new understanding. As with Archetype two, the model can consist of knowledge from serval different areas of expertise. This makes way for potential new cross-boundary knowledge generation and understanding.
2.4.1.4 Archetype four 	A person implements a change to the business reality based on newly generated knowledge and understanding of the business model. As in archetype one, it is also important to emphasize that interpretation of the business model can vary based on the interpretant area of expertise etc. and can therefore affect the final implementation.

Table.: 2.2. Human Intermediary Business Model Archetypes

2.4.2 Interaction Archetypes Patterns in Human Intermediary Business Model Section

Archetype two and three in the human intermediary business model section have the interaction archetypes patterns described in table 2.3 in common, while the human intermediary business model archetype is concentrated on the human as an intermediary between the business reality and the business model. The interaction archetype patterns within the human intermediary business model section displayed in table 2.3 are solely concentrated on the interaction archetypes patterns between the human and the business model.

Interaction Archetypes Patterns in the Human Intermediary Business Model Section	**Description**
2.4.2.1 Interaction archetype pattern one: The Physical World	When a person interacts with physical items such as keyboard, mouse, touchscreen etc.;
2.4.2.2 Interaction archetype pattern two: Augmented Reality	When one or more persons intact with 3D virtual object that blend into reality. This offers the possibility of real face-to-face meeting in combination with real-time collaboration on complex and abstract 3D virtual representations of the business models.
2.4.2.3 Interaction archetype pattern three: Virtual Reality	When two or more persons -separated by great distance - are able to come together in one virtual room and thereby to collaborate real-time on complex and abstract 3D virtual representations of the business models.

Table 2.3. Interaction Archetypes Patterns in the Human Intermediary Business Model Section

2.5 Machine Intermediary Business Model Interaction

The conceptual model consists of a machine intermediary section which represents all interaction between the business reality and the business model. The arrows marked with red in figure 2.3 show the possible interactions.

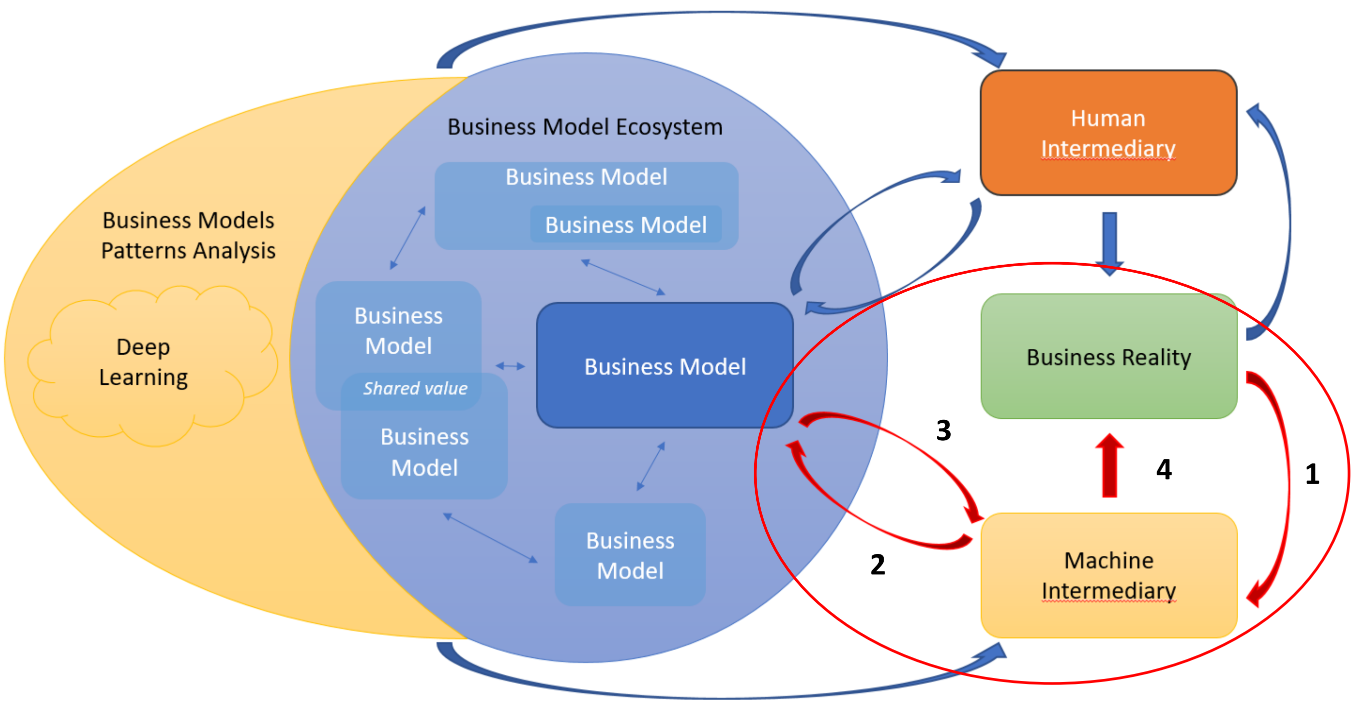
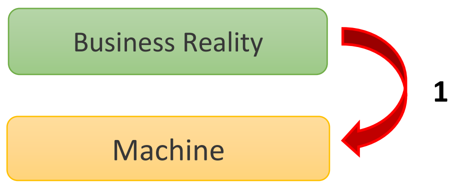


Figure 2.3.: Machine Intermediary Business Model Interaction

2.5.1 Archetypes in Machine Intermediary Business Model Interaction

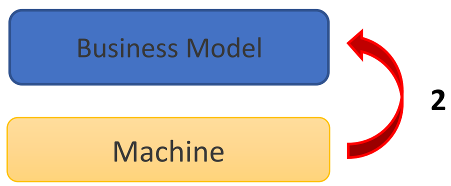
<table>
<tr><th>Archetypes in Machine Intermediary Business Model Interaction.</th><th>Description</th></tr>
<tr><td>

2.5.1.1 Archetype one



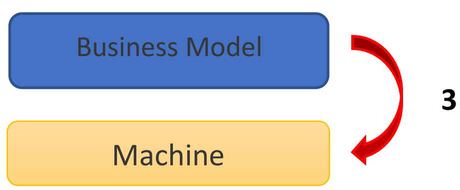
</td><td>A machine observes the business reality. The machine in question can be any observing Internet of Things (IoT) device or computed input like location-based devices, heatmaps, data input robots etc. A simplified example could be customer counter input devices that are distributed within a store to measure the behavioral patterns of customers’ actions in the store.</td></tr>
<tr><td>

2.5.1.2 Archetype two



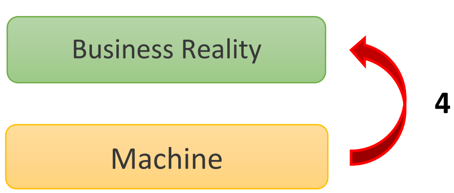
</td><td>A machine updates the model with new measurement of the business reality with the help of: Internet of Things sensors. It is important to emphasize that the business model is not limited to the machine input to the business reality but could also represent the understanding of different people with different areas of expertise.</td></tr>
<tr><td>

2.5.1.3 Archetype three



</td><td>A business model triggers one or more events in the machine intermediary. This can be illustrated by a simplified example: If a business owner wants to have a certain number of customers in his store within a specific time period, triggers could be defined within the business model (based on the current number of customers inside the store at a given time) as the lowering or heightening of prices on special offers displayed on digital signs outside the store.</td></tr>
<tr><td>

2.5.1.4 Archetype four



</td><td>A machine implements a change to the business reality based on new events triggered by the business model in arrow 3. A simplified example of this could be as follows: a business owner decides to change his business model and gives away a product for free or at an extremely low price in order to increase earnings on related products. When the owner updates his business model, all the digital signage automatically changes to represent the new business model. The owner could even apply the new business model only on a subset of the whole enterprise, to obtain measurements on its performance before applying it to the entire enterprise.</td></tr>
</table>

Table 2.4.: Machine Intermediary Business Model Interaction Archetypes

2.5.2 Interaction Archetypes Patterns in Machine Intermediary Business Model Interaction Section

Archetype one and four in the machine intermediary business model interaction section have the interaction archetypes patterns described in table 2.5 in common. while whereas the machine intermediary business model interaction archetypes are concentrated on the machine as an intermediary between the business reality and the business model, the interaction archetypes in the machine intermediary business model interaction section displayed in table 2.5 are solely concentrated on the interaction archetypes patterns between the machine and the business reality.

Interaction archetypes patterns in the machine intermediary business model interaction section	**Description**
2.5.2.1 Interaction archetype pattern one: Internet of Things Sensing	One-way sensors are sensing the business reality, is with the use of pure IoT input-based devices, these devise senses the business reality and send this information to the BM.
2.5.2.2 Interaction archetype pattern two: Internet of Things Applying	When sensors are modifying the business reality, pure IoT output-based devices are manipulating the business reality.
2.5.2.3 Interaction archetype pattern three: Robotics & Drones	When an advance form of interaction takes place such as robotics and drones manipulating and/or sensing the business reality.

Table 2.5.: Interaction archetypes patterns in the machine intermediary business model interaction section.

2.6 Business Model Pattern Analysis with Artificial Intelligence and Deep Learning

The conceptual model consists of the artificial intelligence and deep learning section which represents the interaction between deep learning pattern analysis and the business model, and the human and the machine. The symbols marked with red in figure 2.4 show the possible interactions.

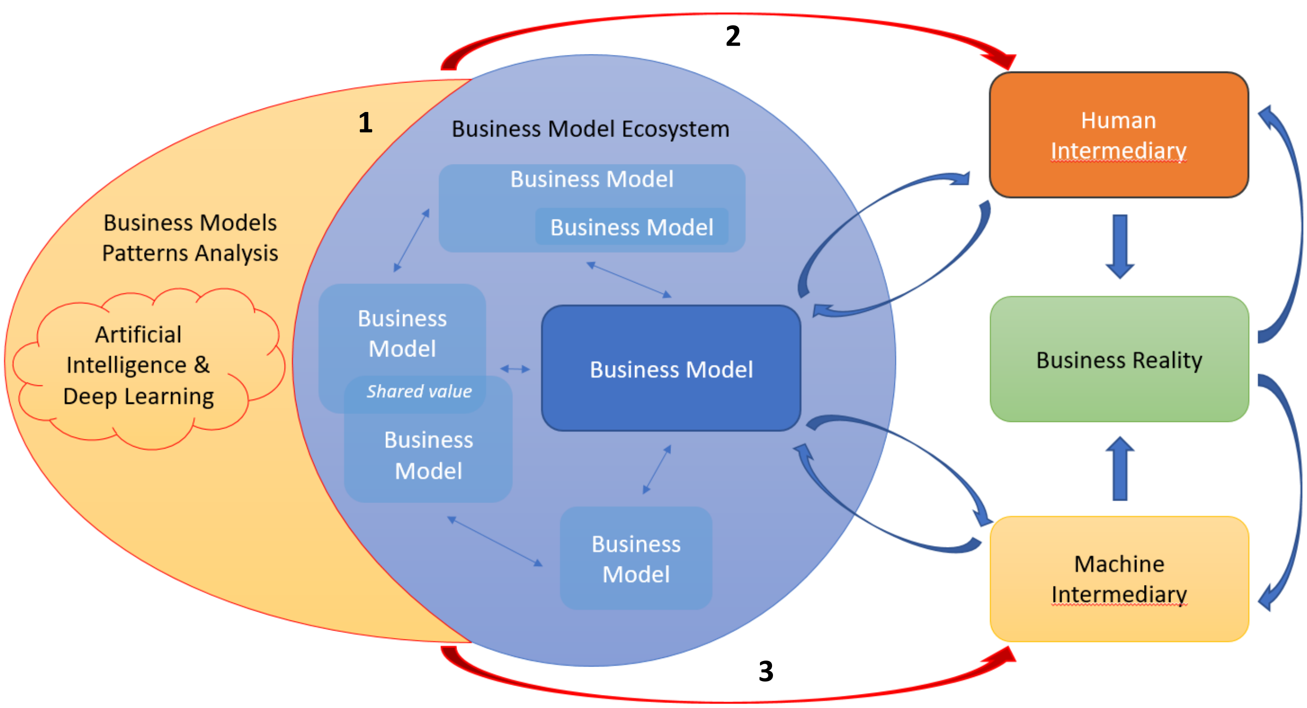


Figure 2.4.: Business Model Pattern Analysis with Artificial Intelligence and Deep Learning

Interaction Archetype patterns one, two and three are described in table 2.6

2.6.1 Interaction Archetype Patterns in Business Model Pattern Analysis with Artificial Intelligence and Deep Learning

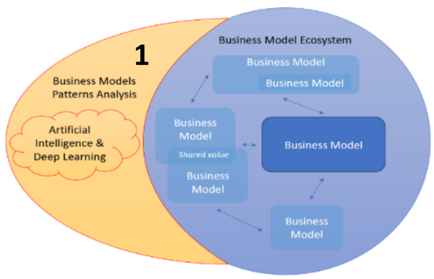
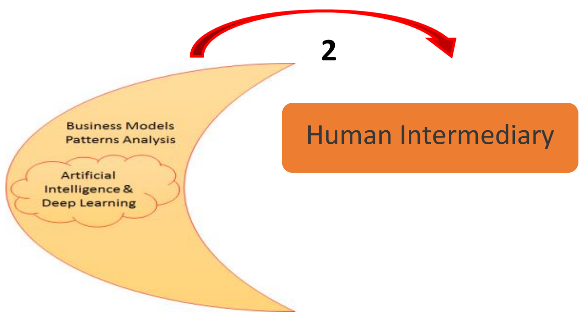
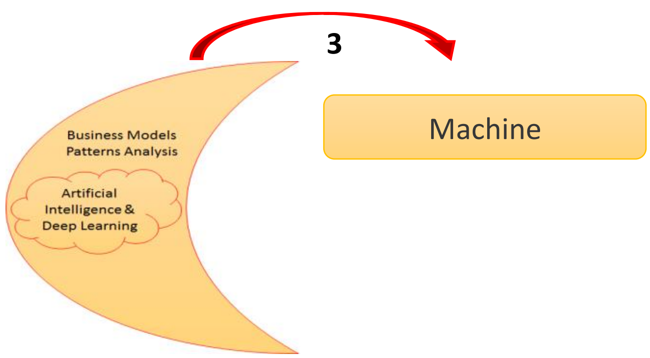
Interaction Archetypes Patterns in Business Models Patterns Analysis with Artificial Intelligence and Deep Learning	**Description**
2.6.1.1 Archetype patterns one:  	Artificial intelligence and deep learning algorithms analyze all business models and all business model ecosystems with the aim to optimize existing business models and to suggest new business models based on the success of other business models in other business model ecosystems.
2.6.1.2 Archetype patterns two:  	Based on the success of business models in other business model ecosystems, artificial intelligence and deep learning algorithms suggest new business models directly to the responsible person in the organization., It is important to emphasize that this has the potential to open up the possibility for cross-boundary knowledge generation and to facilitate the understanding of other businesses models that exists in other business domains and could potential be beneficial elsewhere.
2.6.1.3 Archetype patterns three:  	Artificial intelligence and deep learning algorithms implement a change into the business reality based on the algorithm’s analysis of the business models and business model ecosystems in archetype one. This could be illustrated by a simplified example: The artificial intelligence and deep learning algorithms apply minor changes on a small subset of the entire enterprise and measure the success of the change. If successful changes are identified, they are rolled out to the rest of the enterprise.

Table 2.6.: Interaction Archetype Patterns in the Business Models Patterns Analysis with Artificial Intelligence and Deep Learning.

2.7 Business Model Ecosystem Interrelated Business Model Interaction

The business model ecosystem is related to the business model interaction described in the preceding part. which represent the relationship between the business models and business model ecosystems.

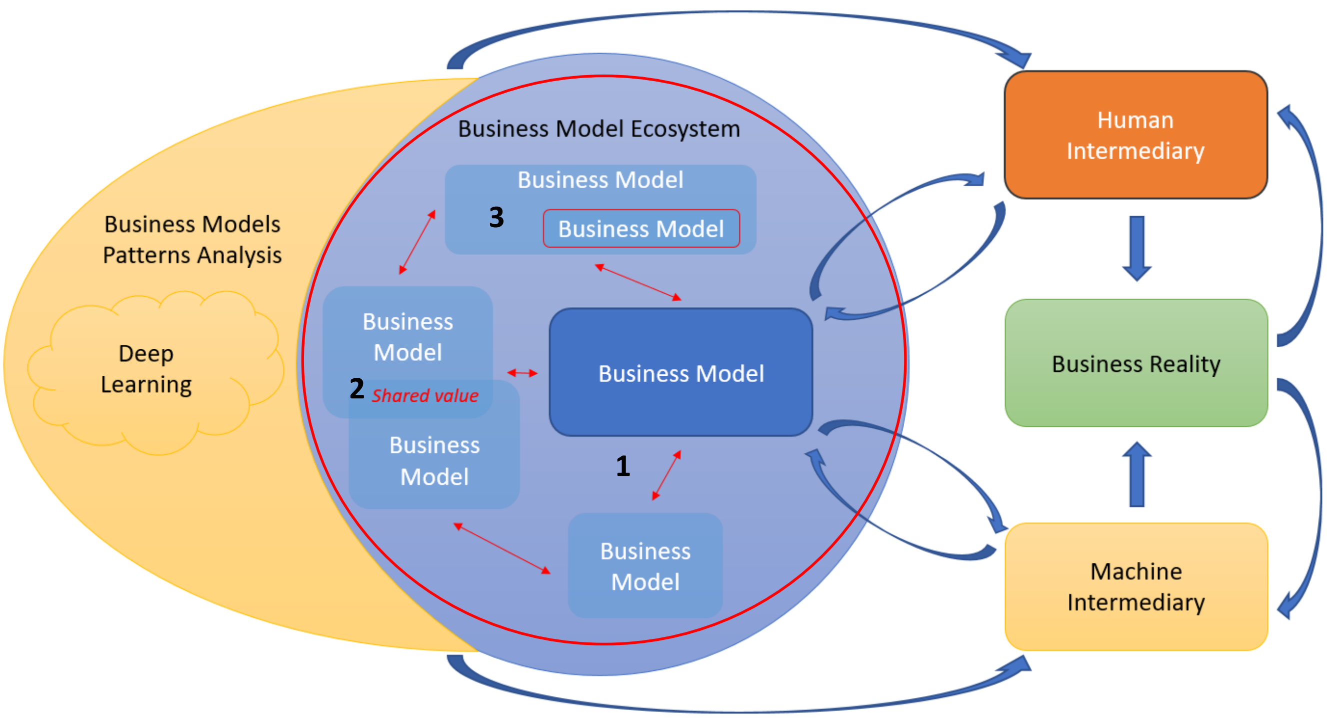


Figure 2.5.: Business Model Ecosystem Interrelated Business Model Interaction

Business Model Ecosystem Interrelated Archetypes one, two and three are described in table 2.7

2.7.1 Business Model Ecosystem Interrelated Business Model Interaction Archetypes

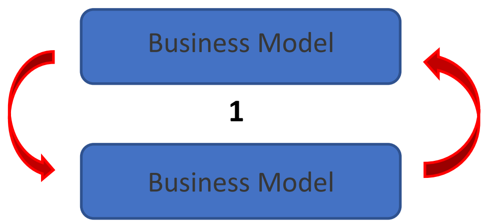
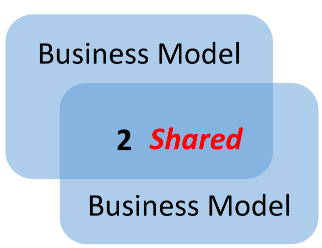
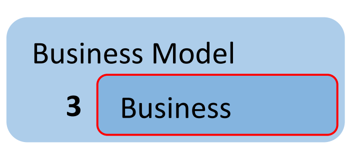
Business Model Ecosystem Interrelated Business Model Interaction Archetypes	**Description**
2.7.1.1 Archetype one: Interrelated Business Model Relationships 	This is where the relationship between the business models is defined. This can be illustrated by a simplified example: The business model of a movie theater and the business model of the parking lot in front of the movie theater are connected in the sense that the customers use both services. Therefore, a major change in one of the business models would affect the other business model. like if the parking fee is raised considerably, the customers would be more likely to find another movie theater.
2.7.1.2 Archetype two: Shared Business Model Values 	This is where the shared business model values are defined. This can be illustrated by a simplified example: if an organization measures the satisfaction of their customers at one sales location by offering the choice of two buttons – one happy smiley and one angry smiley – then over time, the aggregated value would potentially be a shared value between multiple business models. This is primarily because serval business models could impact that value and thereby make it a shared value.
2.7.1.3 Archetype three: Business Models Hierarchy Structures 	This is where the hierarchical structures of the business model are defined. The lowest level comprises all the entities and their relationships to fulfill a business model, higher levels consist entirely of a logical grouping of lower levels.

Table 2.7.: Business Model Ecosystem Interrelated Business Model Interaction Archetypes

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Chapter 3 Engineering setup & Laboratory Experiments

In this chapter we first develop and propose the original engineering setup for measuring the BMI process, the engineering setup proposed can measure hart-rate, face image for emotion detection on each participant, CO2, temperature humidity, pressure in the environment of the lab, 360° live video streaming and sound recording of the group working in the lab. After developing the engineering setup, the engineering setup was tested at the Biogas2020 event in Skive (Denmark) on the 6-9 November 2017.

3.1 Introduction

At the Biogas2020 event in Skive (Denmark) 6-9 November 2017, three multi business model innovation challenges were posed.

Figure 3.1: Overview of the set-up of the multi business model innovation labs at the Biogas2020 event in Skive (Denmark)

Each of the multi business model innovation challenges had a group of approximately four participants that worked with their own specific real-business Technological Business Model Innovation (TBMI) challenge defined by a business. The participants worked with the challenge for three days within a multi business model innovations challenges lab tailored specifically to enhance multi business model innovation. Within each of the three multi business model innovation labs, the multi business model tools Bee Board and Bee Star developed by Professor Peter Lindgren were available [28] All the multi business model innovation labs were set up in a large hall as shown in figure 3.1

3.2 The TBMI Challenges

Each of the three TBMI challenges was defined as a challenge to develop business models related to biogas. All the groups were mixed with participant from Denmark, Norway and Sweden and with mixed competences/background. Each of the groups was given a real-business challenge to work with. One group was to work with a business case from Thise Mejeri; Another group was to work with a business case from Veas, and the last group was to work with a business case from Sweden (West Coast Smolts). The three challenges and their corresponding multi business model innovation processes were undertaken inside the three multi business model innovation labs. Figure 3.2 shows one of the labs seen from the inside. The Bee Board multi business model innovation tool is mounted on the wall, and the Bee Star multi business model innovation tool is placed on the table.

Figure 3.2: One of the multi business model innovation labs shown from the inside.

