FACULTY OF SCIENCE AND TECHNOLOGY

MSc by Research

THE POWER OF AFFECTIVE TOUCH WITHIN SOCIAL ROBOTICS

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ABSTRACT

There have been many leaps and bounds within social robotics, especially within human-robot interaction and how to make it a more meaningful relationship. This is traditionally accomplished through communicating via vision and sound. It has been shown that humans naturally seek interaction through touch yet the implications on emotions is unknown both in human-human interaction and social human-robot interaction. This thesis unpacks the social robotics community and the research undertaken to show a significant gap in the use of touch as a form of communication. The meaning behind touch will be investigated and what implication it has on emotions. A simplistic prototype was developed focusing on texture and breathing. This was used to carry out experiments to find out which combination of texture and movement felt natural. This proved to be a combination of synthetic fur and 14 breaths per minute. For human's touch is said to be the most natural way of communicating emotions, this is the first step in achieving successful human-robot interaction in a more natural human-like way.

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I would like to express my sincere gratitude to both my Director of Studies: Juan Augusto and Supervisor: Michael Margolis, without whom this thesis would not have been possible. I thank them for their guidance, expertise, motivation and most importantly, for their patience. Thanks, are also due to Professor Mehmet Karamanoglu and Dr. Aleksander Zivanovic who have always been there as a source of support and advice. I am grateful to my family for their support, encouragement and understanding.

CONTENTS

1. INTRODUCTION

Traditionally, autonomous robots have been targeted for applications such as; inspecting oil wells, sweeping minefields or exploring other planets. Such robots require very little interaction with humans (Breazeal, 2001) but the growing market for personal service robots requires robots to play a beneficial role in the daily lives of people. Within the robotics community, there is a growing interest in building robots that share the same workspace as humans or a personal service robot (Breazeal, 2002). Some projects focus on autonomous robots others on tele-operational. New questions arise from this domain, such as how to design for a successful relationship where a long-term appeal could be provided by the robot which can be a benefit to the human for a longer period of time (Breazeal, 2005). A lot of thought and time has gone into the functionality of the system and making it reliable. It is now moving towards making a sociable robot able to perceive and understand the complexity of natural human social behaviour and to interact with people in a human-like manner (Breazeal, 2002). There has been a rise in robots being used as a research platform to study human emotions and others to assist the elderly in the home. However, it must also be able to send signals to the human in order to provide feedback of its own internal state which would allow the human to interact in a simplistic and transparent manner (Fong *et al*, 2003). Whatever the application, it is known that a physical embodiment of a bodily presence plays an important role assisting a meaningful social interaction (Lee *et al,* 2006).

In human social life touch plays an important role, it communicates positive or negative emotions (Simon, 2011). Although, within social human-robot interaction, research has focused almost exclusively on the modalities of vision and sound; touch has received disproportionate attention (Yohanan & MacLean, 2008). Touch is increasingly seen to play an important role in mental health (Field, 2003). Robots have been predicted to transform everyday life, including the way healthcare is delivered (Nestorov *et al*, 2014). Much research in robot therapy has shown the positive health benefits of animal therapy (Stiehl *et al*, 2005) observing that when patients engage physically with an animal type robot, it stimulates affection (Shibata *et al,* 2001). Research in socially assistive robotics demonstrated success in hands-on rehabilitation; this presents a new set of research challenges as roboticist try to understand how human-robot interaction can effectively and measurably assist in the process of recovery, rehabilitation, socialisation and companionship (Mataric & Tapus, 2006). There are many theories and beliefs about the ‘power of touch’ being an affective input (McGlone *et al*, 2014). However, understanding the possibilities by which affective touch can operate has implications for the design of many social robots in applications ranging from companionship to therapeutic.

The motivation behind this thesis is to explore the meaning of touch within human-human social interaction and to see if it can be used in social robotics to enhance the human-robot interaction. It will investigate how different types of tactile information affects human perception of social interaction with robots. Investigating if a small change such as texture can affect how something feels to someone to the point it feels unnatural. Understanding the meaning of touch, researching the connection it may have with human emotions and how it can be used to create a device to interact with humans in a more human-like way.