3.3 Engineering Setup & Laboratory Measurements

In this section the technology tools used to measure the multi business model innovation process is described. The section is divided into three sub sections. The first sub section is the Environment Measurement section which describes the sensors required to measure the environment in the three multi business model innovation labs. The second sub section is the Group Measurement section which describes the sensors required to measure the group as a hole during the multi business model innovation process. The third sub section is the Personal Measurement section which describes the sensors required to measure a person during the multi business model innovation process. Preferably all the participant would conduct the BMI process while wearing EEG (electroencephalography) equipment that measures the electrical activity of the brain via electrodes that are placed on the scalp or in a functional magnetic resonance imaging (fMRI) scanner that measures the brain activity indirectly, however such type of measurement would interfere with the participant degree of freedom and limit the possibility for groupwork in the process on an unacceptable level, to protect the BMI process from equipment that would interfere on an unacceptable level the following set of rules were made:

Rule number 1, all the equipment that the participants needs to wear have to be completely wireless and run on batteries to ensure the participant freedom to interact.

Rule number 2, all of the equipment needs to be non-Invasive.

Rule number 3, if the equipment interferes with any of the senses of the participant, the value of the measurement should be carefully evaluated up against the level of interferes it creates.

Rule number 4, the actual measurement should give a relatively precise and meaningfully purpose related to understanding the BMI process and be carefully weighed against the resources, time and founding available for this research.

In the process of staying in compliance with all four rules, the list of possible equipment was getting shorter for each rule, the final list of equipment is described in the next three sections, environment measurement, group measurement and personal measurement.

In figure 3.3 and in compliance with the four rules, the engineering setup in the multi business model innovation lab, is shown with a diagram.

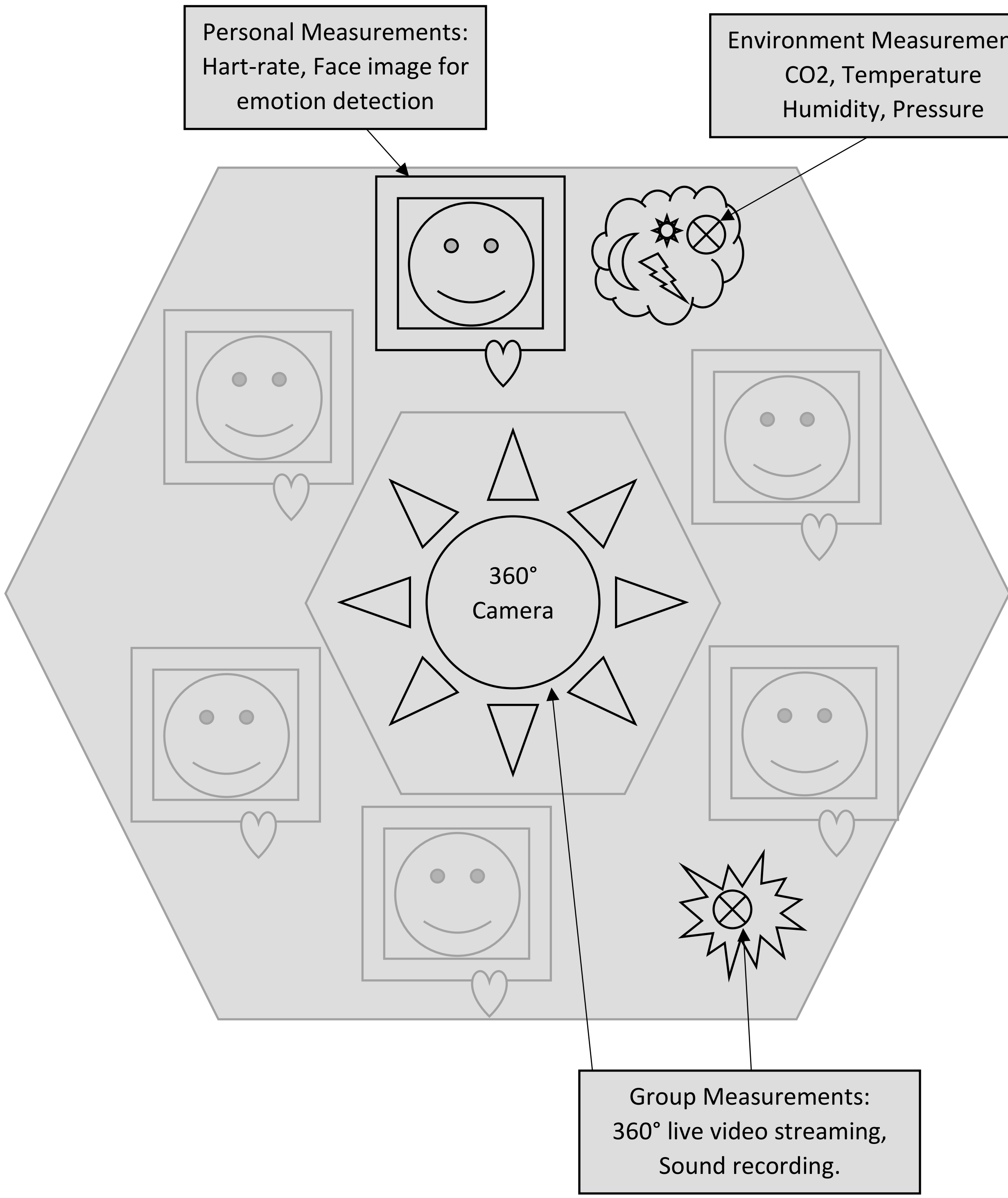

Figure.: 3.3 Engineering setup in the multi business model innovation lab.

3.3.1 Environment Measurement

The following environmental measurements were collected inside each multi business model innovation lab:

- CO_2 level approximate every second.
- Temperature approximate every second.
- Humidity approximate every second.
- Pressure approximate every second.

3.3.1.1 CO_2 level Measurement

Our requirements to the CO_2 sensor included a high level of programmatic control and the ability to measure within 0 to 5000 ppm with an accuracy of ±3% of reading. After a quick screening of the market for CO_2 sensors the K-30-FR FAST Response 1% CO_2 was chosen [29]. This sensor fulfilled our requirements and could relatively easily be connected to a Raspberry Pi 3 - Model B [30] to obtain maximal programmatic control. Interfacing the sensor with the Raspberry Pi was done straightforwardly with a serial connection [31] as shown in figure 3.4

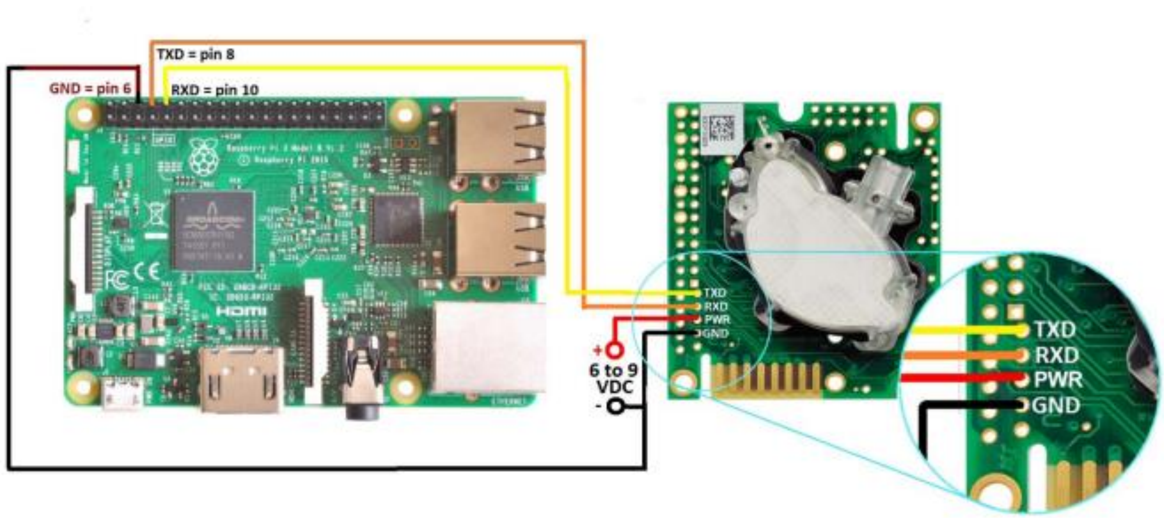

Figure 3.4: Diagram connecting Raspberry Pi 3 - Model B to K-30-FR sensor. [31]

To ensure programmatic control and to allow the retrieval of readings, the Raspberry Pi was installed with the image Raspbian stretch with desktop, Version: September 2017, Release date:2017-09-07, Kernel version:4.9. After enabling GPIO Serial [32], Node-RED [33] was chosen and installed to enable flow-based programming for the Internet of Things. In addition, the K-30.py file [31] with the code for receiving values from the K-30-FR sensor was created. The flow-based Node-RED programming is responsible for executing the K-30.py file in addition to log and display measurements on the Node-RED dashboard are shown in figure 3.5. The logfile containing Co2 level entries was saved locally on the raspberry pi's SD memory card in the following JSON format: {"timestamp":"2017-11-08T13:18:40.687Z","CO2":"1052"}.

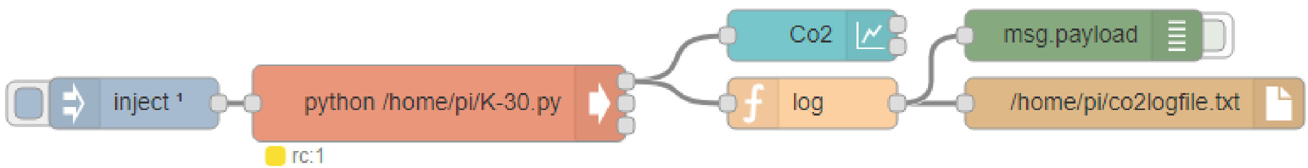

Figure 3.5: Flow-based Node-RED programming for executing the K-30.py file, log and display measurements on the Node-RED dashboard.

An example of the Node-RED dashboard with CO2 level can be seen in figure 3.7.

3.3.1.2 Temperature, Humidity and Pressure Level Measurement

Now that it has been decided to use a raspberry pi 3 for CO2 measurement, it makes sense to use the same device to acquire temperature, humidity and pressure levels. Luckily, an extension board called Raspberry Pi Sense HAT exists [34] which can measure all such values. The flow-based Node-RED programming responsible for logging and displaying all our measurements on the Node-RED dashboard are shown in figure 3.6. The logfile with Co2 level entries are saved locally on the Raspberry Pi's SD memory card in the following JSON format: {"timestamp":"2017-11-07T15:30:58.225Z","temperature":25.36,"humidity":38.18,"pressure":1027.09}.

An example of the Node-RED dashboard with the measurements can be seen in figure 3.7.

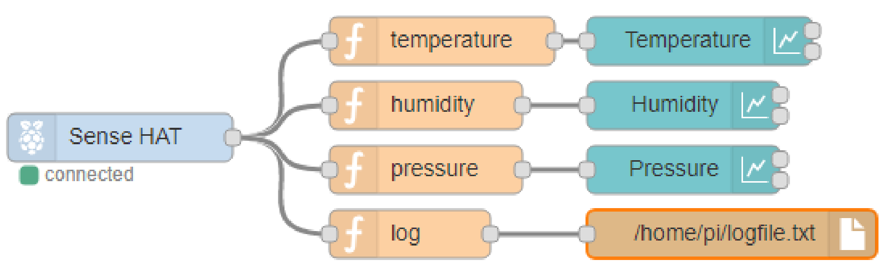

Figure 3.6: Flow-based Node-RED programming to log and display temperature, humidity and pressure measurements on the Node-RED dashboard.

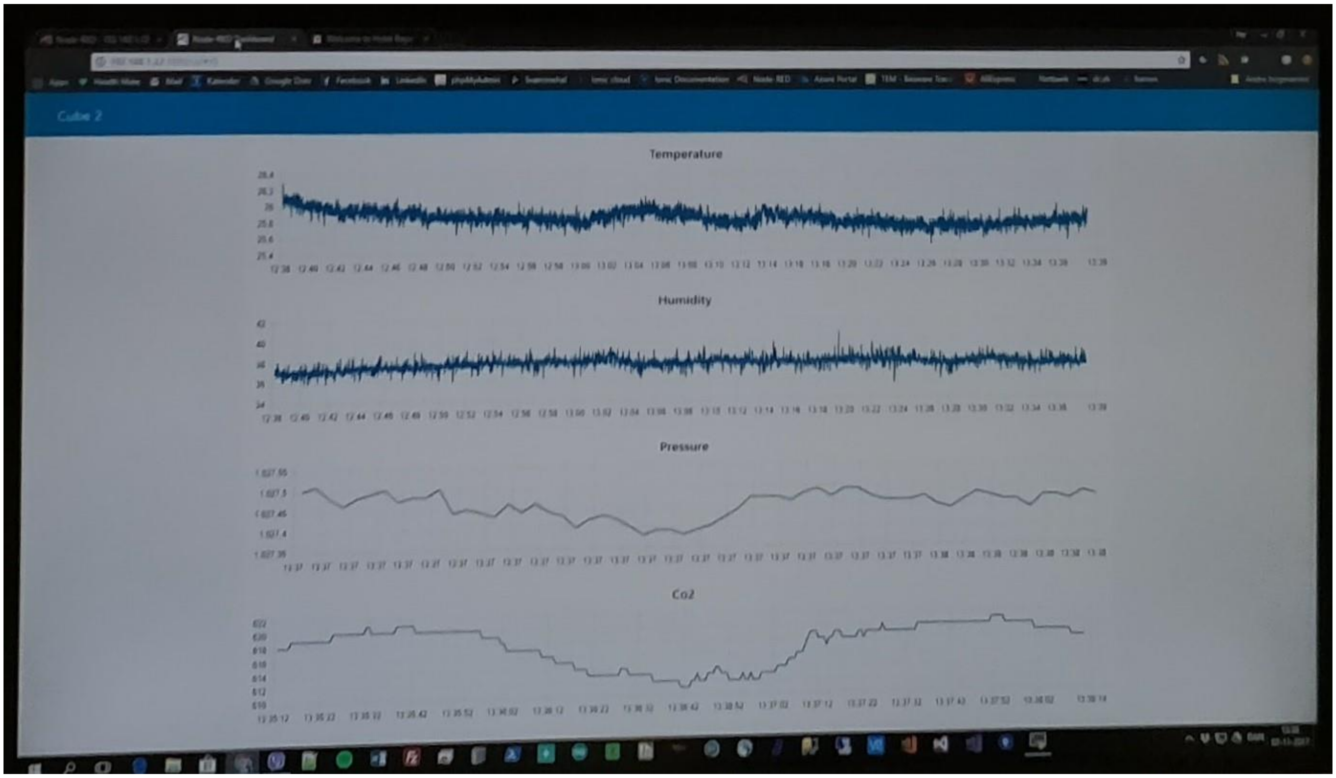

Figure 3.7: Node-RED dashboard with the CO2, temperature, humidity and pressure measurements in a multi business model innovation lab.

The decision to use the Sense HAT module did not prove entirely uncomplicated. One complication was that the module uses 2x20-pin female headers to connect to the Raspberry Pi 3 computer. This was problematic as some of the pinouts were already used by the CO2 sensor as shown in figure 3.4. However, the specific pins were not used by the Sense HAT module and could be quickly solved with a bit of iron soldering. Another complication was that the Sense HAT module temperature sensor seemed to make measurements some degrees of Celsius too high when the module was placed on the Raspberry 3, this was due to the temperature sensor was placed too close to the CPU and as a consequence became affected by the temperature [35]. As an experiment, the module was moved away from the Raspberry 3 with a GPIO Ribbon Cable for Raspberry Pi (40 pins) which solved the problem. The final solution is shown in figure 3.8.

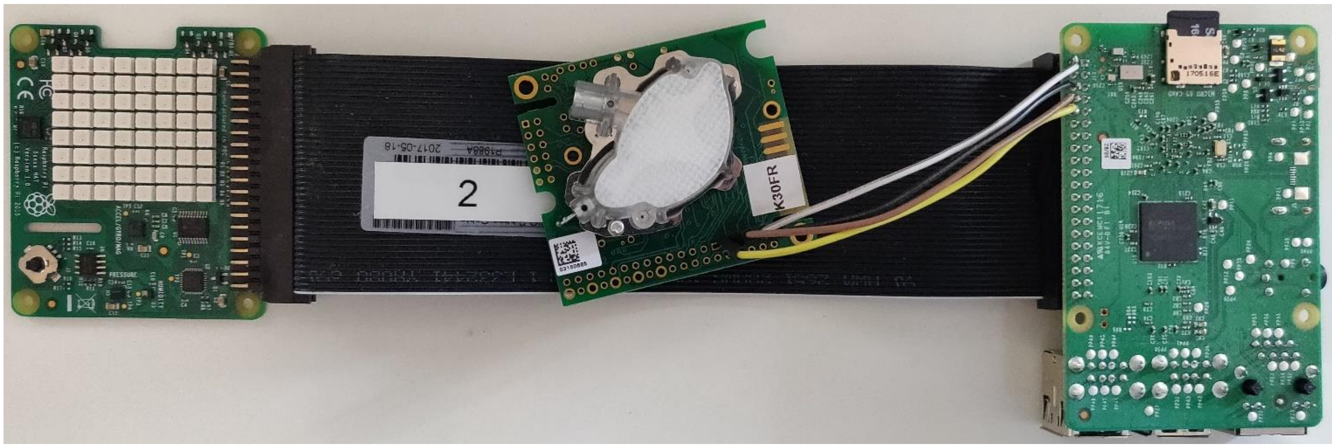

Figure 3.8: The final hardware solution for CO2, temperature, humidity and pressure measurements.

3.3.2 Group Measurement

The following group measurements were collected inside each multi business model innovation lab:

- 360 Degree camera live streaming
- Live sound recording

3.3.2.1 360 Degree Video Camera Recording

To be able to record the multi business model innovation process it was decided to use the RICOH THETA V camera. The decision was based on the capability of the camera to record 4K (3840x1920, 56Mbps) 30 fps high-resolution 360º videos [36] of the multi business model innovation process at a reasonable price. Due to the size of the recordings and to the fact that a daily multi business model innovation session could easily last more than eight hours, archiving video on the approximately 19GB internal memory of the camera was not an option. Instead, live streaming with the following resolution/frame rate over USB was chosen: 4K, H264: 3840×1920/29.97fps/120Mbps [36]. To be able to archive the livestream, a Windows computer was placed in each multi business model innovation lab with the open source media player for Windows MPC-HC [37]. With this setup, it was possible to archive the live stream on the hard drive of the computers [38]. Additionally, the placement of the RICOH THETA V camera was important to enable the recording of as much as possible of the multi business model innovation process. The center of the hexagon table was seen as the optimal position to cover the entire lab. However, the table would also be used by the participant with their laptops during the multi business model innovation process, and a tripod was therefore chosen to lift the RICOH THETA V camera above the laptops placed on the table.

3.3.2.2 Sound Recording

Although the RICOH THETA V 360 Degree Video camera hardware is capable of recording audio while live streaming with AAC-LC encoding in mono [36], the MPC-HC software used to archive the live stream was unstable and out of sync with the audio part. Therefore, since the computers placed inside the labs already was equipped with a microphone, this was set up to audio record the multi business model innovation process with the open source program Audacity [39].

3.3.3 Personal Measurements

The equipment to collect the personal measurements outlined below were implemented as part of the experiment. An emotion recognition cap with a camera directed towards the participant's face producing approximately one picture per second. For live sampling approximately every fifth photo was run through face detection algorithms and post-processed with emotion detection algorithms before the live sampling results were displayed and archived. Furthermore, each participant was fitted with pulse measurement equipment strapped around their chest to measure the heart rates of the participants. Before any measurement was taken, each participant was asked to complete an insights® discovery personal profile. In the subsequent three sections the following are discussed in greater detail: the insights® discovery personal profile, the emotion recognition cap and the heart rate measurement.

3.3.3.1 Insights® Discovery Personal Profile

Before the participants were introduced to the challenge, each participant was asked to complete a work-profile test that gives the participant an insight into his/her own strengths, challenges and development opportunities. The personal profile is a work profile - it shows how the participant works in a professional context - and is recognized in business as a tool when recruiting new employees or assembling work teams.

3.3.3.2 Emotion Recognition Cap

One of the requirements to the research experiment was to measure the emotions of each participant during the multi business model innovation process. Several approaches on how to fulfil this requirement was suggested. Each of these approaches had to be carefully evaluated since the opportunity to conduct the experiment at the Scandinavia Biogas Conference 2017 in Skive, Denmark was approaching very fast, and therefore the project had limited time available. The first approach considered was to use the livestream from the RICOH THETA V 360 Degree Video camera to detect the emotions of the participants. This would of course be possible, but such a technical solution would first have to run face detection algorithms on the live stream and feed the results into an emotion recognition process that returned the emotions to the faces detected. However, such a solution would have some serious drawbacks. The first drawback is the difficulty of retrieving from the dataset the relationship between the specific participant and the emotion that the participants are experiencing since the emotion recognition process does not identify the participant, but only the emotion returned. Therefore, yet another process would have to be introduced with a facial recognition algorithm that would identify each participant. Each step of such a process would have its limitations and would have limited accuracy, which would reduce our number of quality measurements with the face correctly detected, the emotion correctly detected, and the identity correctly detected at the same time for all measurements.

To make it even worse, a lot of movement inside the lab is to be expected since the multi business model innovation process is a very complex and creative process. The multi business model innovation labs are also designed to facilitate such creativity as all the walls and even the glass windows can be used in the process as shown in figure 3.9, and therefor since the 360° camera are placed on the table in the center, it would rarely even capture the faces of the participants.

Since the quality of the previously mentioned algorithms depends heavily on the size of the visible part of the face and on the angel from which the picture is taken – the above approach was not considered to generate the accuracy of the emotions required and wanted for this experiment and was therefore not chosen.

Figure 3.9: A participant deeply involved in the multi business model innovation process drawing on the window.

Another approach considered was to use livestreaming and to add many cameras all over the multi business model innovation labs. However, this was quickly dismissed due to the complexity of a setup that would be able to deliver the desired quality. The setup was not considered feasible before the Scandinavia Biogas Conference 2017.

In order to be able both to catch the opportunity and to deliver the required quality of the reading of the participants emotions, a third approach was considered. Our approach was to mount a camera to a cap for each participant with the camera direction pointing into the face of the participant as shown in figure 3.10. This approach was considered a trade-off as the participants were required to relinquish their convenience. The participants were asked to wear the emotion recognition cap in return for very good face frontal images no matter how or where they were positioned. Another benefit to be gained from this solution was that the researchers could know the exact identity of the participant wearing the cap which eliminated the need for facial recognition.

This was the chosen approach, and the emotion recognition cap is described in greater detail in the next section.