The thesis will begin by exploring different aspects of social robotics, summarising different types of robots and what the core research focus was. The thesis will also break down the different forms of communication social robotics have in various applications. Concluding with a comparative analysis where a lack of touch will be shown in both robot build, interaction and research. Touch as a form of human to human communication will be analysed showing a link between the touch and emotion felt. Affective touch within social robotics will then follow, analysing the Haptic Creature. The thesis will then introduce a prototype, an experiment will be carried out to find the most natural combination of external coverings and breathing movement. Data collected and results will be presented. This will be the first step in creating a device which utilises touch as a form of communication. It will follow with improvements and additional mechanisms for the prototype to continue enhancing the human-robot interaction.

2. SOCIAL ROBOTICS

Traditional robots required very little, if any, interaction with humans (Breazeal, 2001) but the growing market for personal service robots requires them to play a beneficial role in the daily lives of people. Human-robot interaction is an area of research where the impact of design is yet to be understood (DiSalvo *et al*, 2002). However, it is a key function which can increase the use of social robots in daily human life (Salichs *et al*, 2006) and it can be defined as the study of humans, robot and the ways they influence each other (Fong *et al*, 2003).

A social robot is a socially intelligent autonomous or semi-autonomous robot which interacts with humans or other robots in a human-like way (Breazeal, 2002). Autonomous robots are intelligent machines and are capable of performing tasks in an unstructured environment without explicit human control (Bekey, 2005). There are a number of robots that have been created by several roboticists for many different applications ranging from a research platform to study human emotions, to assisting the elderly in the home. Others focus on displaying a range of facial expressions as a form of communication to evoke emotional responses. Whatever the application, it is known that a physical embodiment of a bodily presence plays an important role in assisting a meaningful social interaction (Lee *et al*, 2006).

Numerous projects focus on the development of the robot face; many have developed human-like robotic faces which incorporate hair, teeth, silicone skin and a large number of control points (Hara, 1998). Using a camera, normally mounted in the left eyeball, the robot recognises facial expressions and can produce a predefined set of emotions, corresponding to anger, fear, disgust, sorrow, happiness and surprise (Breazeal, 2002).

With gremlin-like features, the disembodied head robot named Kismet (Figure 2.1) learns about its environment like a baby (Rowe, 1998). Developed in the artificial intelligence department of the Massachusetts Institute of Technology by Cynthia Breazeal, Kismet is capable of engaging humans in social exchanges that adhere to the infant-caregiver role. It was designed to recognise several natural social cues and deliver a number of social signals through gaze direction, facial expression, vocalisation and body posture. Kismet is being used as a research platform to understand social behaviours.

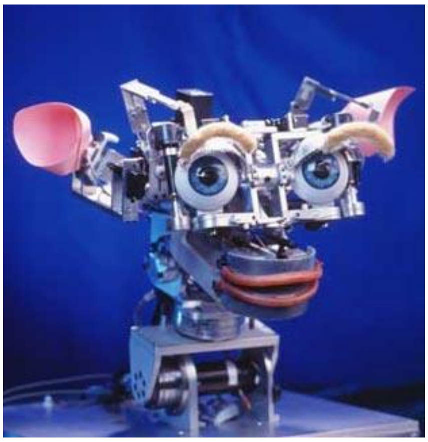


Figure 2.1: Kismet

http://www.robotliving.com/rob

Figure 2.2: Geminoid F, Geminoid HI and Geminoid DK
http://www.geminoid.jp/en/robots.html

Geminoid robots (Figure 2.2) were introduced by Professor Hiroshi Ishiguro in 2005 when he created a replica of himself, Geminoid HI. It is said to be a hybrid system in which android and human are integrated. Geminoid appears and behaves like its source person (Nishio *et al*, 2007), movement is restricted to the head and the upper torso and speech is controlled by the operator. In 2010 Professor Hiroshi Ishiguro created a new simpler version of the original HI robot, Geminoid F. Geminoid F was modelled on a young female, she was the first android to become an actress in a play in Tokyo (Toto, 2010). She was the most realistic robot until the launch of Geminoid DK in early 2011. Geminoid DK is the first non-Japanese geminoid and the most realistic one yet, constructed to look like Professor Henrik Scharfe from Denmark. Both professors are using their geminoids to study human-robot interaction with a particular interest in people’s emotional response when they are first introduced to the android. They also want to find out if the robot can transmit the presence of a person to a remote location (Ackerman, 2011).

A growing number of humanoid robotic projects also exist where development is focused on creating bipedal robots, that walk in a human-like manner. Full-bodied humanoid projects focus on arm control, especially integrated with vision to mirror human gestures and demonstrated tasks (Schaal, 1999).