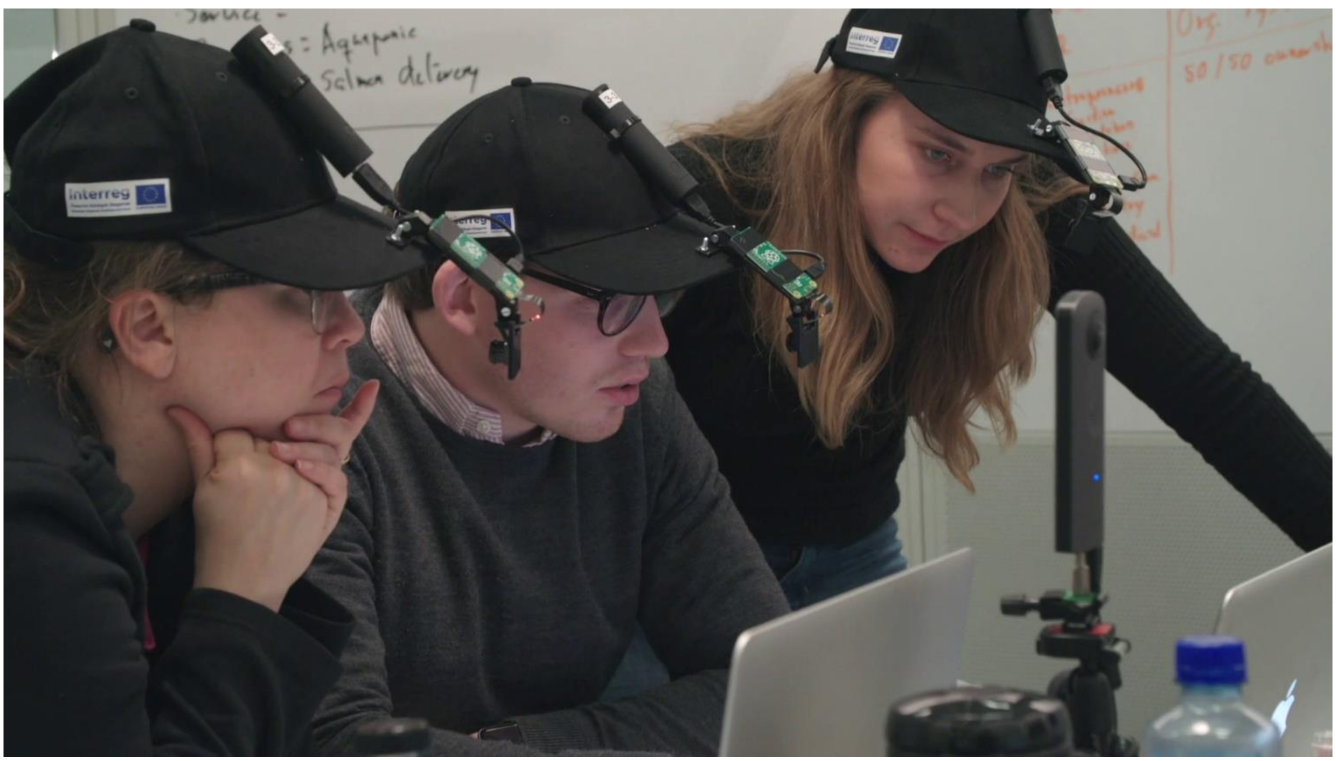

Figure 3.10: Participants wearing the emotion recognition cap while deeply involved in the multi business model innovation process.

The decision to make use of emotion recognition caps came with several requirements. The first requirement was that the emotion recognition cap had to be wireless. The next requirement was that the cap must be able to run on a battery charge for approximately eight hours. Another requirement was that the device should interfere as little as possible with the activities of the participants. However, some interference – such as the discomfort of wearing the cap – was acceptable. As we had already decided to introduce Raspberries into this experiment, the Raspberry Pi Zero W [40] with the small camera [41] was chosen due to its very small dimensions and its technical configuration supporting Wi-Fi for image transfer.

Another trade-off made to allow us to conduct the experiment at the Scandinavia Biogas Conference 2017 was to use the Microsoft Azure Emotion API online service [42] instead of setting up our local emotion recognition software. However, this decision had a few implications. One of the implications was the way the Microsoft Azure Emotion API online service documentation suggested that we analyze videos in real-time [43]. Such an analysis would involve grabbing single frames from the stream periodically and sending them to the API as images. The actual video stream itself was not mentioned as an input option. Another implication was the limitation of maximum 10 image transactions per second on Microsoft Azure Emotion API online service [44].

With the above implications in mind, the process of making the emotion recognition cap a reality had begun. To ensure programmatic control, the Raspberry Pi Zero W was installed with the image Raspbian stretch light (minimal image based on Debian stretch) Version: September 2017, Release date:2017-09-07, Kernel version:4.9. This version was chosen due to the limited CPU power of the hardware. Next, Node-RED was installed and set up, since one of the implications of using the Microsoft Azure Emotion API online service was to grab images and send them individually. The command line tool raspistill [45] for capturing still photographs with the camera module was chosen. However, to speed up the process of taking capturing still photographs continuously, the time-lapse mode was used and set to capturing one still image each second. This was considered good enough in view of the quality of the input image. Additionally, the interpretation of a participant’s emptions should be based on a longer timeframe to make logically sense. The flow-based Node-RED program to call raspistill and to synchronize the results are shown in figure 3.11 and explained below.

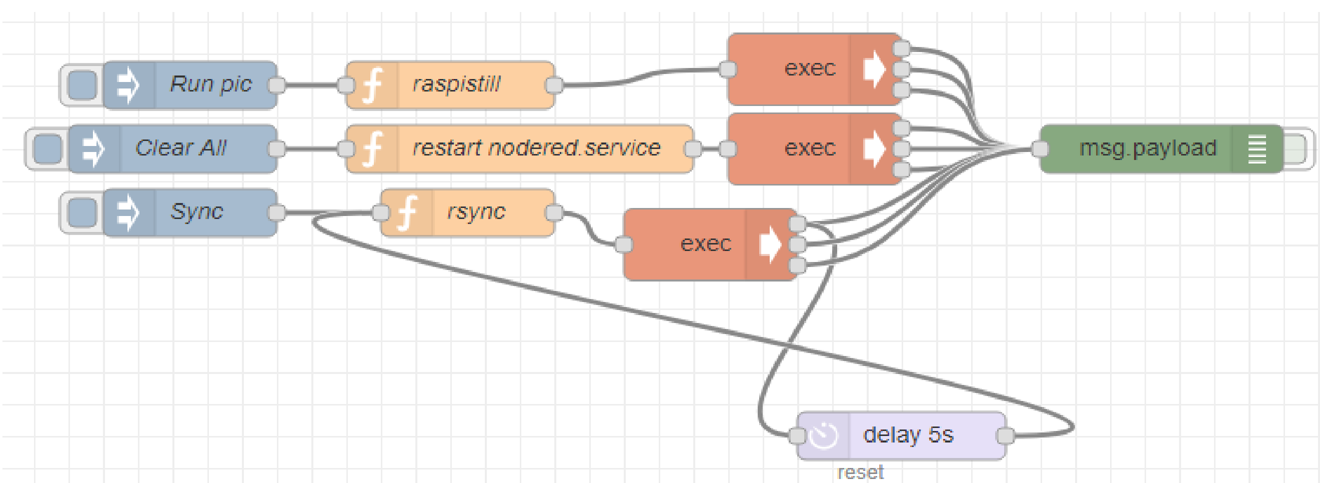

Figure 3.11: The flow-based Node-RED program to call raspistill and sync the results.

In figure 3.11, the node “Run pic” is executing the function node “raspistill” at start-up which sends the command *"raspistill -th none -t 0 -tl 1000 -w 640 -h 480 -o img/" + new Date().toJSON().replace(/:/g , "-") + "%04d.jpg"* to the “exec” node. This makes the Raspberry Pi Zero take one image every second with a width of 640 pixels and a height of 480 pixels and save it with a name with the following format: “2017-11-09T07-10-46.507Z5886.jpg”. The first part before the “T” “.” is the date at which the raspistill program is executed; the next part after the “T” and before the “Z” is the time at which the raspistill program is executed; the last number after the “Z” is the number of seconds elapsing between the time at which the raspistill was executed and until the image was captured. This naming convention makes it possible to calculate the time at which the image was actuality captured. However, simply saving the images on the memory card of the Raspberry Pi Zero W is not sufficient; the images need to be wirelessly transferred to the computer placed in each cube for archiving and sending it to Microsoft Azure Emotion API online to get the resulting emotion and present them nicely for all participants in the multi business model innovation lab. To ensure a fail-safe transfer of the images from the Raspberry Pi Zero W to the computer in the multi business model innovation lab, rsync[46] which is an open source utility providing fast incremental file transfer is used to make that transfer. The node “sync” in figure 3.11 is executing the function node “rsync” at start-up which sends the command *“rsync --rsh="/usr/bin/sshpass -p raspberry ssh -o StrictHostKeyChecking=no -l pi" --remove-source-files /home/pi/img/*.jpg 192.168.1.31:/media/sf_PISHARE/3”* to the “exec” node. This makes the Raspberry Pi Zero move all the images captured by the camera to the folder /home/pi/img/ to the computer in the lab with this IP 192.168.1.31 in this folder /media/sf_PISHARE/3. To make the transfer of images continually and not only a one-time transfer event on boot, the node “delay 5 sec” in figure 3.11 was introduced. This ensures that every time the “exec” node has finished the command, it waits five seconds and executes it once more. In this way, all images are transferred every fifth second. The rest of the nodes in figure 3.11 are there for debugging and testing purposes. However, since the computer in the lab is running Windows and although packages like Cygwin [47] and cwRsync [48] are available from 3rd-parties to make rsync work on windows. Not all such packages are free, and they are more complicated to use. Therefore, the choice to use the open source virtualization product VirtualBox [49] was made. Our choice of operating system was the open source Debian with Raspberry Pi Desktop [50] due to that fact that we already used the Raspberry operating systems on both the Raspberry Pi 3 and the Raspberry Pi Zero W. Such a set-up has serval advantages. Firstly, ssh and rsync are built for Unix systems and are therefore very easy to install, configure and use on Unix systems. Secondly, since we had to set up one computer in each multi business model innovation lab, we needed in total three computer setup with this configuration. By using VirtualBox, the filesystem image containing the system could be made once and thereafter simply copied, to have it up and running in all three multi business model innovation labs with minimal effort. Since the functionality for image transfer to the main computer was in place, our next task was to send it from the computer to the Microsoft Azure Emotion API online service getting results back and presenting the emotions nicely for all participants in the multi business model innovation labs. To overcome this task, Node-RED was installed on each computer in the laps and the flow shown in figure 3.12 was created.

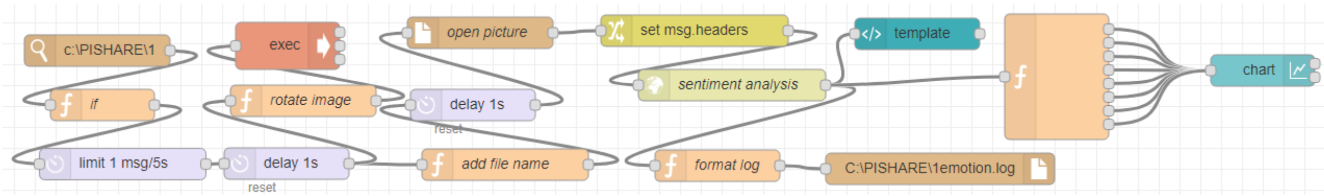

Figure 3.12: Flow-based Node-RED programming to call emption API log and display the results on the Node-RED dashboard.

The first node “c:\PISHARE\1” is watching the folder “C:\PISHARE\1” (which is added as virtual folder in VirtualBox and is where the node flow in the Raspberry Pi Desktop saves the pictures for emotion recognition cap one). When a picture is created in the watched folder, it is sent to the “if” node which then makes validations and forward to the “limit 1 msg/5s” node. The “limit 1 msg/5s” node makes sure that an image is forwarded only once every five second and then the “delay 1s” node delays it for one second to make sure the image are fully created before continuing. From here the path splits into two., The first path leads to the “rotate image” node., This node makes a command for rotating the image with the program jpegtran.exe [52] and sends it to the execute node. The image rotating is not done with the raspistill program on the Raspberry Pi Zero W due to the image rotation loss issue [51], raspistill makes a simple rotation of the image without preserving the dimensions, whereas jpegtran.exe on the other hand makes a rotation while preserving the dimensions. The other path is to the node “add file name” which adds the file name attribute and goes to the “delay 1s” node which ensures that the image rotation is complete before continuing to the “open picture” node. This node makes the image ready for transfer by reading the image into a single buffered array. The next node “set msg.headers” sets the "Content-Type" and "Ocp-Apim-Subscription-Key” headers required by the by the Microsoft Azure Emotion API online service. Finally, the node “sentiment analysis” makes the https POST call to the Microsoft Azure Emotion API online service with the object created. The results are directed three ways: one direction is to the “Template” node which displays the images on the dashboard, another direction go to the chart which creates the pi chart diagram and finally the last direction go to the “format log” which formats the result and sent it to the 1emotion.log that’s saves it into a file, In figure 3.13 the Node-RED dashboard with the captured images from the emotion recognition caps and the corresponding results from the Microsoft Azure Emotion API online service shown in the pie chart are displayed for each participant in the multi business model innovation lab.

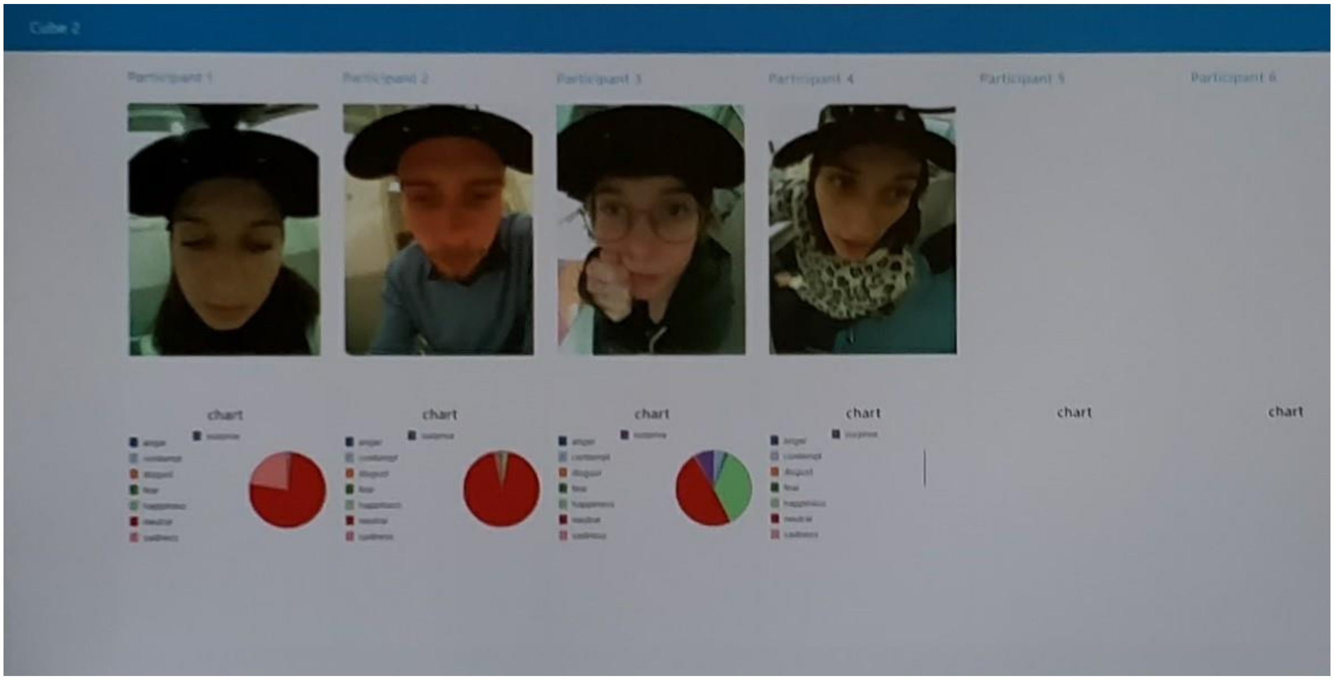

Figure 3.13: The captured images from the emotion recognition caps and the results on the Node-RED dashboard for one of the multi business model innovation labs.

However, the previously described Node-RED flow running on the computers within the multi business model innovation labs only handle one emotion recognition cap. To handle all the six possible emotion recognition caps within one multi business model innovation lab, the flow in figure 3.14 is used.

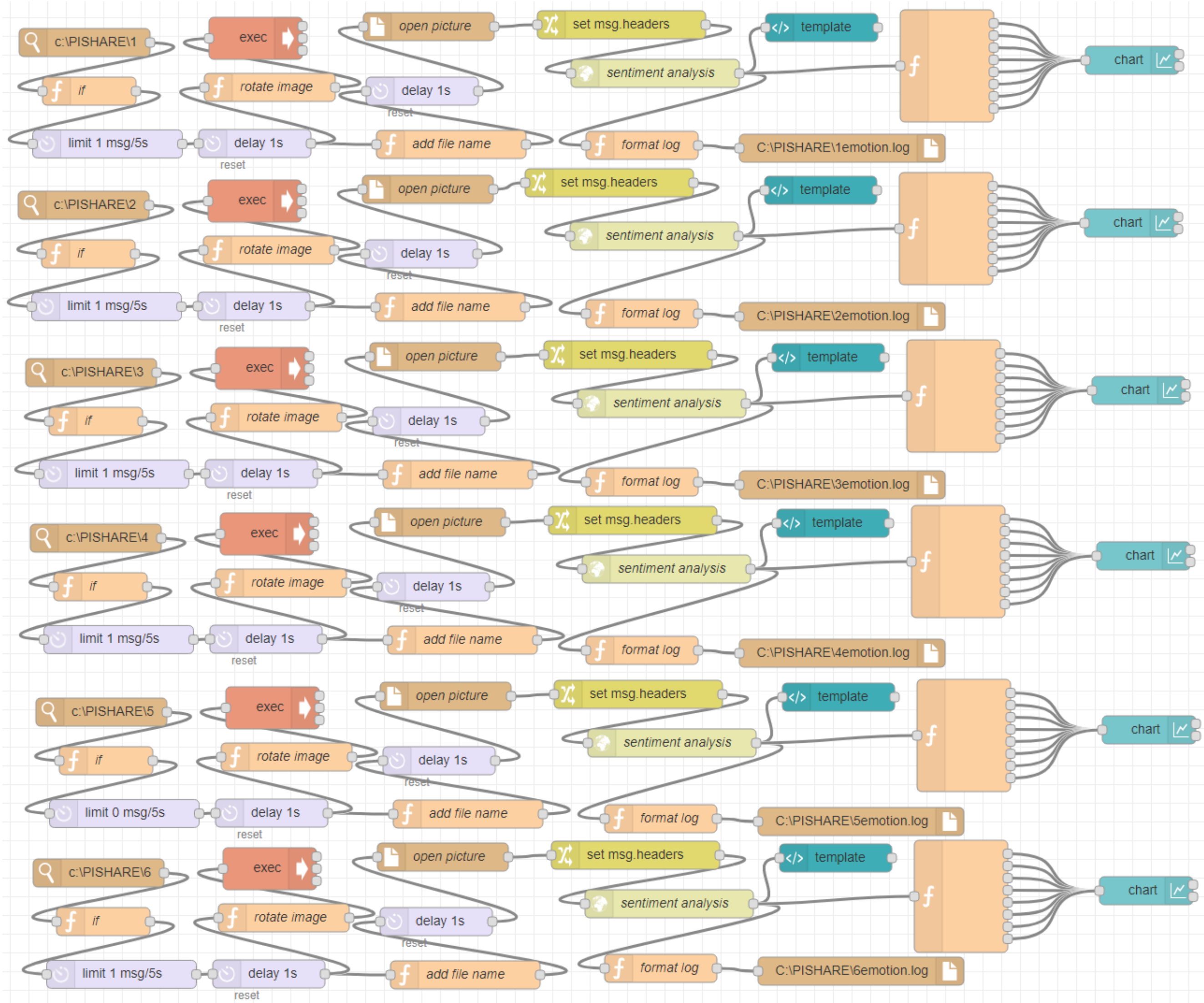

Figure 3.14: The complete flow-based Node-RED programming to call emption API log and display the results on the Node-RED dashboard for one multi business model innovations lab.

Besides the challenge of getting the hardware and software in line for overcoming the challenge, there was the physical challenge of mounting the camera on the cap and making it wireless with a battery source that would run continually for minimum eight hours without the need for charging. To overcome the mounting issue, the 3D models in figure 3.15 and figure 3.16 were made and 3D printed to finally be mounted on the cap as shown in figure 3.17.

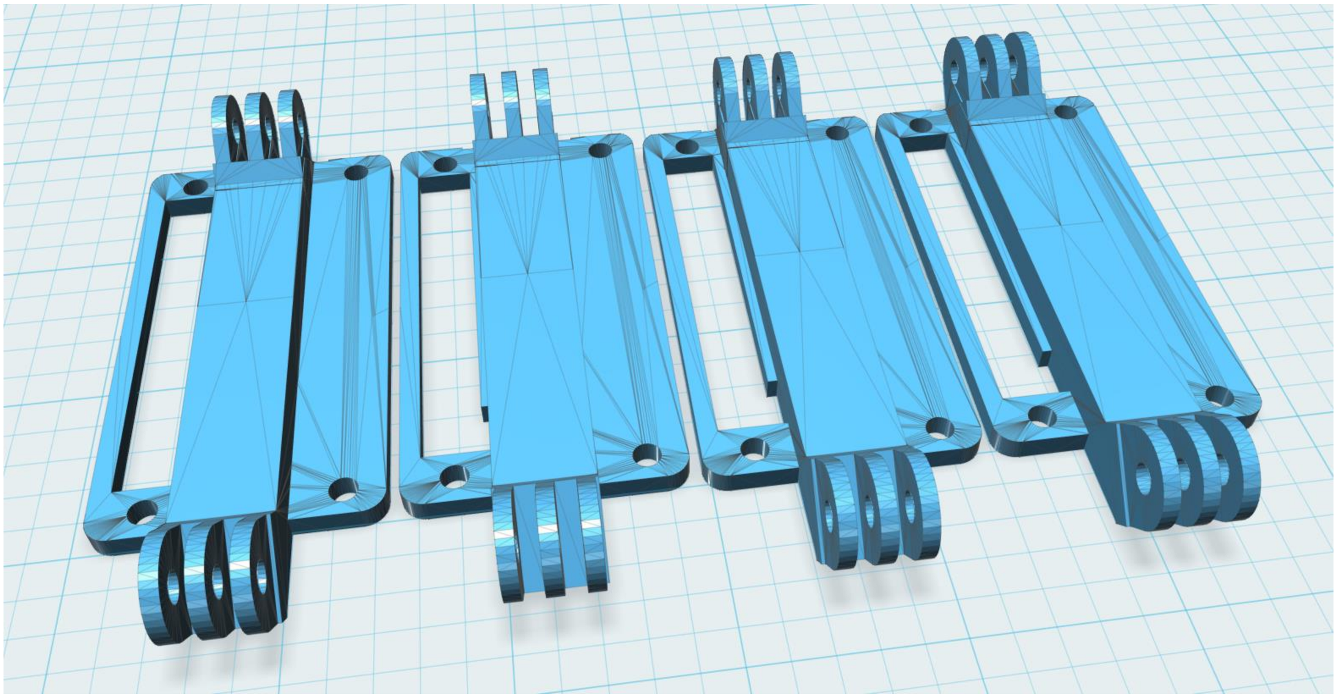

Figure 3.15: The 3D model for the unit to which the Raspberry Pi Zero W will be attached and the ends with flexible attachment possibilities for the cap and the camera.