Developed by Honda, ASIMO is the most advanced bipedal humanoid robot and can successfully function in indoor environments (Figure 2.3). He can walk, run on uneven slopes and surfaces, turn, climb stairs, reach and grasp objects. He can also understand and respond to simple voice commands, has the ability to recognise the face of an individual from a select group, as well as being able to map the environment and register fixed objects by using the camera in his eye (Sakagami, 2002). As he moves around in an environment he is able to recognise and avoid moving obstacles. ASIMO is used to encourage and inspire young minds to study the sciences that may someday be used to assist the elderly and handicapped. He could also be used for tasks that are harmful and dangerous to a human.

Figure 2.3: ASIMO

http://asimo.honda.com/gal

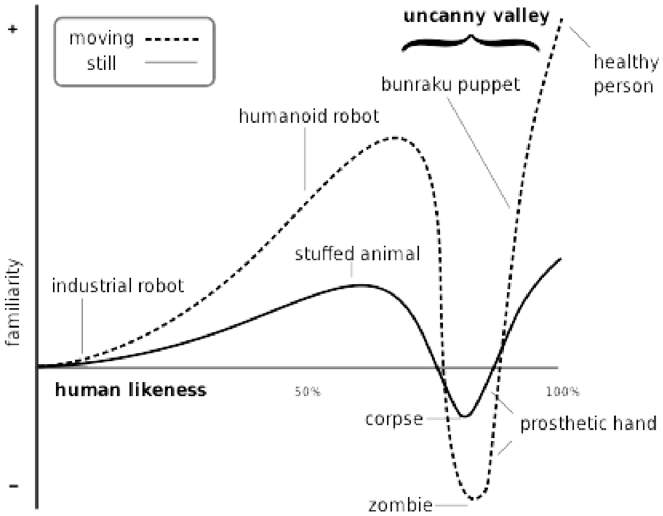


Figure 2.4: Mori’s Uncanny Valley

https://spectrum.ieee.org/automaton/robotics/human

The more human-like the robots become in appearance and motion, the more positive the human emotion becomes. This continues until the similarity becomes almost perfect but not quite and at this point, the subtle imperfections change the human emotional response which can quickly become negative (Fong *et al,* 2003). This unease and discomfort when people look at realistic virtual humans is often referred as the uncanny valley (Mori, 1970). If the robot has the ability to move, the emotional response increases compared to if the robot is static (Bartneck *et al,* 2007) (Figure 2.4).

Ever since the uncanny valley was first noted, it has been a popular subject in human-robot interaction research (Bartneck *et al,* 2007). Some researchers believe the uncanny valley is a myth, while some question the translation, others believe the meaning needs to be updated and a few think it can be avoided through careful design. The uncanny valley often appears as a design consideration or is used as a reason for the potential failure or success of a robot (Gee *et al,* 2005). If the robot looks too human-like in appearance it can make it unfriendly, using a nonhuman face to develop facial expressions avoids the dip in to the uncanny valley. Deforming the expressions by giving them a simple design makes it easier to recognise and give them a friendlier look (Fukuda *et al,* 2004). Gemenoids fall into the uncanny valley for their realistic design and evokes a negative response when static, one that increases when they are in motion. Zoomorphic design is an easier way of avoiding the valley as human-creature relationships are simpler than human-human relationships (Fong *et al*, 2003).

Figure 2.5: Sophia
http://www.hansonrobotics.com/robot/

Dr. David Hanson, the founder of Hanson Robotics, created the company's latest and most advanced robot Sophia (Figure 2.5). Designed to look like Audrey Hepburn, Sophia is said to be classically beautiful with porcelain skin, high cheekbones, a slender nose and expressive eyes. Her main function is to talk to people, engaging them in conversation. With cameras in her eyes, Sophia can track faces and make eye contact, this is a key element in successful human-robot interaction. Sophia's intelligence grows through interaction as she can remember faces while also processing conversational and emotional data to help form relationships with humans. She has the ability to animate different human expressions but has yet to learn the meaning of the emotions behind them.

Every human interaction impacts Sophia's development and shapes who she will become eventually. She has proved her intelligence in face-to-face meetings with key decision makers in industries, including but not limited to banking, entertainment and auto manufacturing. She has also appeared in a conference as a panel member discussing the implications of robotics and artificial intelligence and how it will integrate into human life. Her interviews in global media outlets have received positive responses from the public, carrying conversations and engaging them with jokes. However, her almost perfect human likeness and expressive face does dip the robot into the uncanny valley with some people describing her as creepy. Hanson (*et al*, 2005) has always believed the uncanny valley is a myth and uses this sensitivity humans have to realistic human-like robots, versus cartoon-like robot, as a refined metric. Using this metric to assist in exploring human social cognition in the pursuit of better cognitive science. Hanson aims to keep developing his technology to make Sophia as human-like as possible.

DiSalvo *et al* (2002) made design suggestions for a humanoid robotic head to prevent it from dropping into the valley. To retain a certain amount of robot-ness a design with a wide head and eyes makes it look less human-like. Features that dominate the robot's face should be from the mouth to the brow line; this distribution contrasts a human's and will clearly state the head as being robot-like. Human features such as nose, mouth and eyelids should be added and detailed eyes give the perception of humanness. A casing of some sort must cover the mechanics of the inside to give a finished appearance (DiSalvo *et al*, 2002).

http://www.hansonrobotics.com/ Accessed October 2017
http://sophiabot.com/ Accessed October 2017

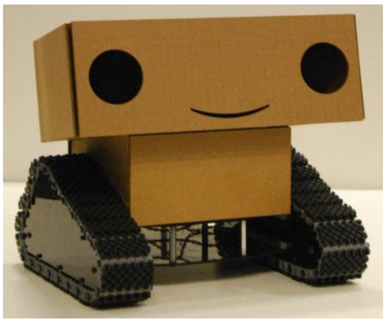


Figure 2.6: Boxie

http://bostinno.com/2012/01

Figure 2.8: Pixar movie Wall-E

http://disney.wikia.com/wiki/Cate

Designed by Alexander Reben, a researcher from MIT Media Lab, Boxie (Figure 2.6) was designed based on its level of endearment to gather stories from people. With a shaky head and childlike voice, Boxie was able to encourage humans to interact and answer questions (Landry, 2012) varying from "I'm really short. Can you put me on a table or hold me, so I can see you?" to a more personal "Can you tell me what you do here?" (Cha, 2012). Originally Boxie was to be made out of white plastic (see figure 2.7), however people's opinion was that the model looked frightening and that the cardboard model was more organic, friendlier and approachable (Reben, 2011). The design can best be described as a cardboard version of Pixar's Wall-E (see figure 2.8) (Landry, 2012), by having a resemblance to a character from a movie it avoids the dip into the uncanny valley.

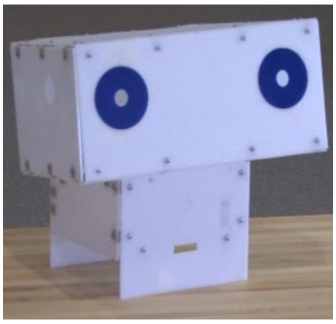


Figure 2.7: Plastic model

http://labcast.media.mit.e

Not all social robots are autonomous; some are semi-autonomous or remotely controlled. Telepresence robots are used to be a physical representation of someone, operated by remote control and can communicate with others over great distances. The operator usually uses a webcam which captures the voice and tracks the operator's face and head movements, transmitting them to the robot (Guizzo, 2010). Many projects focus on the functionality within the human environment; these are not usually humanoid robots but are designed to support natural communication channels such as speech or gestures (Breazeal, 2002).

Figure 2.9: Telenoid R1
http://spectrum.ieee.org/

Telenoid R1 (Figure 2.9) is a teleoperated android designed by Hiroshi Ishiguro. His previous androids had realistic appearances with a great deal of detail to imitate the features of a human. The Telenoid R1 is quite different with a minimalistic design and the same size of a small child. A soft torso with a doll-like face and a bald head but no legs and stumps instead of arms is unique (Guizzo, 2010). This design was chosen so that the Telenoid R1 can appear young or old, male or female and is easy to transport (Ogawa *et al*, 2011). With its jerky movements, obvious absence of limbs and lack of familiarity when first seen the Telenoid R1 falls into the uncanny valley. Even the creators admit that the unique appearance of Telenoid R1 may be creepy when first met but the initial response may change once used to communicate. When Telenoid R1 emits the voice of a friend, people can possibly imagine their friend is with them (Guizzo, 2011).