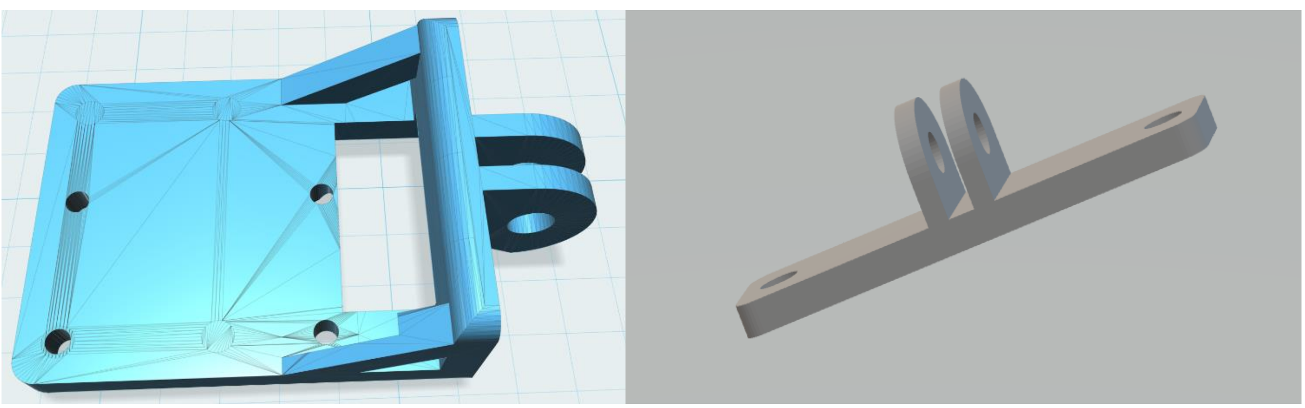

Figure 3.16: The 3D model for the unit to which the camera was attached and the 3D model for the unit that attached the gather pieces to the cap.

Figure 3.17: The emotion recognition 3D printed units with hardware and the battery mounted on the emotion recognition cap.

Now the last thing needed to be done was to select the battery power source for mounting on the emotion recognition cap. The chosen power bank was the one visualized in figure 3.17 with 3350 mAh capacity. This power bank was chosen due to its relative light weight. Furthermore, since the Raspberry Pi Zero W power consumption during shooting 1080p video is only 230 mA as shown in table 3.1, it is fulfilling our requirement of delivering minimum eight hours of usage (3350mAh/230mA=14,57hours of usage).

	Zero /mA	Zero W /mA	A+ /mA	A /mA	B+ /mA	B /mA	Pi2B /mA	Pi3B /mA
Idling	100	120	100	140	200	360	230	230
Loading LXDE	140	160	130	190	230	400	310	310
Watch 1080p Video	140	170	140	200	240	420	290	290
Shoot 1080p Video	240	230	230	320	330	480	350	350

Table 3.1: The power consumption of the different Raspberry Pi versions from raspi.tv [53]

3.3.3.3 Heart Rate Measurement

The last requirement left with regard to personal measurements is the heart rate measurements. To fulfil this requirement the H10 HR sensor [54] shown in figure 3.18 was used. The H10 HR sensor was chosen because of its accuracy. Other sensors were considered, e.g. the wristband heart rate sensors, but the chest strapped H10 HR sensor was deemed superior in accuracy due to its chest mounting feature.

Figure 3.18: The H10 HR sensor for measuring the participants' heart rate during the multi business model innovation process.

It is possible to retrieve the measurement from the sensor through Bluetooth, and since the Raspberry Pi Zero W also supports Bluetooth and is always close to the participants chest, the Raspberry Pi Zero W was chosen as the responsible unit for retrieving such values. Here noble [55] and a small node.js [56] script form Jake Lear [57] was used with the small addition of the following code:

```
var peripheraladdress = "";
for (let j = 0; j < process.argv.length; j++) {
	peripheraladdress = process.argv[j];
}
if(peripheral.address == peripheraladdress){
	//execute the original script.
}
```

This code makes it possible to pair the emotion recognition cap with the H10 HR sensor by passing the UUID of the H10 HR sensor to the node.js script as argument. In this way it was possible to retrieve the heart rate measurement with the Node-RED flow in figure 3.19.

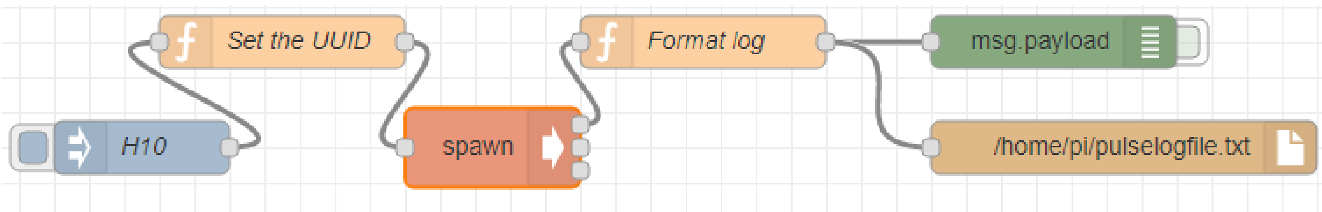

Figure 3.19: The flow-based Node-RED flow to call the noded.js script and to log the results on the Raspberry Pi Zero W memory card.

The Node-RED flow in figure 3.19 takes care of retrieving the measurements from the H10 HR sensor and logs them on the memory card of the Raspberry Pi Zero W. The first node “H10” makes sure that the flow is initiated once the Node-RED service is started. The next node “Set the UUID” prepares the following command “sudo node /home/pi/h10.js da:80:35:a6:e6:b0”. This command makes sure that the Node.js script /home/pi/h10.js is executed with root privileges and parses the UUID of the H10 HR sensor “da:80:35:a6:e6:b0”. The next node “spawn” takes the command crated by “set theUUID” node and spawns it. The difference between the “exec” and “spawn” node type is that “exec” node only returns the result when the process is done, whereas the “spawn” node type returns the results continuously as the process is being executed which is exactly what is required here. The next node “Format log” formats the log with the following line “msg.payload = {timestamp: new Date().toJSON(), pulse: msg.payload.replace("\n", "")};”. Finally, the “/home/pi/pulselogfile.txt” saves the logs into a file.

3.4 Empirical Data Gathering Process

To make the data gathering process more fault-tolerant it was decided not to rely on the general publicly available Wi-Fi network at the Scandinavia Biogas Conference 2017. Instead it was decided to bring our own Wi-Fi networks set-up. Our set-up consisted of three of the Ubiquiti Unifi AP-AC Pro [58] – one for each multi business model innovation lab — and one Ubiquiti Unifi Switch US-8-150W – Switch [59] which handles the cabling between the access point and the network, there was also added one Ubiquiti Networks USG, 512 MB Security Gateway [60] between our local network and the ethernet network with internet access provided at the Scandinavia biogas conference 2017. Finally, the last part of the local networks set-up was the Ubiquiti Unifi Cloud Key [61]. The Unifi Cloud Key makes it possible to set up, monitor and log the local network with a well-organized web interface as shown in figure 3.20.

Figure 3.20: Example of the web interface of the Ubiquiti Unifi Cloud Key used at the Scandinavia Biogas Conference 2017.

Another decision was to build a control room where it was possible to continuously oversee and monitor the data gathering process of the three multi business model innovation processes being conducted in the three multi business model innovation labs. Therefore, a control room computer with a 6-screen monitor set-up was chosen to display the data gathering process of all the multi business model innovation labs simultaneously as shown in figure 3.21.

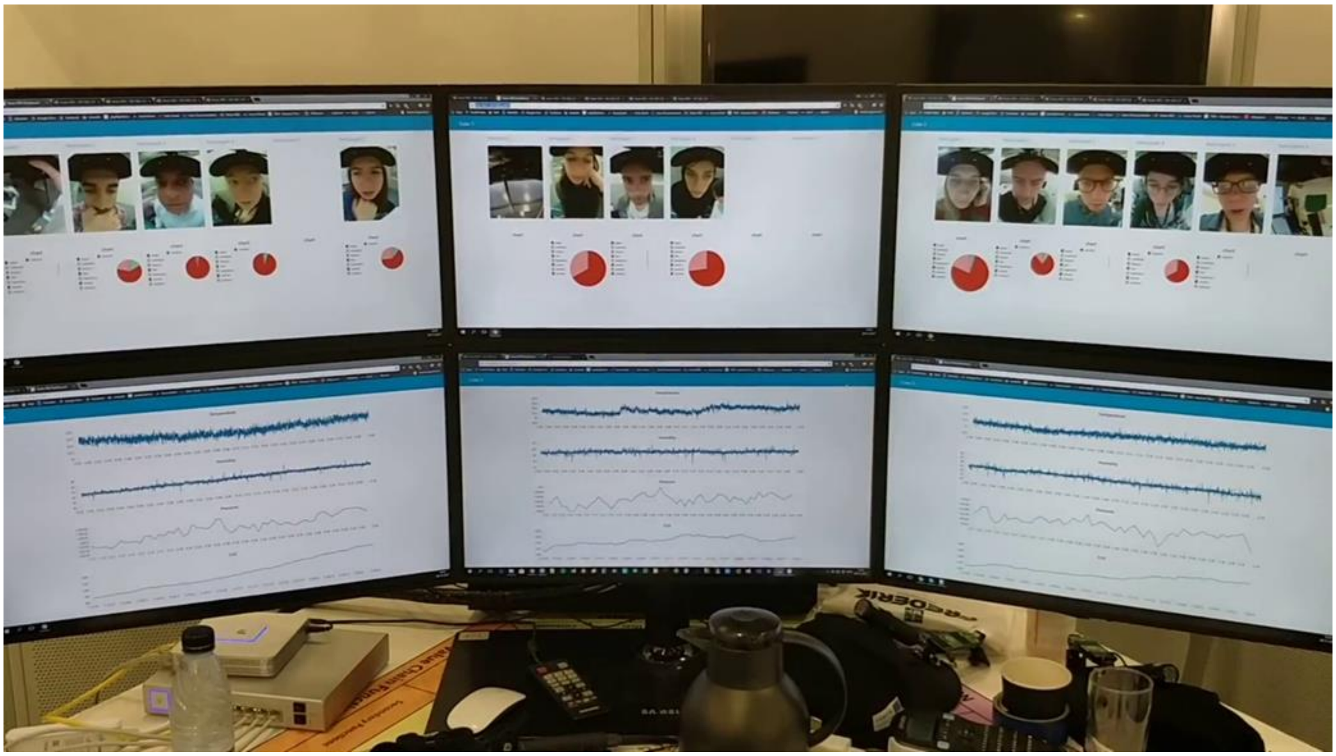

Figure 3.21: The control lab monitor setup with live images and emotions from the emotion recognition caps and the environment measurements in the three multi business model innovation labs

Each column of monitors in figure 3.21 represents one multi business model innovation process being conducted in one multi business model innovation lab as shown in figure 3.22. The top monitors show the image captured with the emotion recognition caps with the corresponding results from the Microsoft Azure Emotion API online service shown in a pie chart. The emotion recognized are: anger, contempt, disgust, fear, happiness, neutral, sadness and surprise. Emotions are displayed as a pie chart because the results from the Microsoft Azure Emotion API online service are weighted results and can therefore meaningfully be shown as pie charts. Although the emotion recognition caps capture images every second, the images and the corresponding results on the live dashboard are only updated every fifth second due to restrictions in the Microsoft Azure Emotion API online service. The images are archived as explained in the emotion recognition cap section. The bottom row of monitors display CO2, temperature, humidity and pressure level measurements in the multi business model innovation labs. The heart rate measurements of each participant are shown within another tab on the corresponding monitor in the top row of monitors.

Figure 3.22: The multi business model innovation lab with four participants involved in an ongoing multi business model innovation process.

During the data gathering process at the Scandinavia biogas conference 2017, some surprises occurred. A major surprise came when everything was set up and the experiment started. All computers, cameras, emotion recognition caps and other equipment had been tested and everything was working and prepared for the participant to arrive and start the multi business model innovations processes, then a camera operator comes by to let us know that he would like to close down all electricity in the entire hall to fly one drone with a camera around and take videos and pictures. Having explained to him that all multi business model innovations labs where ready for the participant and that his suggestion would change that since we would then need to start and test everything once more, we agreed that he would make his videos and pictures after the multi business model innovation processes was done for the day or early the next day before the powering up and readiness test. A second surprise came while we were giving the participants instructions on how to use the emotion recognition caps and strapping on the H10 HR sensor. One of the participants asked if she could speak to me privately. We walked inside the control room and she explained that she was pregnant and this was actually a secret. She had concerns about strapping on the H10 HR sensor to her chest and was afraid that it would not be safe for her unborn child. After having explained to her that it would be completely save and that it was in any case completely voluntary to put on the H10 HR sensor, she chose not to put on the H10 HR sensor during the multi business model innovation process.

Another unforeseen event was that the internet access provided by the Scandinavia Biogas Conference 2017 broke down for a period of time duo to the high number of participants at the conference. The number of mobile phones accessing the internet through the general publicly available Wi-Fi network overloaded some of their network equipment. During the breakdown, the actual data gathering was not affected thanks to our own network set-up, however the live dashboard with the samplings of emotions from the Microsoft Azure Emotion API online service was not available during that period of time due to the missing internet connection. Furthermore, some difficulties were noticed in handling the process of the 360-degree camera recording. Firstly, the RICOH THETA V 360 Degree Video device itself was suffering from a power drain issue. Even when it was receiving power through the USB cable attached to the computer saving the recording, the RICOH THETA slowly consumed power from the internal battery in live recording mode and thereby limited the length of recording to approximately four hours before recharging of the internal battery in the RICOH THETA V 360 Degree Video device was necessary. Therefore, recharging was done in the multi business model innovation labs when the participants involved in the multi business model innovation processes had their lunch break. Secondly, it was complicated to record and save the sound separately from the RICOH THETA V 360 Degree Video recording process. Finally, the very large files produced from the recordings were difficult to handle during backups between session days.

3.5 The Data Gathering Results

When the three multi business model innovation challenges were finished, around one million face pictures have been collected with the emotion recognition caps. The pictures were ready for post-processing with face detection and emotion detection algorithms. Additionally, our set-up had collected around one million heart rate measurements taken by the H10 HR sensor; around one million CO_2, Temperature, Humidity, Pressure measurements taken by the Raspberry Pi 3 set-up; around 3 Terabyte of 360-degree 4K archived video of the multi business model innovations process; and around 50 gigabyte of sound recording.

Many ways exist to look at this data collection. One way is to use Microsoft Power BI Desktop [62] to view the data with different graphs. A few examples of viewing the data with Microsoft Power BI Desktop are shown in figures 3.23, 3.24, 3.25 and 3.26.

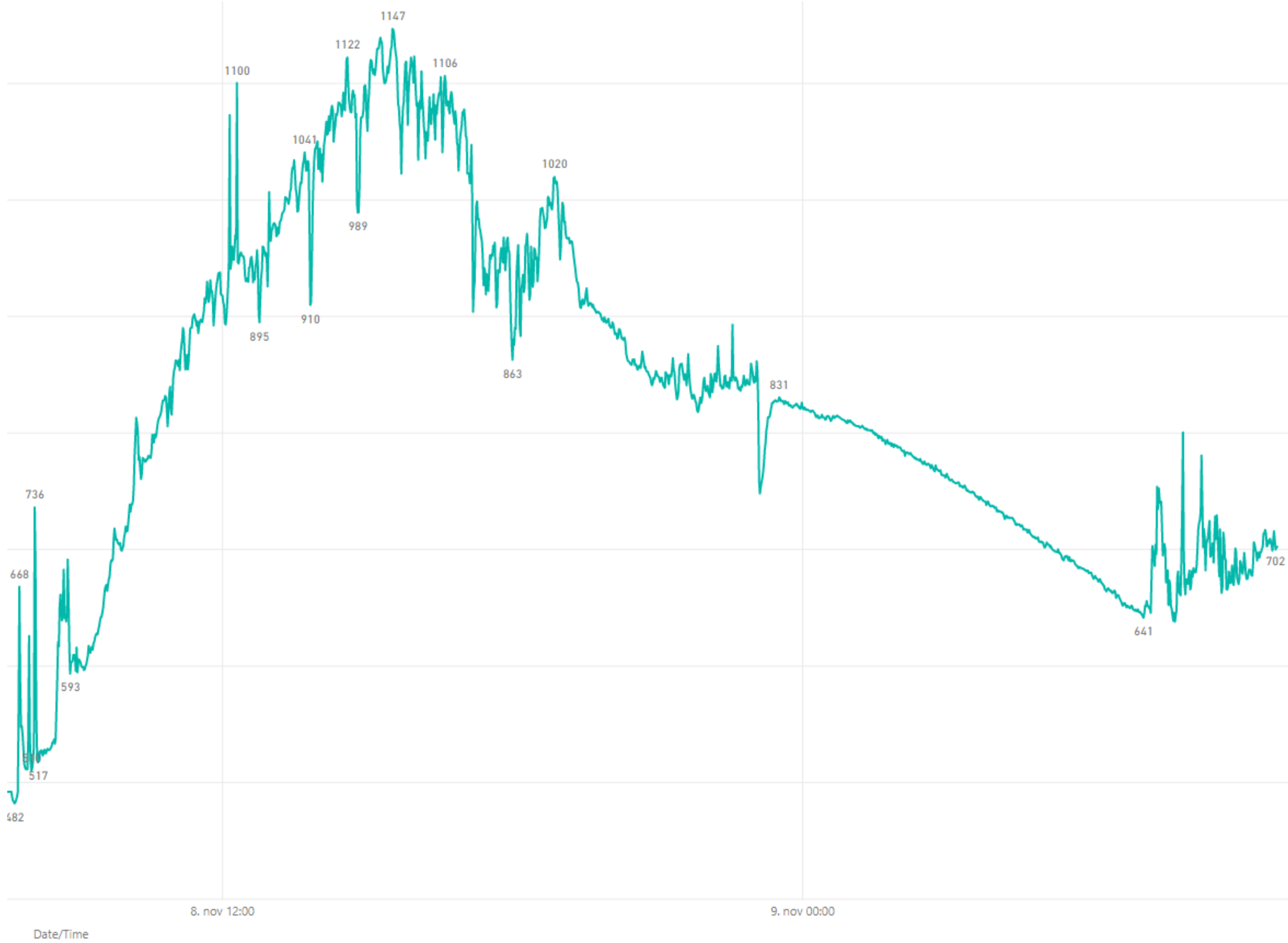

Figure 3.23: Example with the CO2 measurement from one multi business model innovation lab showing the increases and decreases of Co2 before, during and after a session.

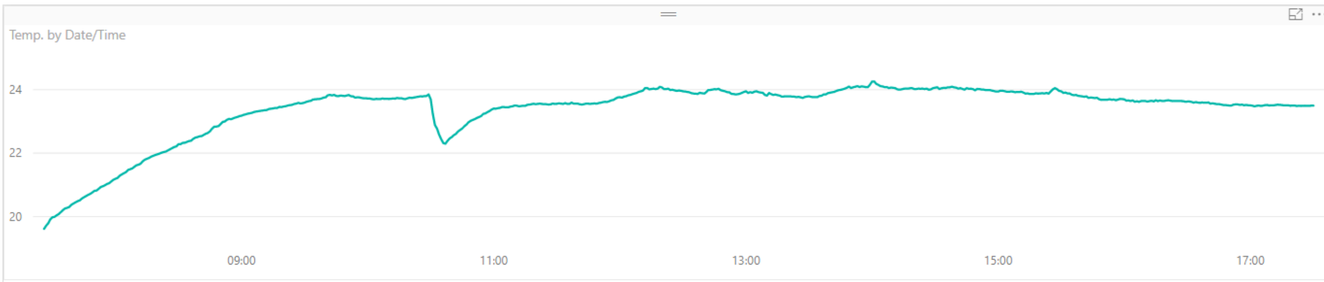

Figure 3.24: Example with temperature measurement from one multi business model innovation lab showing the increases of temperature at the beginning of a session and the sudden decrease in temperature around 10:30.

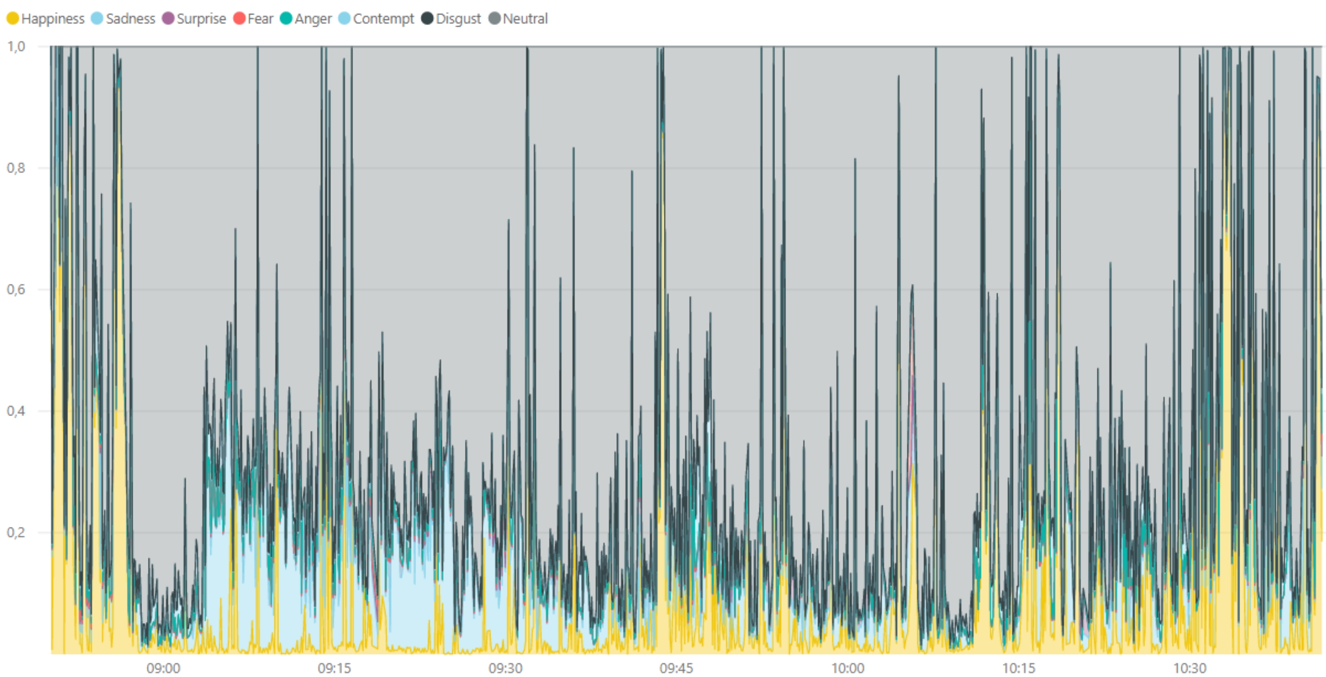

Figure 3.25: Example with the stacked area chart showing the logged emotions of one emotion recognition cap that was sent to the live dashboard.

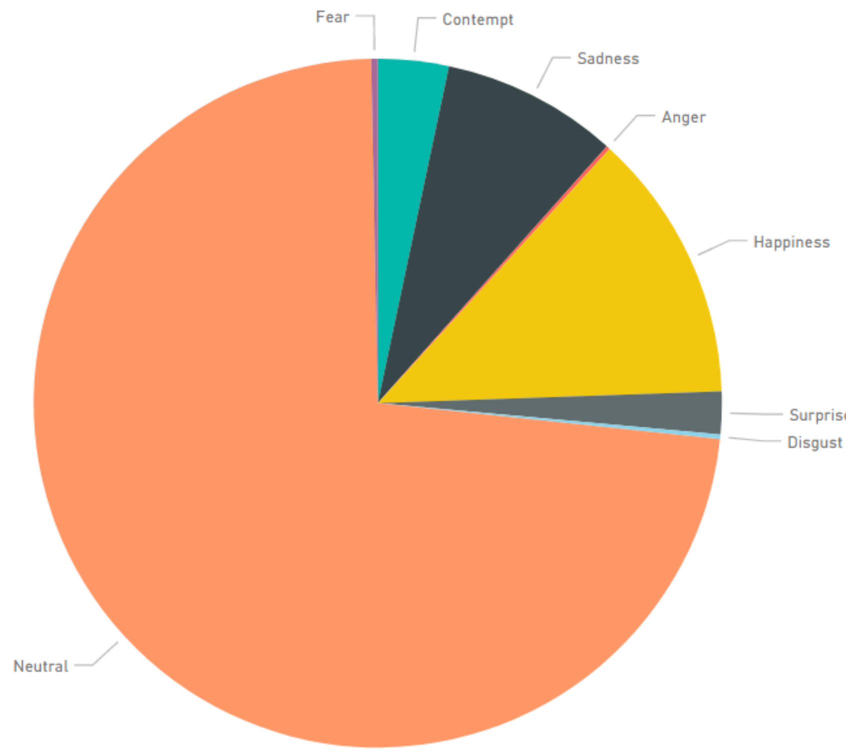

Figure 3.26: Example with a pie chart showing the weighted average of the logged emotions of one emotion recognition cap. The data was sent to the live dashboard during the same period as depicted figure 3.25.

There exist many ways of viewing and interpreting this dataset. One possibility would be to look for sudden changes in the emotions within a multi business model innovation session and then analyze the 360 degrees video for that specific time period with the aim of acquiring more knowledge about that specific event. Another possibility is to look at sudden changes in the environment data and compare such changes to change in the emotions in a multi business model innovation session during the same time period. At the same time, the 360 degrees video should be examined in the attempt to generate more knowledge about the role of the environment in a multi business model innovation session.

Yet another approach could be to look at the data with a pie chart like figure 3.26 showing the weighted average of the emotions within each multi business model innovation lab and see how the pie chart of the winning group compares to the other pie charts. As stated at the beginning, there are many ways of viewing and interpreting this dataset, however, the interpretation of the collected data is beyond the scope of this thesis which focuses on the novelty of laboratory measurement tools in multi business model innovation.

3.6 Summary

In the beginning of this chapter we have in figure 3.3 proposed the original engineering setup for the multi business model innovation lab, the proposed engineering setup was designed to be in compliance with the four rules:

Rule number 1, all the equipment that the participants needs to wear have to be completely wireless and run on batteries to ensure the participant freedom to interact.

Rule number 2, all of the equipment needs to be non-Invasive.

Rule number 3, if the equipment interferes with any of the senses of the participant, the value of the measurement should be carefully evaluated up against the level of interferes it creates.

Rule number 4, the actual measurement should give a relatively precise and meaningfully purpose related to understanding the BMI process and be carefully weighed against the resources, time and founding available for this research.

After the proposed original engineering setup, the development of the setup was started.

Firstly, we developed the setup for the following environment measurements, CO2, temperature, humidity and pressure, with the use of censors and one raspberry pi with node-red installed for each lab.

Secondly, we developed the setup for the following group measurement, the sound recording with the use of build in microphone on the PC in the lab and the 360-degree video from the RICOH THETA V camera.

Finally, we developed the setup for the personal measurement's, the insights® discovery personal profile, heart rate measurement with the H10 HR sensor and Bluetooth Low Energy, emotion recognition cap with the use of cap, raspberry pi zero w, battery, 3D printed mounting equipment and node-red.

Furthermore, we tested the original proposed and developed engineering setup at the Scandinavia Biogas Conference 2017 in three multi business model innovation labs simultaneously during three days with our own Wi-Fi network set-up based on Ubiquiti.

In the very end of this chapter, we checked the consistency of the data archived from the test with the original proposed and developed engineering setup, finally we conducted serval experimental experiment on ways of viewing the data with Microsoft Power BI Desktop.

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Chapter 4 - Engineering Setup Improvements

In this chapter we will make improvement to the engineering setup based on the experience from the laboratory experiments conducted at Scandinavia Biogas Conference 2017. After a brief introduction we start by improving the capability and stability of the group measurement with a new enhanced powering setup and a new recording and encoding software, afterwards we turn our focus to improvement of at laboratory personal measurements, here we improve the emotion recognition with a local implementation of a deep convolutional neural network set-up, finally we make a short summary of the achievements within this chapter.

4.1 Introduction

In chapter 3, the laboratory experiments conducted at Scandinavia Biogas Conference 2017 were described. In this chapter, based on our experience from the laboratory experiments, there will here be propose improvements to the laboratory measurement tools.

In the first section the focus will be on improving the process difficulties identified during the data gathering process. Those difficulties were also described in section 3.4 and concerned the 360-degree camera recording which was rather difficult to handle during the laboratory experiments at the conference due to power drain issues and to the large recorded files with the unstable and out-of-sync sound and the resulting need for extra sound recording

In the next section of this chapter the focus is turned to the laboratory personal measurements with special attention given to the emotion recognition cap improvements. Based on our experience from the laboratory experiments conducted at Scandinavia Biogas Conference 2017, improvements will be suggested to uses live streaming and to perform emotion recognition using an local algorithm, the first choice to be made was what approach should be used before a solutions could be designed, basically there are two approaches available, the categorical approach pioneered by Carl-Herman Hjortsjö with the FACS (Facial Action Coding System) with the emotions happiness, sadness, surprise, fear, anger, disgust, and contempt developed by a group of scientists led by Paul Ekman [63] or the Dimensional approach which assumes that the emotions exist on a spectrum and can’t be defined concretely. The choice made was to adopt the categorical approach which opens up for the possibility for design a solution with a convolutional neural networks set-up since convolutional neural networks can and are being used to conduct image classification [64].

4.2 Laboratory Group Measurements

In this section, our experience from the laboratory experiments conducted at Scandinavia Biogas Conference 2017 regarding the laboratory group measurement tools will be used to propose improvements to the group measurements tools. As described in section 3.4, we encountered some difficulties with the RICOH THETA V 360-degree video device during the recording process. The difficulties can basically be divided into two categories: one category concerns the power drain during the live recording streaming process; the other concerns the saving of the live stream into a file for later viewing where the separated sound and the large file size were making the process of reviewing the video unnecessary difficult and inefficient. The subsequent two sections will examine the issues outlined above and will propose related improvements to overcome the issues.

4.2.1 RICOH THETA V 360-Degree Video Device Removal of Power Drain Issue

The core issue in the power drain of the internal battery in the RICOH THETA V 360-degree video device is the reality that power consumption during live streaming was higher than the available 500mA on version USB 1.0 and 2.0 [65], and 900mA on USB 3. 0 [66]. To overcome this limitation, a new set-up in compliance with the USB Battery Charging 1.2 is proposed [67]. The proposed set-up includes one USB booster extender cable and the ICY BOX IB-HUB1405 USB hub [68] with all its four ports in compliance with the USB Battery Charging 1.2. In this way each port can deliver 5 V / 2.4 A which is more than the RICOH THETA V 360-degree video device consumes during live streaming. Thus, the limitation with the approximate maximum four hours of live streaming before recharging the internal battery in the RICOH THETA V 360 Degree Video device is eliminated, and live steaming can continue without interruptions caused by insufficient power capabilities. The entire set-up is shown in figure 4.1. The set-up was tested and was able to record for 15 hours, 33 minutes and 53 seconds without power loss on the internal battery in the RICOH THETA V and without the ensuing need to recharge the internal battery. The test was therefore stopped, since more than 15 hours of continuous recording meet the requirements of recording the multi business model innovation process. The file-size of 15 hours, 33 minutes and 53 seconds recording was around 18.7 Gigabytes which was also acceptable.

Figure 4.1: RICOH THETA V 360-degree video device with USB Battery Charging 1.2 Compliance IB-HUB1405 USB HUB.

4.2.1 Live Stream Recording Sound and File Size Issue

The core issue of live stream recording sound and file size can largely be attributed to the use of the Media Player Classic - Home Cinema software recommended in the User Guide of the RICOH THETA V [69]. Due to the issues experienced with live streaming, retrospectively that recommendation should not have been followed, and moreover the Media Player Classic - Home Cinema software is also officially announced as a dead open source product [70]. To overcome the issues and not to rely on an officially announced dead open source product, it is proposed to use the open broadcaster software studio [71] instead. When this program is used, the sound is stable and in synchronization with the video, and when encoding is used, the file size is considerably smaller. 30 min of 4K 360-degree video with at resolution of 3840x1920 and a framerate per second of 30 including sound is approximately 700 Megabyte when the video is encoded with H264 – MPEG-4 AVC (part 10) (avc1) codec and the sound is encoded with MPEG AAC Audio (mp4a). In comparison, 30 min of video at the first laboratory experiment at the Scandinavia Biogas Conference 2017 was at approximately 30 Gigabytes of size in unencode format without counting the separate sound recording. In figure 4.2 a screenshot is shown of test of the live capturing with the RICOH THETA V 360-degree video device set up with USB Battery Charging 1.2 Compliance IB-HUB1405 USB HUB and recording with open broadcaster software studio.

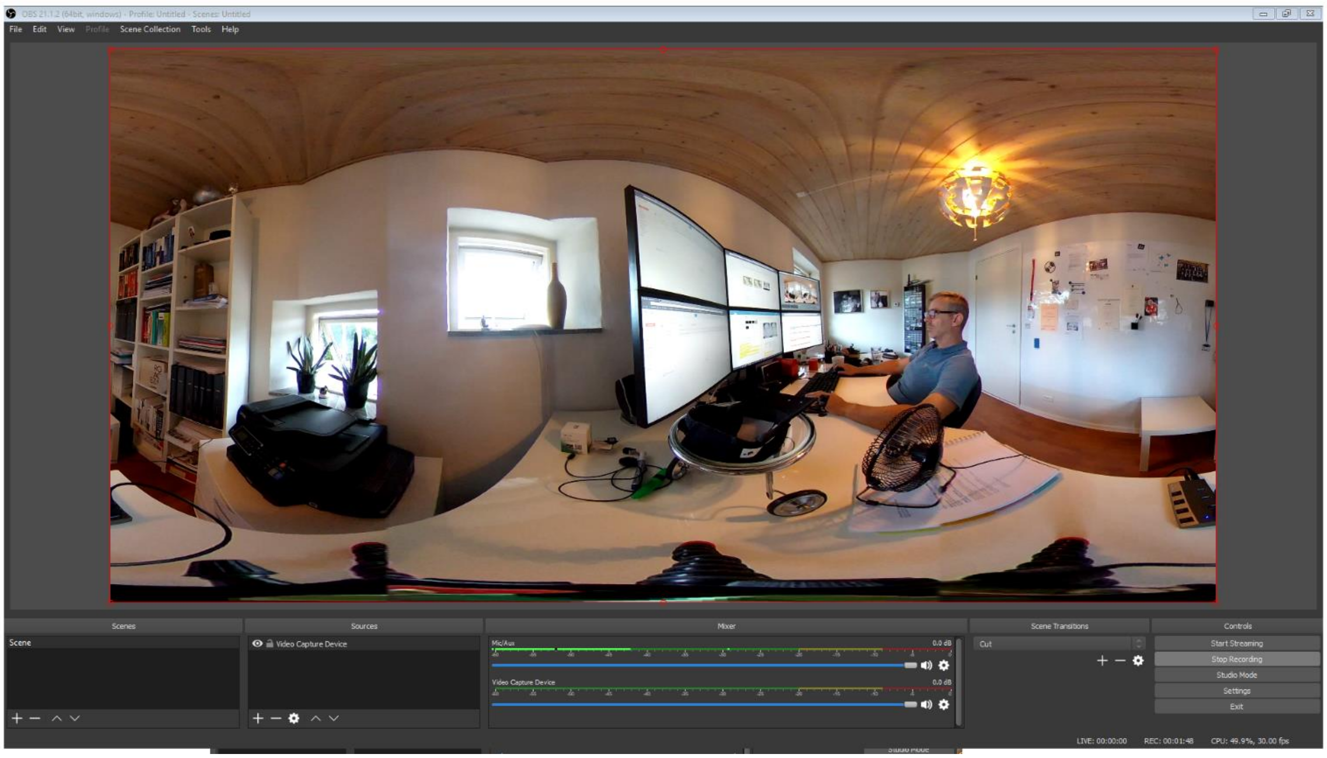

Figure 4.2: Screenshot of testing the live capturing with the RICOH THETA V 360-degree video device set up with USB Battery Charging 1.2 Compliance IB-HUB1405 USB HUB and recording with open broadcaster software studio.

4.3 Laboratory Personal Measurements

In this section, our experience with the experiments on the laboratory personal measurements tools conducted at Scandinavia Biogas Conference 2017 is used to propose improvement to the personal measurement's tools. As described in section 3.4 there were some difficulties during the internet breakdown at Scandinavia Biogas Conference 2017, the missing internet connection made it impossible to live monitor emotions transferred from the emotion recognition caps in the experiment's control lab monitor set-up. The main reason for this was our dependency on the Microsoft Azure Emotion API online service which requires internet access to be used. In the following two sections it will be explained how we change and optimize the emotion recognition cap to be independent of an internet connection.

4.3.1 Emotion Recognition Cap Improvements

In this section our knowledge gained from the laboratory experiments is used to improve the emotion recognition cap tool. Firstly, we want to change the way we capture images with the Raspberry Pi Zero W camera and move from raspistill for single image capturing to live streaming with User space Video4Linux (UV4L). The reason for this is that if we take 30 pictures per second with raspistill and if we have six participants for eight hours in one multi business model innovation session, we would have a total of (30x60x60x8x6) = 5.184.000 image files to handle instead of six 8-hour video files with 30 frames per second. Naturally, the last option is a more practically manageable one, and it is therefore decided to move from raspistill for single image capturing to live streaming with UV4L, this procedure is described in section 4.3.1.1. Secondly, we want to move away from our dependency on internet access and from the limitations imposed by the Microsoft Azure Emotion API online service by building and using an emotion recognition set-up by means of our own convolutional neural network. This procedure is described in section 4.3.1.2.

4.3.1.1 Move from raspistill for Single Image Capturing to Live Streaming with UV4L

In this section the change from raspistill for single image capturing to live streaming with UV4L will be describe. Our first task was to download a new updated image for the Raspberry Pi Zero W. The image downloaded this time is RASPBIAN STRETCH LITE, Minimal image based on Debian Stretch, Version: June 2018, Release date:2018-06-27, Kernel version:4.14. After installing the new image, we installed the User space Video4Linux projects UV4L core module and Streaming server [72]. Figure 4.3 shows the end result with the UV4L Streaming Server landing page and the UV4L Camera Control Panel installed and up and running on the Raspberry Pi Zero W.

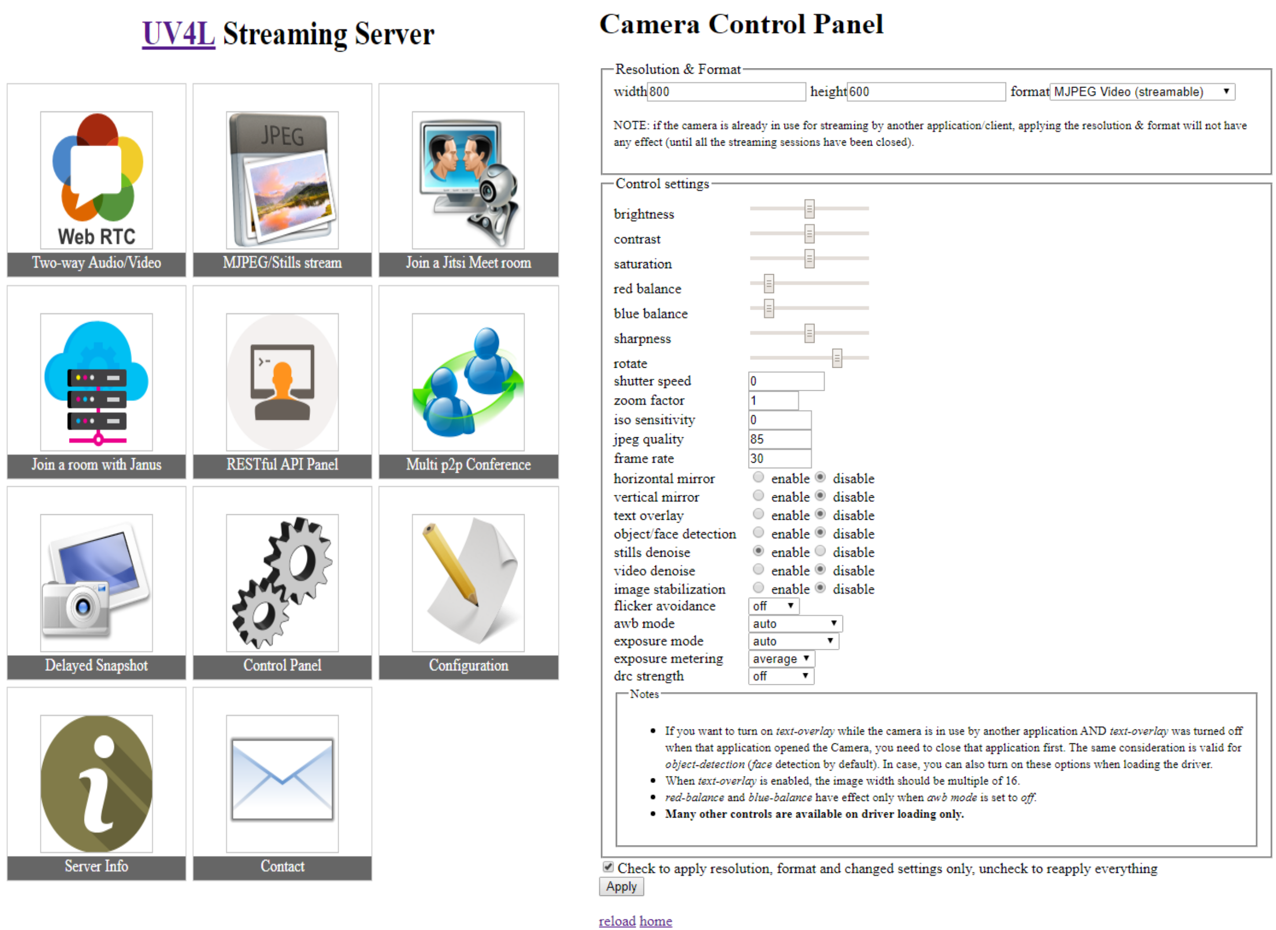

Figure 4.3: The UV4L Streaming Server landing page and the UV4L Camera Control Panel installed on the Raspberry Pi Zero W.

During the laboratory experiments at Scandinavia Biogas Conference 2017 the emotion recognition caps used the program rsync to transfer captured image files to the computer placed in the multi business model innovation labs. This is no longer necessary with the new engineering setup, since the stream can be captured by the computer as long as it is on the same network with the Ip's of the emotion recognition caps concatenated with the path "/stream/video.mjpeg". Another program that is also no longer necessary is jpegtran.exe. This program was used to rotate the image file on the computer. However, we no longer have any image files but instead a video stream, and therefore the jpegtran.exe is no longer useable. Nevertheless, we are actually still faced with the same issue: even though the UV4L Streaming Server has the possibility to rotate the video stream, it makes a simple rotate of the stream without preserving the dimensions. Therefore, we need to solve this in our code retrieving the stream. This is done at the beginning of the next section.

4.3.1.2 Emotion Recognition Using Own Convolutional Neural Network Set-up

In this section I will explain how we build a convolutional neural networks setup to conduct emotion recognition on the streams from our emotion recognition caps. The first step is to handle the rotation issue described in the previous section. However, before we are able to do that, we need to choose the program for retrieving the stream. The Open Source Computer Vision Library also called OpenCV is chosen because it is a free open source computer vision and machine learning software library [73] Having made the choice, we can now begin to overcome the first issue of rotating the video stream without losing any information. This problem was solved by Adrian Rosebrock in January 2017 when he described how to rotate images (correctly) with OpenCV and Python [51] by installing and importing his packages imutils. The images from the stream can be rotated with the function imutils.rotate_bound(image, angle). However, before we begin to make any code and build our convolutional neural networks to perform emotion recognition, there are a few more choices that need to be made. We need to choose the program langue and the tools used for the convolutional neural networks. The open source python is chosen due to its applicability for data science, machine learning, systems automation, web and API development etc. [74], since Google's open source machine learning and neural network library named TensorFlow version r1.5 is chosen. Google's open source machine learning and neural network library is more capable, more mature, and easier to learn and use [74]. Once the choices have been made, we can begin to create the program for retrieving the video stream and to make our own convolutional neural network to conduct emotion recognition on the received video stream. The convolutional neural network part of the engineering setup will build upon the work of Madalina Buzau [77] and will follow the same steps with minor changes such as using the video stream and rotating the video stream instead of using local webcam and using different values for displaying sample data and random seed value and num_epochs value. As data science UI it is decided to use JupyterLab due to its support of interactive data science and scientific computing [78]. In figure 4.4 an overview of the building of a Convolutional Neural Network (CNN) for emotion recognition with TensorFlow Eager adopted from Madalina Buzau [77] is shown. In table 4.1 the steeps we need to accomplish to build a Convolutional Neural Network (CNN) for emotion recognition with TensorFlow Eager are shown. The procedure is adopted from Madalina Buzau [77] with a few minor changes and with the addition of steps.

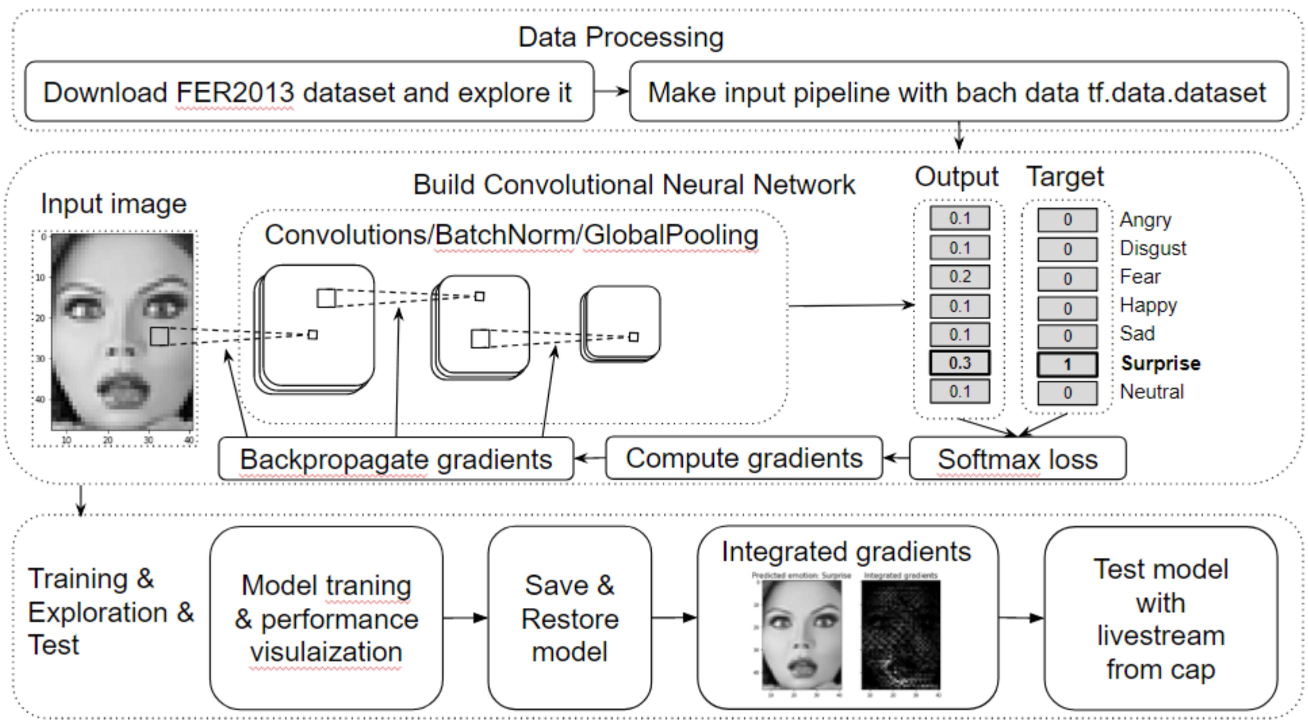

Figure 4.4: Overview of the building of a Convolutional Neural Network (CNN) for emotion recognition with TensorFlow Eager adopted from Madalina Buzau [77]

Step	Action to preform
1	Download and process the FER2013 dataset available on Kaggle
2	Exploratory data analysis on the entire dataset
3	Split the dataset into a train and dev dataset
4	Normalize images
5	Using the tf.data.Dataset API to iterate through train and dev dataset
6	Creating a class for a CNN in Eager mode
6.1	With ability to save the model or restore from a previous checkpoint
7	Create a loss function, an optimizer and a function to compute gradients
8	Train the model with gradient descent
8.1	Whether from scratch or start with a pre-trained model
9	Visualize the performance during training and compute the accuracy
10	Visualize the CNN attribution on sample images using Integrated Gradients
11	Retrieve the video stream from the camera on the Raspberry Pi Zero W using OpenCV
12	Rotate the video stream images without loss of data using OpenCV
13	Testing the CNN on video stream images using OpenCV and the Haar Cascades algorithm
14	Make final program for emotion recognition on the video stream

Table 4.1: Steps to build a Convolutional Neural Network (CNN) for emotion recognition with TensorFlow Eager adopted from Madalina Buzau [77] with some small changes and with the addition of steps.

The first step is to download the FER2013 dataset available on Kaggle [79] for training purpose. The picture in the dataset is 48x48 pixel 8 bit grayscale of faces more or less centered and occupies the same space within the image. The dataset consists of 35887 samples in total where each is labelled in one of the following seven categories: (0=Angry, 1=Disgust, 2=Fear, 3=Happy, 4=Sad, 5=Surprise, 6=Neutral). The dataset file is a csv file where the format and separators are “emotion, pixels, usage”. After downloading the dataset, we carry out the exploratory data analysis on the entire dataset to generate a better understanding of the data we will be using for training our model. Table 4.2 shows what the data looks like by listing the first ten rows of the FER2013 dataset showing the three columns *emotion*, *pixels* and *usage*: Table 4.3 shows a listing of the numbers of samples in each of the seven categories – happy, neutral, sad, fear, angry, surprise and disgust. As Madalina Buzau [77] also notices and mentions, the imbalance between the number of samples in each of the seven emotion categories will make it difficult for the network to learn the representation of the emotions with the smallest number of samples, and easier to learn the representation of the emotions with the highest number of samples. Therefore, we notice that the network has more opportunity to learn the emotion category *happy* with its 8989 samples than to learn the emotion category *disgust* with its 547 samples.

	emotion	pixels	Usage
0	0	70 80 82 72 58 58 60 63 54 58 60 48 89 115 121...	Training
1	0	151 150 147 155 148 133 111 140 170 174 182 15...	Training
2	2	231 212 156 164 174 138 161 173 182 200 106 38...	Training
3	4	24 32 36 30 32 23 19 20 30 41 21 22 32 34 21 1...	Training
4	6	4 0 0 0 0 0 0 0 0 0 0 0 3 15 23 28 48 50 58 84...	Training
5	2	55 55 55 55 55 54 60 68 54 85 151 163 170 179 ...	Training
6	4	20 17 19 21 25 38 42 42 46 54 56 62 63 66 82 1...	Training
7	3	77 78 79 79 78 75 60 55 47 48 58 73 77 79 57 5...	Training
8	3	85 84 90 121 101 102 133 153 153 169 177 189 1...	Training
9	2	255 254 255 254 254 179 122 107 95 124 149 150...	Training

Table 4.2: The first ten rows of the FER2013 dataset showing the three columns *emotion*, *pixels* and *usage*, where the image is represented in the pixel column as a string of integers that each represent one 8-bit pixel in the grayscale image.

	emotion	number of samples
0	Happy	8989
1	Neutral	6198
2	Sad	6077
3	Fear	5121
4	Angry	4953
5	Surprise	4002
6	Disgust	547

Table 4.3: Listing the numbers of samples in each of the seven categories *happy*, *neutral*, *sad*, *fear*, *angry*, *surprise* and *disgust*.

In figure 4.5 we look at ten randomly selected examples of the FER2013 dataset showing the image of the face and the corresponding emotion above. Here we can familiarize ourselves with the position of the face within each image. We notice that faces are placed within the frame with the nose in the center of the image. We also notice that the viewing angel is not always directly frontal but can also be from other viewing angels where the full face is not necessarily shown. This is particularly apparent in the first image.

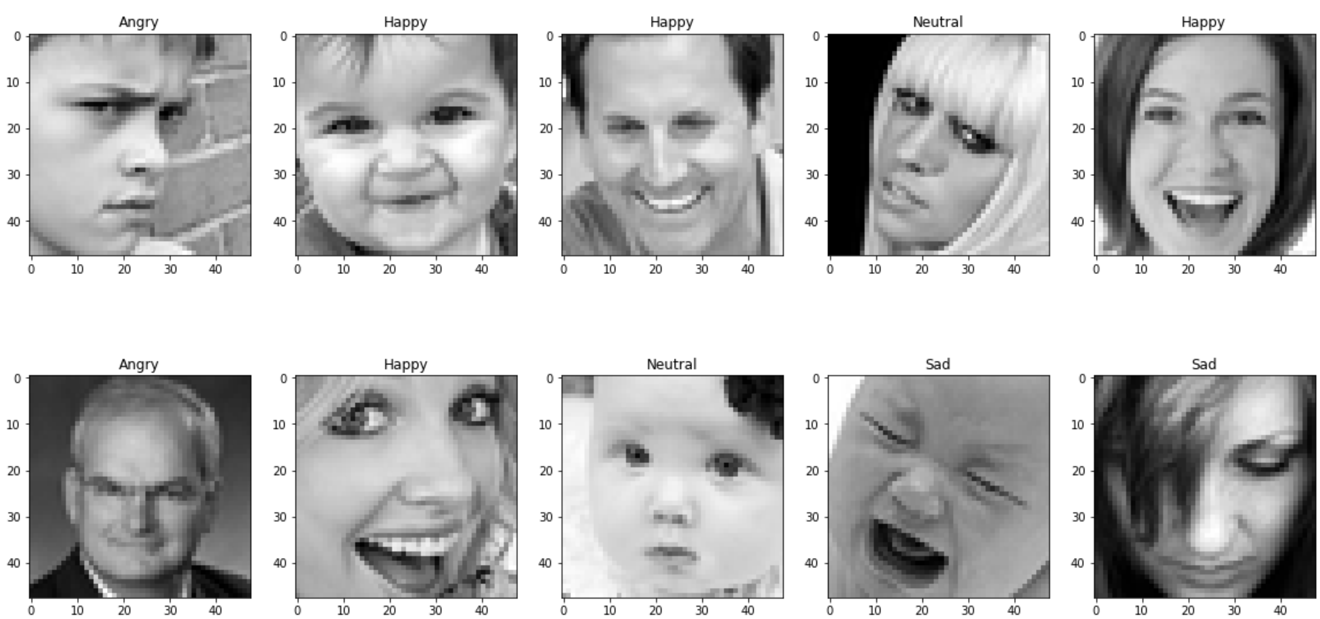

Figure 4.5: Ten randomly selected examples of the FER2013 dataset showing the image of the face and the corresponding emotion above.

After having performed an exploratory data analysis on the entire dataset, we split the dataset into a training dataset and a development dataset. The number of samples in the training dataset is 28709 whereas the number of samples in the development dataset is 7178. After splitting the dataset, we then normalize the image with the maximum pixel intensity of 255 and use the tf.data.Dataset API to prepare our dataset to our network. We begin creating our class for a CNN in Eager mode with the ability to save the model or to restore it from a previous checkpoint. For this purpose, we reuse the class EmotionRecognitionCNN, the loss function, optimizer and a function to compute gradients by Madalina Buzau [77] with its original architecture of the convolutional neural network inspired from Octavio Arriaga et al [80] since we would like to reuse the already trained model from Madalina Buzau [77] instead of having to train our own from scratch. The pretrained model has been pretrained with 35 epochs. The training loss and evaluation/development loss during the process of pertaining are shown in figure 36 with a graph of the model performance during the pretraining with number of epochs as the x-axis and loss as the y-axis and with the two lines showing the train loss and the eval/dev loss during the 35 epochs by Madalina Buzau [77].

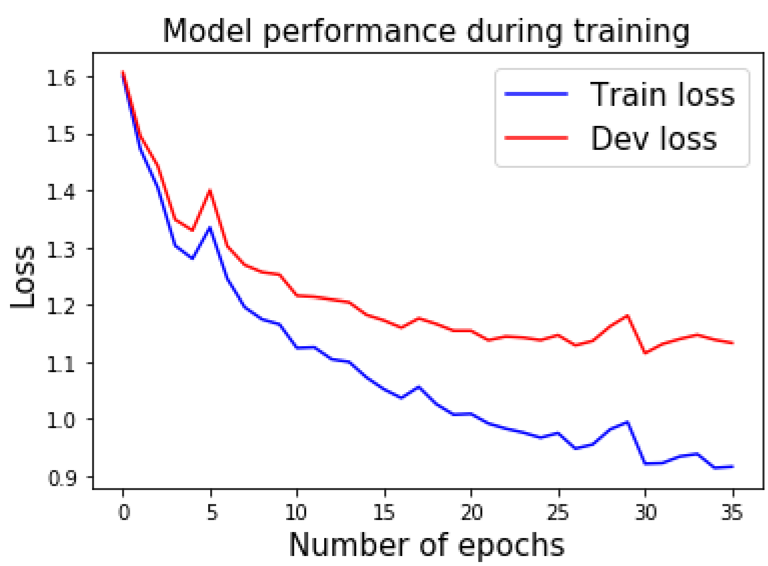

Figure 4.6: Graph of the model performance during the pretraining with number of epochs as the x-axis and loss as the y-axis with the two lines showing the train loss and the eval/dev loss during the 35 epochs by Madalina Buzau [77].

We load the pretrained model and conduct additional ten epochs. In figure 4.7 you will see the graph of the model performance during the training with number of epochs as the x-axis and loss as the y-axis with the two lines showing the train loss and the eval/dev loss during the additional ten epochs on the pretrained model.

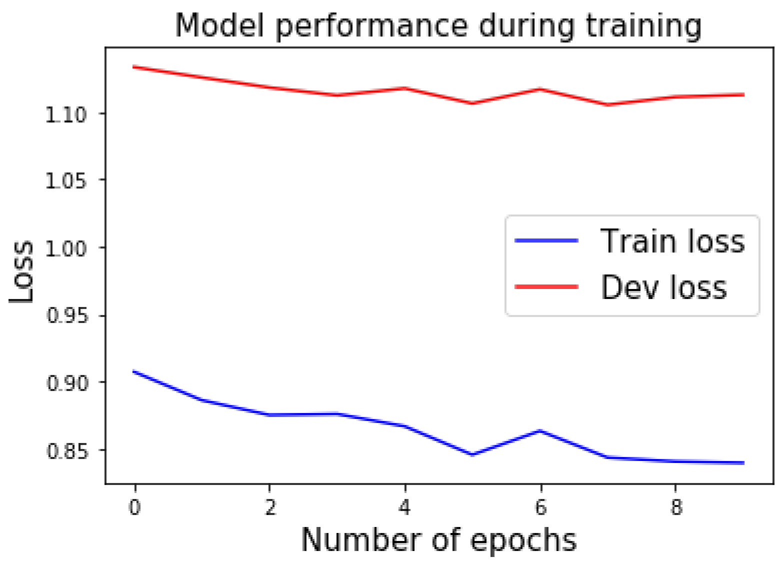

Figure 4.7: Graph of the model performance during the training with number of epochs as the x-axis and loss as the y-axis and with the two lines showing the train loss and the eval/dev loss during the additional ten epochs on the pretrained model.

In step nine we compute the accuracy of the ten epochs extra pretrained model, the resulting training accuracy and evaluation accuracy are shown in table 4.4.

Train accuracy	0.688251071093
Eval accuracy	0.583031485093

Table 4.4: Listing the resulting training accuracy and evaluation accuracy from computing the accuracy of the ten epochs extra pretrained model.

In table 4.4 we notice that training accuracy is higher that evaluation accuracy. By definition this means that we have an overfit model which results in pure performance on data other than our training set, which means the model are good at predicting on our test dataset but not on other real live data. Looking at table 4.5 with the resulting training accuracy and evaluation accuracy from computing the accuracy of the pretrained model without the additional ten epochs, we decide to go back to the pretrained model without the additional ten epochs in our final version with capturing of video stream since that model is less overfit.

Training accuracy	0.66153471037
Evaluation accuracy	0.572861521315

Table 4.5: Listing the resulting training accuracy and evaluation accuracy from computing the accuracy of the pretrained model without the additional ten epochs.

Now in step ten we will visualize the convolutional neural network attribution on sample images using integrated gradients where the most influence on the predicted label is shown with the brightest parts. An image with its predicted emotions together with its corresponding integrated gradients image for each of the seven emotions is show from figure 4.8 to figure 4.14 The integrated gradients are an attempt to understand the reasoning for the prediction by the convolutional neural network [81].

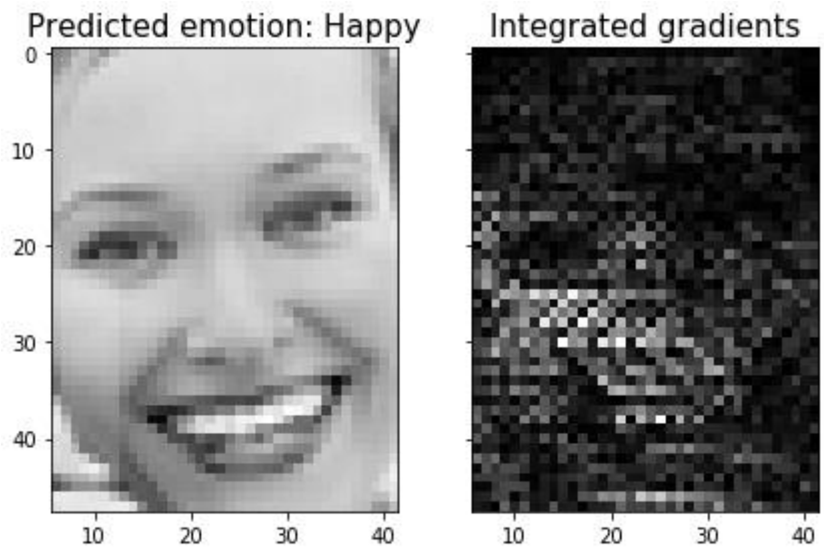

Figure 4.8: Image with the predicted emotion *happy* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

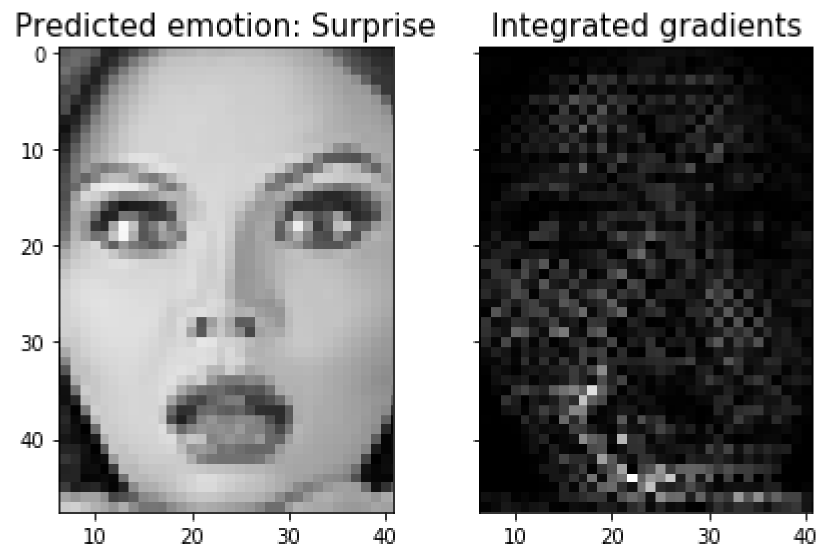

Figure 4.9: Image with the predicted emotion *surprise* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

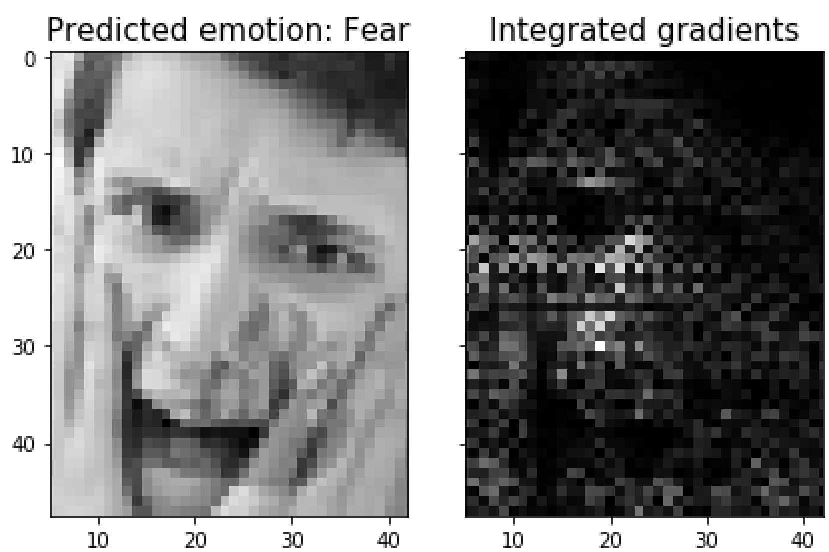

Figure 4.10: Image with the predicted emotion *fear* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

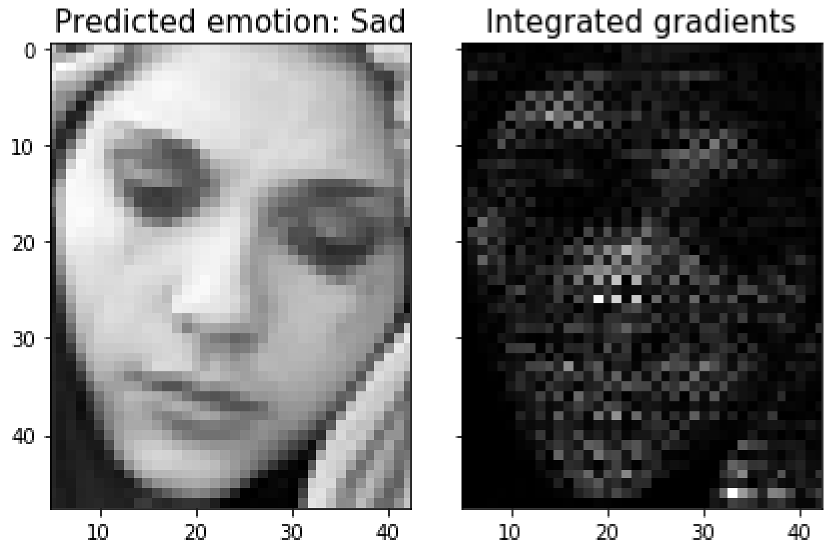

Figure 4.11: Image with the predicted emotion *sad* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

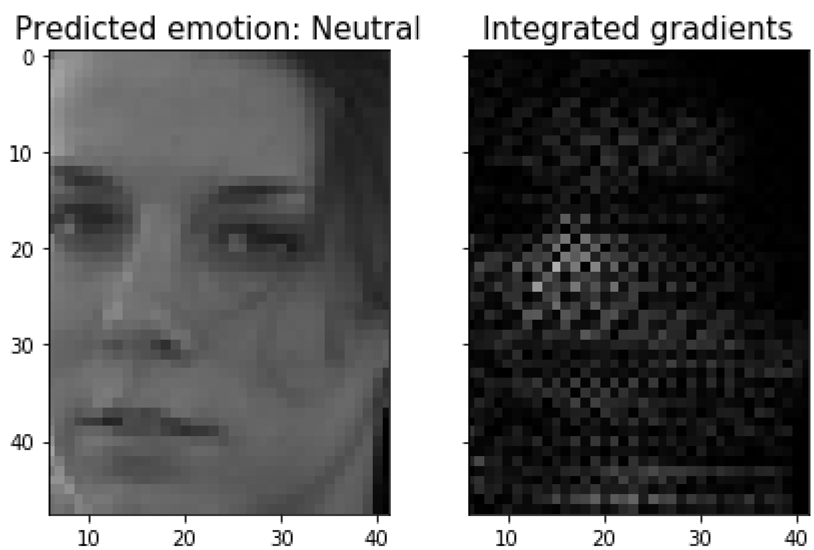

Figure 4.12: Image with the predicted emotion *neutral* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

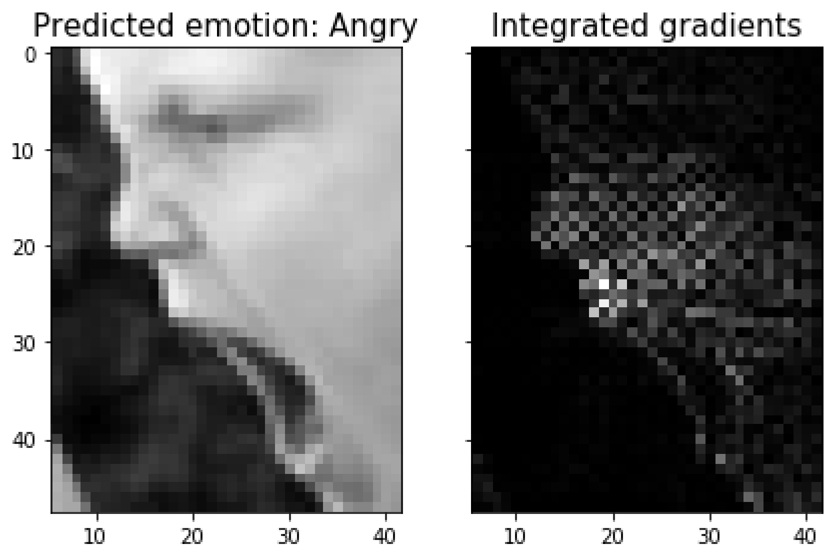

Figure 4.13 Image with the predicted emotion *angry* compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

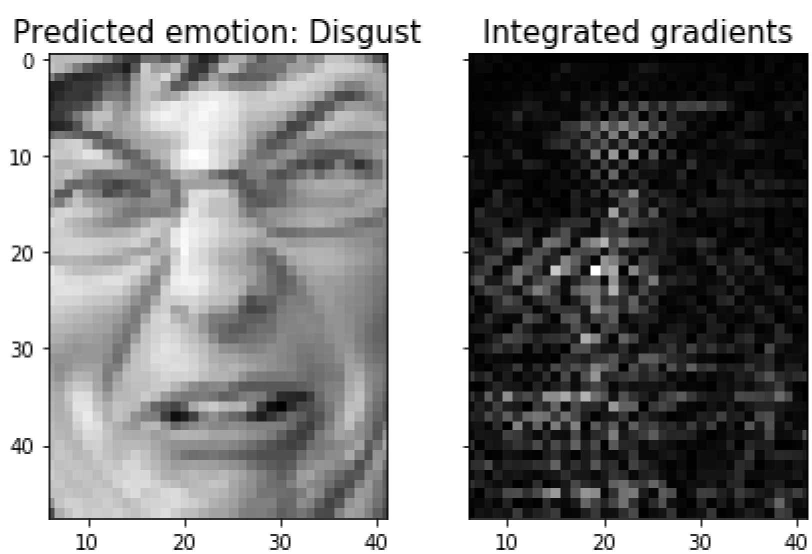

Figure 4.14: Image with the predicted emotion disgust compared with the integrated gradients image where the most influence on the predicted label is shown with the brightest parts.

In step 11 we retrieve the video stream from the camera on the Raspberry Pi Zero W using OpenCV with the command “cap = cv2.VideoCapture('http://**192.168.1.173**:8080 /stream/video.mjpeg')“ where the bold part is the IP of the emotion recognition cap. The settings on the UV4L Streaming server on the Raspberry Pi Zero W is set to the resolution of 640×480. At this resolution the hardware is able to do 90 frames per second, however the UV4L Streaming server is set up to ten frames per second because we do not wish to overload the convolutional neural network and because measuring the emotions ten times every second seems sufficient. In step 12 we rotate the video stream images without loss of data using OpenCV. This is done with the packages imutils by Adrian Rosebrock [51], and the images are simply rotated with the function imutils.rotate_bound(image, angle). In step 13 we test the convolutional neural network on video stream images using OpenCV and the Haar Cascades algorithm. Sample images of the results of the tests are shown in figure 4.15.

Figure 4.15: Images of the results of the test of the convolutional neural network on the video stream images using OpenCV and the Haar Cascades algorithm.

In the step 14 we make the final program for emotion recognition on the video stream. The entire program is shown in figure 4.16. The program was originally made by Madalina Buzau in her work," Building a Convolutional Neural Network (CNN) for emotion recognition with TensorFlow Eager. "[77] but have been modified it to satisfy the need of the emotion recognition cap.

```
# Import libraries for data visualization and processing
import matplotlib.pyplot as plt
import pandas as pd
import numpy as np
import imutils
import time
import cv2
import datetime

# Import TensorFlow and TensorFlow Eager
import tensorflow as tf
import tensorflow.contrib.eager as tfe

# Enable eager mode. Once activated it cannot be reversed! Run just once.
tfe.enable_eager_execution()

# Get the meaning of each emotion index
emotion_cat = {0:'Angry', 1:'Disgust', 2:'Fear', 3:'Happy', 4:'Sad', 5:'Surprise',
6:'Neutral'}

class EmotionRecognitionCNN(tf.keras.Model):

    def __init__(self, num_classes, device='cpu:0', checkpoint_directory=None):
        ''' Define the parameterized layers used during forward-pass, the device
            where you would like to run the computation on and the checkpoint
            directory.

            Args:
                num_classes: the number of labels in the network.
                device: string, 'cpu:n' or 'gpu:n' (n can vary). Default, 'cpu:0'.
                checkpoint_directory: the directory where you would like to save or
                                      restore a model.
        '''
        super(EmotionRecognitionCNN, self).__init__()

        # Initialize layers
        self.conv1 = tf.layers.Conv2D(16, 5, padding='same', activation=None)
        self.batch1 = tf.layers.BatchNormalization()
```

```
        self.conv2 = tf.layers.Conv2D(16, 5, 2, padding='same', activation=None)
        self.batch2 = tf.layers.BatchNormalization()
        self.conv3 = tf.layers.Conv2D(32, 5, padding='same', activation=None)
        self.batch3 = tf.layers.BatchNormalization()
        self.conv4 = tf.layers.Conv2D(32, 5, 2, padding='same', activation=None)
        self.batch4 = tf.layers.BatchNormalization()
        self.conv5 = tf.layers.Conv2D(64, 3, padding='same', activation=None)
        self.batch5 = tf.layers.BatchNormalization()
        self.conv6 = tf.layers.Conv2D(64, 3, 2, padding='same', activation=None)
        self.batch6 = tf.layers.BatchNormalization()
        self.conv7 = tf.layers.Conv2D(64, 1, padding='same', activation=None)
        self.batch7 = tf.layers.BatchNormalization()
        self.conv8 = tf.layers.Conv2D(128, 3, 2, padding='same', activation=None)
        self.batch8 = tf.keras.layers.BatchNormalization()
        self.conv9 = tf.layers.Conv2D(256, 1, padding='same', activation=None)
        self.batch9 = tf.keras.layers.BatchNormalization()
        self.conv10 = tf.layers.Conv2D(128, 3, 2, padding='same', activation=None)
        self.conv11 = tf.layers.Conv2D(256, 1, padding='same', activation=None)
        self.batch11 = tf.layers.BatchNormalization()
        self.conv12 = tf.layers.Conv2D(num_classes, 3, 2, padding='same',
activation=None)

        # Define the device
        self.device = device

        # Define the checkpoint directory
        self.checkpoint_directory = checkpoint_directory

    def predict(self, images, training):
        """ Predicts the probability of each class, based on the input sample.

            Args:
                images: 4D tensor. Either an image or a batch of images.
                training: Boolean. Either the network is predicting in
                          training mode or not.
        """
        x = self.conv1(images)
        x = self.batch1(x, training=training)
        x = self.conv2(x)
        x = self.batch2(x, training=training)
        x = tf.nn.relu(x)
        x = tf.layers.dropout(x, rate=0.4, training=training)
        x = self.conv3(x)
```

```
        x = self.batch3(x, training=training)
        x = self.conv4(x)
        x = self.batch4(x, training=training)
        x = tf.nn.relu(x)
        x = tf.layers.dropout(x, rate=0.3, training=training)
        x = self.conv5(x)
        x = self.batch5(x, training=training)
        x = self.conv6(x)
        x = self.batch6(x, training=training)
        x = tf.nn.relu(x)
        x = tf.layers.dropout(x, rate=0.3, training=training)
        x = self.conv7(x)
        x = self.batch7(x, training=training)
        x = self.conv8(x)
        x = self.batch8(x, training=training)
        x = tf.nn.relu(x)
        x = tf.layers.dropout(x, rate=0.3, training=training)
        x = self.conv9(x)
        x = self.batch9(x, training=training)
        x = self.conv10(x)
        x = self.conv11(x)
        x = self.batch11(x, training=training)
        x = self.conv12(x)
        return tf.layers.flatten(x)

    def loss_fn(self, images, target, training):
        """ Defines the loss function used during
            training.
        """
        preds = self.predict(images, training)
        loss = tf.losses.sparse_softmax_cross_entropy(labels=target, logits=preds)
        return loss

    def grads_fn(self, images, target, training):
        """ Dynamically computes the gradients of the loss value
            with respect to the parameters of the model, in each
            forward pass.
        """
        with tfe.GradientTape() as tape:
            loss = self.loss_fn(images, target, training)
        return tape.gradient(loss, self.variables)

    def restore_model(self):
```

```
        """ Function to restore trained model.
        """
        with tf.device(self.device):
            # Run the model once to initialize variables
            dummy_input = tf.constant(tf.zeros((1,48,48,1)))
            dummy_pred = self.predict(dummy_input, training=False)
            # Restore the variables of the model
            saver = tfe.Saver(self.variables)
            saver.restore(tf.train.latest_checkpoint
                          (self.checkpoint_directory))

    def save_model(self, global_step=0):
        """ Function to save trained model.
        """
        tfe.Saver(self.variables).save(self.checkpoint_directory,
                                       global_step=global_step)

    def compute_accuracy(self, input_data):
        """ Compute the accuracy on the input data.
        """
        with tf.device(self.device):
            acc = tfe.metrics.Accuracy()
            for images, targets in tfe.Iterator(input_data):
                # Predict the probability of each class
                logits = self.predict(images, training=False)
                # Select the class with the highest probability
                preds = tf.argmax(logits, axis=1)
                # Compute the accuracy
                acc(tf.reshape(targets, [-1,]), preds)
        return acc

    def fit(self, training_data, eval_data, optimizer, num_epochs=500,
            early_stopping_rounds=10, verbose=10, train_from_scratch=False):
        """ Function to train the model, using the selected optimizer and
            for the desired number of epochs. You can either train from scratch
            or load the latest model trained. Early stopping is used in order to
            mitigate the risk of overfitting the network.

            Args:
                training_data: the data you would like to train the model on.
                                Must be in the tf.data.Dataset format.
                eval_data: the data you would like to evaluate the model on.
                            Must be in the tf.data.Dataset format.
```

```
            optimizer: the optimizer used during training.
            num_epochs: the maximum number of iterations you would like to
                        train the model.
            early_stopping_rounds: stop training if the loss on the eval
                                   dataset does not decrease after n epochs.
            verbose: int. Specify how often to print the loss value of the
network.
            train_from_scratch: boolean. Whether to initialize variables of the
                                the last trained model or initialize them
                                randomly.
        """

        if train_from_scratch==False:
            self.restore_model()

        # Initialize best loss. This variable will store the lowest loss on the
        # eval dataset.
        best_loss = 999

        # Initialize classes to update the mean loss of train and eval
        train_loss = tfe.metrics.Mean('train_loss')
        eval_loss = tfe.metrics.Mean('eval_loss')

        # Initialize dictionary to store the loss history
        self.history = {}
        self.history['train_loss'] = []
        self.history['eval_loss'] = []

        # Begin training
        with tf.device(self.device):
            for i in range(num_epochs):
                # Training with gradient descent
                for images, target in tfe.Iterator(training_data):
                    grads = self.grads_fn(images, target, True)
                    optimizer.apply_gradients(zip(grads, self.variables))

                # Compute the loss on the training data after one epoch
                for images, target in tfe.Iterator(training_data):
                    loss = self.loss_fn(images, target, False)
                    train_loss(loss)
                self.history['train_loss'].append(train_loss.result().numpy())
                # Reset metrics
                train_loss.init_variables()
```

```
                # Compute the loss on the eval data after one epoch
                for images, target in tfe.Iterator(eval_data):
                    loss = self.loss_fn(images, target, False)
                    eval_loss(loss)
                self.history['eval_loss'].append(eval_loss.result().numpy())
                # Reset metrics
                eval_loss.init_variables()

                # Print train and eval losses
                if (i==0) | ((i+1)%verbose==0):
                    print('Train loss at epoch %d: ' %(i+1),
self.history['train_loss'][-1])
                    print('Eval loss at epoch %d: ' %(i+1),
self.history['eval_loss'][-1])

                # Check for early stopping
                if self.history['eval_loss'][-1]<best_loss:
                    best_loss = self.history['eval_loss'][-1]
                    count = early_stopping_rounds
                else:
                    count -= 1
                if count==0:
                    break

# The path to restore the trained variables.
checkpoint_directory = 'models_checkpoints/EmotionCNN/'

# Use the GPU if available.
device = 'gpu:0' if tfe.num_gpus()>0 else 'cpu:0'

# Instantiate model. This doesn't initialize the variables yet.
model = EmotionRecognitionCNN(num_classes=7, device=device,
                              checkpoint_directory=checkpoint_directory)

# Restore model
model.restore_model()

# Create font for adding text to images
font = cv2.FONT_HERSHEY_SIMPLEX

# Import pre-trained Haar-Cascade algorithm for face detection
```

```
face_cascade = cv2.CascadeClassifier("C:\\opencv-
3.3.0\\data\\haarcascades\\haarcascade_frontalface_default.xml")

# Open video capture with stream form raspberry pi zerro w
cap = cv2.VideoCapture('http://192.168.137.198:8080/stream/video.mjpeg')
#cap = cv2.VideoCapture('C:\\Users\\au583446\\PhD\\cnn\\1540823810.7452276.mp4')

frame_width = int(cap.get(3))
frame_height = int(cap.get(4))
out = cv2.VideoWriter(str(time.time()) + '.mp4',0x00000021, 10, (frame_height,
frame_width))

mostRecentFaces = None
idx = 0
f = open("LogEmotions.txt", "a")
while(True):
    # Capture frame-by-frame
    ret, frame = cap.read()
    frame = imutils.rotate_bound(frame, 270)
    # Transfrom RGB frame to gray scale
    gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)

    if idx > 10:
        mostRecentFaces = None

    if mostRecentFaces is None or idx > 9:
        # Detect all the faces in the frame
        faces = face_cascade.detectMultiScale(gray, 1.3, 5)
        if len(faces) == 0:
            idx = idx + 1
            if(mostRecentFaces is None):
                mostRecentFaces = faces
        else:
            mostRecentFaces = faces
            idx = 0
    else:
        idx = idx + 1

    # Iterate through each face found (should only be one)
    for (x,y,w,h) in mostRecentFaces:
        # Crop the face from the grayscale frame
        face_gray = gray[y:y+h, x:x+w]
        # Resize images to 48x48 pixels
```

```
        face_res = cv2.resize(face_gray, (48,48))
        face_res = face_res.reshape(1,48,48,1)
        # Normalize image by max
        face_norm = face_res/255.0
        # Forward-pass through the model
        with tf.device(device):
            X = tf.constant(face_norm)
            X = tf.cast(X, tf.float32)
            logits = model.predict(X, False)
            probs = tf.nn.softmax(logits)
            ordered_classes = np.argsort(probs[0])[::-1]
            ordered_probs = np.sort(probs[0])[::-1]
            k = 320
            y = 0
            logEntry =  '{"timestamp":"' + str(datetime.datetime.now()) + '"'
            # Draw the probabilities for each prediction, on the frame
            for cl, prob in zip(ordered_classes, ordered_probs):
                logEntry += ', "' + emotion_cat[cl] + '":' + str(prob)
                # Add rectangle with width proportional to its probability
                cv2.rectangle(frame, (20+y,100+k),(170+y,130+k),(255,255,255),-1)
                cv2.rectangle(frame,
(20+y,100+k),(20+int(prob*150)+y,130+k),(170,145,82),-1)
                # Add the emotion label to the rectangle drawn

cv2.putText(frame,emotion_cat[cl],(20+y,120+k),font,1,(0,0,0),1,cv2.LINE_AA)
                k += 40
                if k > 479:
                    k = 320
                    y = 200
            logEntry += '}\n'
            f.write(logEntry)
    out.write(frame)

    # Display the resulting frame
    cv2.imshow('frame',frame)
    if cv2.waitKey(1) & 0xFF == ord('q'):
        break

# When everything is done, release the capture
cap.release()
out.release()
cv2.destroyAllWindows()
```

Figure.: 4.16 TensorFlow source code in python of the convolutional neural network.

4.4 Summary

In this chapter we have taken the experience from the conducted laboratory experiments at Scandinavia Biogas Conference 2017 and used it to propose, develop and laboratory test improvement to the original proposed engineering setup. After a small introduction we started with the removal of the power drain issue on the ricoh theta v 360-degree video hardware, in the original proposed setup the maximum time of recording was limited to approximately 4 hours due to power drain within the device during recording, after introducing a USB battery charging 1.2 compatible hub into the engineering setup, this limitation was removed, the new engineering setup was tested recording in 15 hours, 33 minutes and 53 seconds and considered solved afterwards. Another improvement achieved in the beginning of this chapter was the shrinking of video file size (from approximately 30 GB to 700 MB for 30 minutes recording) with embedded in sync sound, this was achieved with open broadcaster software studio and encoding. Next, we made improvements to the emotion recognition cap.

Firstly, we changed from single image capturing and saving for emotion detection to live streaming with UV4L, by making this change we reduced the number of files needed to be archived drastically, as an example, if we take 30 pictures per second and if we have six participants for eight hours, we would have a total of (30x60x60x8x6) = 5.184.000 image files to handle instead of six 8-hour video files with 30 frames per second. This change makes it more practically during the data gathering and backup process, since we now only need to handle one file instead of over 5 million files.

Secondly, we changed from doing emotion recognition with the Microsoft azure emotion API online service to using our own local installed convolutional neural network set-up. The originally proposed emotion recognition cap was dependent on the Microsoft azure emotion API online service to do emotion recognition, this has been proved as a weakness due to its dependency on an internet connection, the local installed convolutional neural network set-up was built with TensorFlow, OpenCV and JupyterLab in the programming langue Python. Furthermore, the model was trained with the FER2013 dataset available on Kaggle, finally the development for retrieving the video stream from the emotion recognition cap was made together with some small optimization, in the end, we achieved our goal to remove the dependency on an internet connection from the original proposed engineering setup.

Chapter 5 – Valter's Seven Forces

The overall theme of this thesis is the investigation of the increasing problem of continuously staying competitive and relevant in today's business environments. While being subjected to increasing influence by new competing business models and ever-increasing technological possibilities, both business and managers are faced with this overall theme that has been puzzling researchers as well. The trend is unlikely to change in the near future, in fact, it is likely to continue at an even faster pace. Therefore, a successfully embedded continuous multi business model innovation process within a business would without any doubt increase the likelihood of success for that business. Thus, an improved understanding and measuring tools of the multi business model innovation process itself is of the utmost importance.

Firstly, this thesis focused on improving our understanding of the relationship between the business reality, business models, digitalization and humans. In chapter 2, the proposed digital multi business model innovation conceptual model assumes that after serval iterations businesses, technologies and humans will eventually have to develop new and persuasive business models. Today the supporting tools and environments for developing new and persuasive business models are limited and are in addition non-digital of nature. The proposed conceptual model is a first attempt to create a conceptualized overview of the knowledge, insight and possibilities that lie within the digitalization of the business model concept. During the perusal of optimal digital BM, this first attempt at a conceptual model is proposed. The conceptual model has four key sections:

- Human Intermediary Business Model Interaction
- Machine Intermediary Business Model Interaction
- Business Models patterns analysis with Artificial Intelligence and Deep Learning
- Business Model Ecosystem Interrelated Business Model Interaction

At the first section "Human Intermediary Business Model Interaction", we have identified firstly the four-different archetypes which describe the human as an intermediary between the business reality and the business model. Secondly, we look at the Interaction archetypes patterns:

- The Physical World
- Augmented Reality
- Virtual Reality

which describe the interaction archetype patterns between the human and the business model. At the second section "Machine Intermediary Business Model Interaction", we have the four different archetypes which describe the machine as an intermediary between the business reality and the business model. Next, we look at the interaction archetypes patterns:

- Internet of Things Sensing
- Internet of Things Applying
- Robotics & Drones

which describe the interaction archetypes patterns between the machine and the business reality.

At the third section "Business Models patterns analysis with Artificial Intelligence and Deep Learning", we look only at the three interaction archetype patterns:

- Artificial Intelligence on Business Models and Ecosystems
- Artificial Intelligence to Human Intermediary
- Artificial Intelligence to Machine Intermediary

which describe the interaction archetype patterns between artificial intelligence and the business model; human intermediary and machine intermediary. Nevertheless, we fully recognize that further research could possibly extend this model with different archetypes of artificial intelligence for business model innovation and generation.

Finally, at the last section "Business Model Ecosystem Interrelated Business Model Interaction" we look only at the business model ecosystem interrelated business model relationship archetypes:

- Interrelated Business Model Relationships
- Shared Business Model Values
- Business Models Hierarchy Structures

which describe the relationship between the business models and business model ecosystems. In this instance, we also fully recognize that further research would have the possibility to extend this model with different interrelated interactions archetypes between business models and business model ecosystems.

Secondly, this thesis has developed and proposed the engineering set-up in chapter 3 to measure the multi business model innovation processes. The proposed engineering set-up is capable of measuring many factors of the BMI process such as environmental factors, individual factors and group factors. The environmental factors are defined and measured as CO_2 level approximately every second, temperature approximately every second, humidity approximately every second and finally pressure approximately every second. The group factors are defined and measured as 360-degree camera live streaming and live sound recording. The individual factors are defined and measured as personal profile with Insights® Discovery, emotion detection with the developed emotion recognition cap and heart rate of the participants with the H10 sensor.

Thirdly, the proposed engineering set-up in this thesis has been empirically tested at the Biogas2020 event in Skive (Denmark) 6-9 November 2017 where three multi business model innovation challenges were posed. The participants worked with the challenges for three days in the multi business model innovation challenges lab equip with the developed and original proposed engineering set-up. The empirical test was successfully conducted, and the measurements were collected in a consistent and reliable manner.

Fourthly, based on the empirical test of the original proposed engineering set-up at the Scandinavia Biogas Conference 2017 a new improved engineering set-up is proposed and lab tested. As an example, the emotion recognition process has been moved from a cloud service provider to a locally built service.

Based on the experience from the above activities, the conceptual model “Valter’s Seven Forces” shown in figure 5.1, has been developed with the aim of analyzing the BMI process.

The seven forces in the conceptual model affect the probability for success of an innovation process. The effect from the forces can be either positive or negative depending on the situation. For instance, if the group dynamics hold conflicts and interpersonal power battles, the probability for the success of the innovation process is affected negatively. However, if the group dynamics are characterized by respect, collaboration and harmony, the probability for the success of the innovation process is affected positively. Each of the forces in the model are explained in the following:

5.1 Environment and tools force

The environment and tools available in the BMI process set the foundation for the BMI process. Whereas environment is seen as the surroundings of the BMI process, tools available are seen as the tools that the participants have access to during the BMI process to facilitate the process itself. As an example, by giving the participants access to tools like the Bee Board and the Bee Star at the Scandinavia Biogas Conference 2017 the participants have a common and shared reference point that not only facilitate the MBMI process itself, but also facilitate an alignment of the participant in terms of the MBM (Multi Business Model) language used and thereby limiting the potential misunderstandings and their corresponding conflicts. Therefore, the MBMI process itself at the Scandinavia Biogas Conference 2017 has been positively affected with the infusion of the Bee Board and the Bee Star tools into the MBMI process.

5.2 Coach force

The ability of the coach to facilitate the BMI process affects the performance of the BMI process. A well prepared and supporting, knowable, educated coach will exert a positive influence on the BMI process. As an example, by having a coach educated in the tools like the Bee Board and the Bee Star and the MBMI process itself, the coach would be able to facilitate and instruct the participant about the correct usage of tools and share the understanding of the MBMI process with the participant, this ensures the focus of the participant are directed towards the MBMI process and not caught up in discussions about the tools or the understanding of the MBMI process itself. Therefore, having a well-educated coach in the tools and the MBMI process itself would positively affect the likelihood of a successfully MBMI process.

5.3 Group force

The group force is seen as all the group dynamics, conflicts, alignment, synergy etc. that happen naturally with any group formation. As an example, if you have a group of participants that quickly reach the performing stage in Tuckman's model of stages of group development [82], this would have a positive effect the MBMI process and the probability for success. However, if you have a group of participants that’s stuck a long time in the storming stage in Tuckman's model of stages of group development [82], this would have a negatively effect the MBMI process and the probability for success.

5.4 Individual force

The individual force is seen as all the forces which each participant possesses like personality, culture background, competence, area of expertise, etc. As an example, it would have a positive effect on the MBMI process and the probability for success if you participants have a high level of competence and are experts within their area of expertise. However, poorly skilled participants would have a negatively effect on the MBMI process and the probability for success.

5.5 Competition Space force

The competition space force is seen as all the forces surrounding the BM under development or creation, on way of analyzing these forces is to use Porter's Five Forces Framework [83] as a tool for analyzing the competition. As an example, if the bargaining power of customers is very high in one competition space it would have a negatively effect on the MBMI process and the probability for success. However, if you moved the BM to another competition space where the bargaining power of customers is very low, it would positive effect the MBMI process and the probability for success.

5.6 Process Space force

The process space force is seen as all the forces that affect the BMI process while it is being conducted. Such forces include the time available for the BMI process to be conducted. As an example, if the time available for the BMI process to be conducted is very limited, it would have a negatively effect on the MBMI process and the probability for success. However, if you have the sufficient time required available for the MBMI process, it would positive effect the MBMI process and the probability for success.

5.7 Emotion force

The emotion force is seen as the overall level of happiness within the BM process. An increase in happiness positively affects the capability to be creative and solve problems [84], [85]. As an example, if the participants are happy, they have an increased capability to be creative and solve problems which would positive effect the MBMI process and the probability for success. However, if the participants are unhappy, they have a decreased capability to be creative and solve problems which would negatively affect the MBMI process and the probability for success

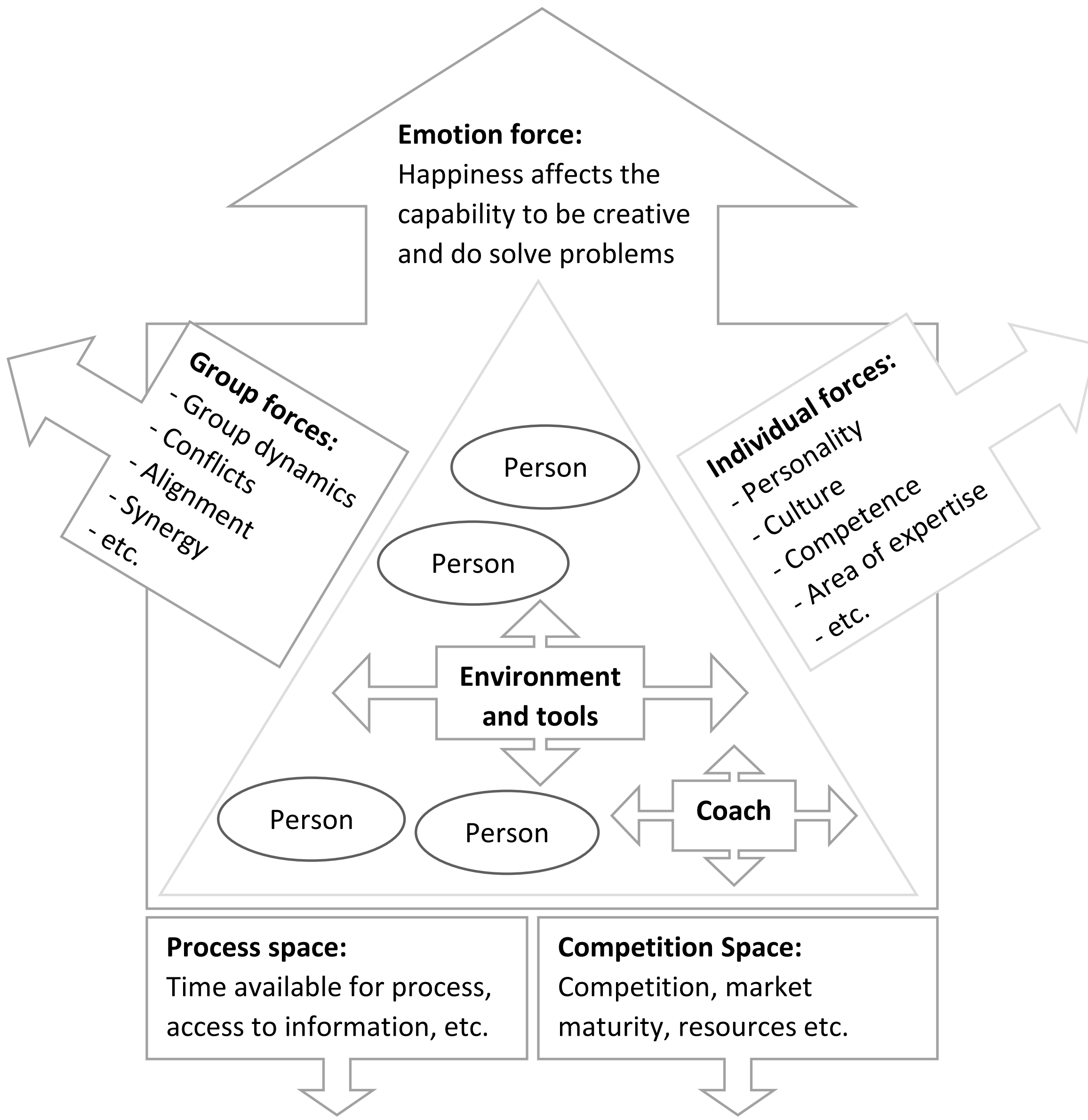

Figure.: 5.1 Valter's Seven Forces; a model for analyzing the BMI process

An interesting aspect of Valter's Seven Forces model is that as the level of happiness affects a person's capability to be creative and solve problems, it follows logically that happiness within the MBMI process positively affects the possibility for a successfully MBMI process. With this in mind it should be possible to measure the level of happiness within the MBMI process and to aim for as high a level of happiness as possible. This could be achieved by making changes in the environment or in the tools to positively influence the environment and tools force; by team building or conducting personalities test and replace team members to positively influence the group force; by building employee competences with courses to positively influence the individual force; by looking for other markets with the aim to positively influence the problem space; by training the coach to positively affect the coach force; or simply by assigning more time to the BMI process to positively affect the process space force.

If we compare Valter's Seven Forces model for analyzing the MBMI process with today's research as e.g. the open Innovation model from Chesbrough, you will see that Valter's Seven Forces focuses on the direction of the BMs within Chesbrough's model for open innovation. Henry Chesbrough coined the term "Open Innovation" which was defined in his book "Open Innovation: The New Imperative for Creating and Profiting from Technology" (2003) [86] where he looked at the innovation process and created models with stages, barriers and boundaries. In the book Chesbrough explains how companies have shifted from so-called closed innovation processes towards a more open way of innovating.) in figure 5.2 the placement of Valter's Seven Forces model within Chesbrough's Open Innovation model is graphically shown.

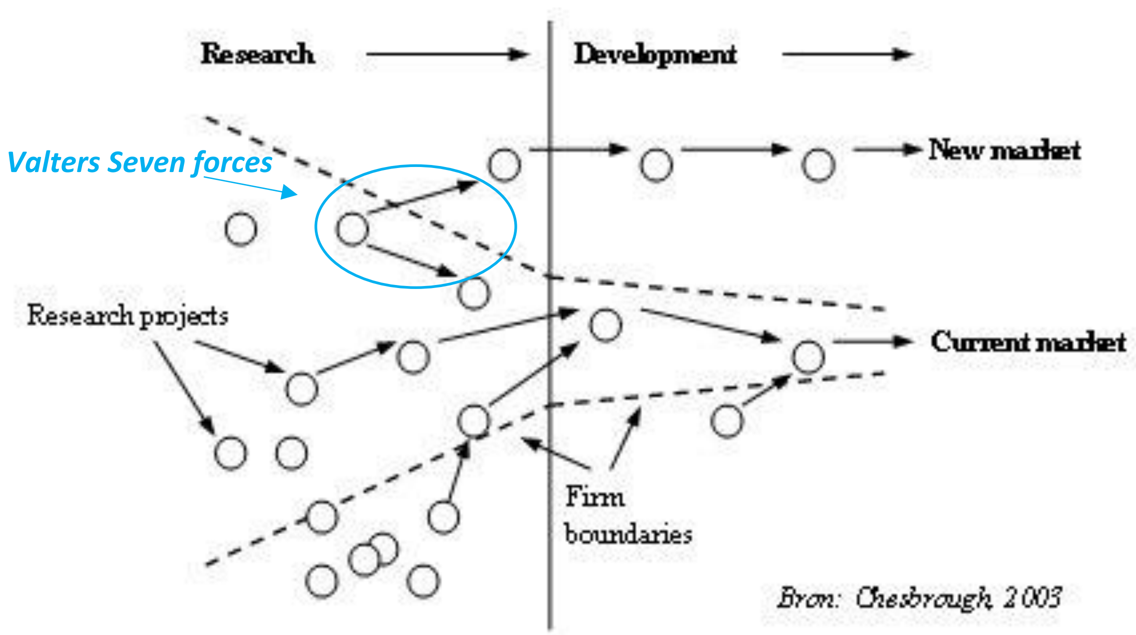

Figure.: 5.2. Placement of Valter's Seven Forces model within Chesbrough's Open Innovation model

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Chapter 6 – Conclusions and Future Scope

Since business and managers are being increasingly influenced by new competing business models and ever-increasing technological possibilities, and since this trend is unlikely to change in the near future, this thesis has embarked on a research journey to create, understand and facilitate successfully embedded continuous multi business model innovation processes within a business. The first step on this scientific research journey was to facilitate and develop a better understanding of the relationship between business reality, business model, digitalization and humans. The attempt resulted in a newly developed conceptual model in digital multi business model innovation as shown in figure 6.1. The new model can be used to facilitate our understanding of the relationship between business reality, business model, digitalization and humans.

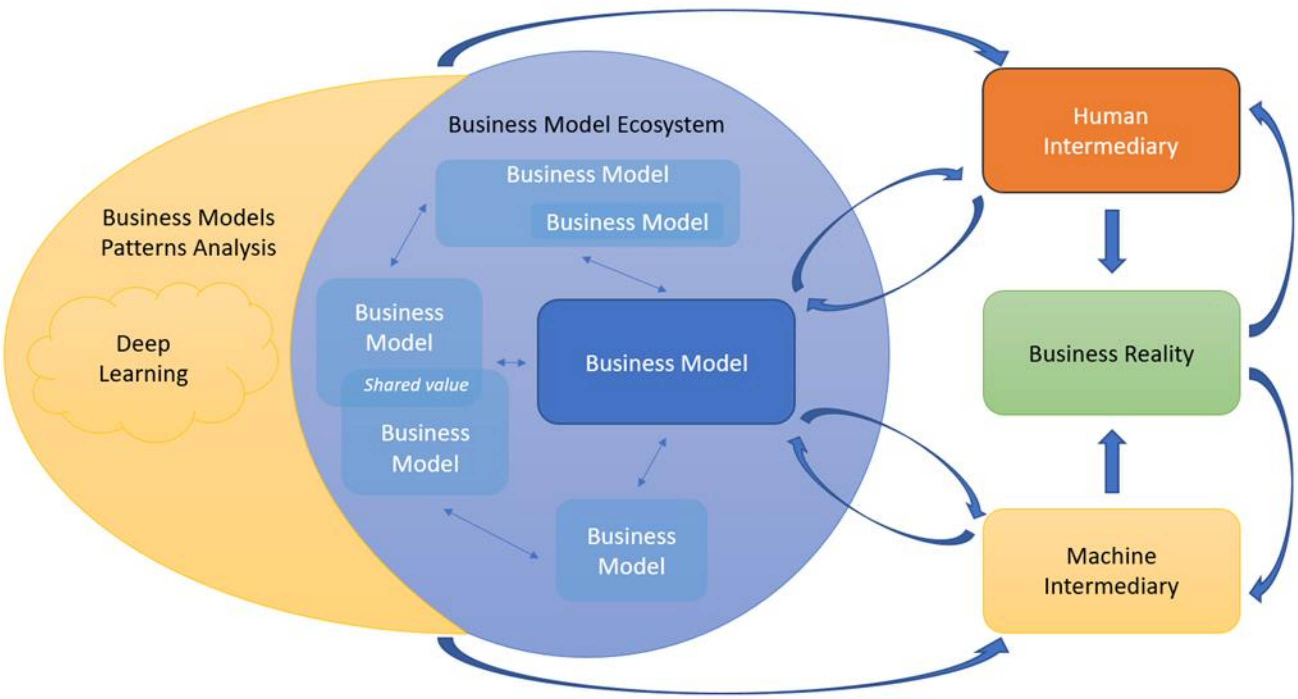

Figure.: 6.1 Conceptual Model, relationship between business reality, business model, digitalization and humans

The conceptual model in figure 6.1 focuses on the relationships between business reality, business model, digitalization and humans and contributes to the research journey with more knowledge about some of the complexity that the MBMI process have to take into consideration during the process.

The next step on the scientific research journey was to find a way to measure the MBMI process. Before it was possible to measure anything, however, the sensors available for measuring had to be investigated and decided upon. After the process of selecting the sensors for measuring, the engineering set-up (figure 6.2) to be used in the multi business model innovation lab had to be developed.

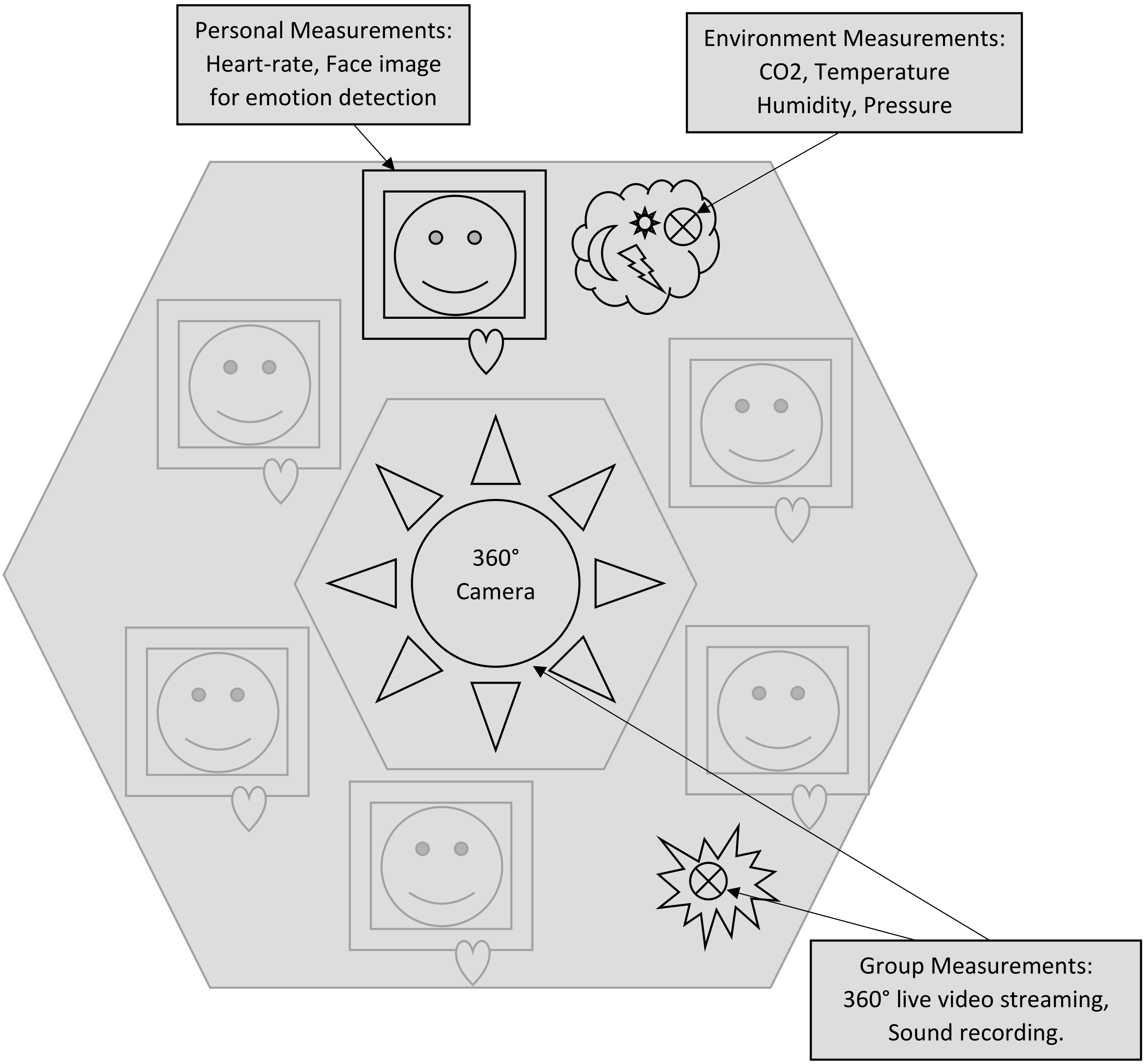

Figure.: 6.2 Overview of engineering set-up in the multi business model innovation lab

After the engineering set-up for use in the multi business model innovation labs were proposed and fully developed, the next step on the journey was to empirically test the engineering set-up. This was done at the Scandinavia Biogas Conference 2017 where three multi business model innovation labs were empowered with the proposed engineering lab set-up. At the conference we collected data regarding the multi business model innovation processes in the three business model innovation laboratory environments. The data collection was conducted over a time span of three days. After the data collection the evaluation of the engineering lab set-up was started and fueled, a new and improved engineering lab set-up, which was proposed based on the experience from the empirical data collection process. Finally, based on experience from the entire experiment, the conceptual model “Valter’s Seven Forces” has been developed (figure 5.1) and proposed with the aim of analyzing the MBMI process. The Seven Forces in the conceptual model affects the probability for success of an innovation process. The effect of the forces can be either positive or negative depending on the situation. For instance, if the group dynamics comprise conflicts and interpersonal power battles, the probability for the success of the innovation process is affected negatively. However, if the group dynamics hold respect, collaboration and harmony, the probability for the success of the innovation process is affected positively.

However, the previously mentioned contributions from the scientific research journey are not the only contributions, since the actual process of the scientific research journey in its retrospective reflection of itself both produced and raised serval important points for future research. This is a contribution in its own right. The resulting points for future research are mentioned in the following sections.

6.1 Future Scope

There are three major future challenges derived from this thesis, each of these challenges are described in its own subsection below.

6.1.1 Processing the convolutional neural network on the cap itself

One possible point for future research is to move the processing of the convolutional neural network to the cap itself and thereby remove the dependency on a centralized computer for processing the convolutional neural network. One approach could be to use the AIY Vision Kit [87] or to wait until the single-board computer with a removable Edge TPU system-on-module called Edge TPU Dev Board or the USB device that adds an Edge TPU coprocessor to your system called Edge TPU Accelerator becomes available [88].

6.1.2 Optimizing precision of the deep convolutional neural network

Although this thesis has developed, tested and proposed the improved engineering set-up which has introduced local emotion detection with TensorFlow and convolutional neural network, it does not claim to have discovered or developed the world's most optimal emotion detection algorithm. Therefore, further research on improved emotion detection is surely one area to mention. The road forward for improvement could be using other (better) databases with training sets, adding layers with factual action point and adding additional date sources like sound. Other suggested approaches could be to carry out the processing on multiple data sources simultaneously, or to use Dlib toolkit containing machine learning algorithms for (Faster) Facial landmark detector [75].

6.1.3 Removing the necessity to wear a cap for emotion detection

Another approach could be to investigate the possibility for removing the necessity to wear a cap for emotion detection. one way to investigate such an approach could be to install multiple cameras and adopt the approach which Luca Surace et al. are using in their paper "Emotion recognition in the wild using deep neural networks and Bayesian classifiers." [89] and combine it with face recognition to identify the participants. A suggested approach here could be to adopt the approach of Florian Schroff et al. in their paper "FaceNet: A Unified Embedding for Face Recognition and Clustering" [90].

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This declaration concerns the following article/manuscript:

Title:	Sensing Multi Business Model Innovation via Advanced Sensor Technology
Authors:	Peter Lindgren, Per Valter and Gitte Kingo

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: "Sensing Multi Business Model Innovation via Advanced Sensor Technology" Peter Lindgren, Per Valter and Gitte Kingo, Nordic and Baltic Journal of Information and Communications Technologies (2018) doi: https://doi.org/10.13052/nbjict1902-097X.2018.002

If accepted or submitted, state journal: *Nordic and Baltic Journal of Information and Communications Technologies*

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Element	Extent (A-E)
1. Formulation/identification of the scientific problem	A
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
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Authors:	Per Valter, Peter Lindgren, Ramjee Prasad

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Title:	The consequences of artificial Intelligence and Deep Learning in a world of persuasive business models.
Authors:	Per Valter, Peter Lindgren, Ramjee Prasad

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

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