Animal-assisted therapy is defined as a form of therapy that involves using animals as part of a person's treatment (Fine, 2010). This treatment is mostly used in hospitals and nursing homes and for a first-time patient, this could be a very stressful environment (Stiehl *et al*, 2006). Nursing homes are becoming larger and overcrowded is leading to residents being over medicated and often suffering from loneliness and a lack of care (Thomas, 1996). Research has shown positive benefits of companion animals (Stiehl *et al*, 2005) that lower stress (Allen *et al*, 1991) and reduce heart and respiratory rates (Ballarini, 2003). Unfortunately, the use of animal-assisted therapy is limited by hygiene, allergens, the high cost of training animals. There is also the common impracticalities of caring for an animal given the patients physical, social, mental, and economic situation (Sefidgar *et al*, 2016). These restrictions led to a new form of therapy to be created where robotic companions are used. There are various robots being developed for domestic situations where ease of use is an important issue as well as safety and minimising impact on human living spaces. Applications for these domestic robots focus on providing assistance to the elderly or to the disabled (Breazeal, 2002), while others are being developed as therapeutic robots for use in care homes or hospitals. Within the entertainment market, a growing number of synthetic pets are being developed. Most are able to locomote and some are being developed to entertain as well as educate. An increasing number of personal and entertaining toy robots are being designed to mimic living creatures. This is a zoomorphic design which is important to establish a human-creature relationship (Fong *et al*, 2003).

Starting in 1998 the Aurora project investigates how autonomous robots can become toys that could serve in an educational or therapeutic role for children with autism. The project aims to use robots as remedial tools to encourage autistic children to become engaged in coordinated and synchronised interactions. The basic belief is this will help them develop and improve their communication and social interaction skills (Dautenhahn, 1999).

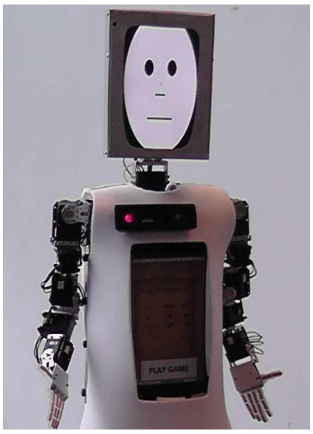


Figure 2.10: CHARLY
http://edition.cnn.com/20

CHARLY is an interactive robot that was built at The University of Hertfordshire as an experiment in human attitudes towards robots (Figure 2.10). It can play interactive games with users, however, its most interesting aspect is that CHARLY's face changes to appear like the ones who surround it (Herrmann *et al*, 2012). CHARLY never fully appears like the user it interacts with, just resembling them enough for the face to look familiar and making the user feel more comfortable. It is capable of facial expressions but cannot express emotions until the morphing face is complete. CHARLY's face does not mimic those around him but resembles them, preventing the fall into the uncanny valley. CHARLY is part of the LIREC project set up to understand how people react to a robot in their home, hence the mimicking face to make it appear part of the family. Started in 2008 the LIREC project explores how people live with digital and interactive companions by examining social environments and assisting in the creation of artificial companions that are suitable for long-term interaction (Syrdal *et al*, 2009). The goal is not to replace human contact but to provide companions that can fulfil tasks and interact with people in a manner that is socially and emotionally acceptable (Castellano *et al*, 2008).

In 2008 the ALIZ-E project started to develop and test interactive mobile robots which can interact with human users over an extended period of time (Ros, 2016). They explore this by using social robots as assistants in the care of children with metabolic disorders. By focusing on four research threads; adaptive user and task modelling, adaptive memory for long-term interaction, adaptive linguistic interaction and adaptive non-linguistic behaviour, the 9 research teams believe long-term human-robot interaction may be achieved (Wilson, 2011).

NAO (Figure 2.11) is a smaller version of ASIMO used for different applications. The initial application was to participate in the international RoboCup competition and is now used in the ALIZ-E project. NAO is also being used as a research platform in over 350 universities and labs to explore a wide range of research topics. With many actuators and sensors and a sophisticated embedded software, NAO is capable of face and object recognition; whole body movement, speech recognition and text-to-speech in seven languages (Pierris & Lagoudakis, 2009).

Figure 2.11: NAO

http://asimo.honda.

2.1. Assistive Robotics

Assistive Robotics (AR), essentially refers to robots that assist people with physical disabilities through physical interaction (Feil-Seifer & Mataric, 2005). This includes manipulator arms for the physically disabled (Graf *et al*, 2002), companion robots (Wada *et al*, 2002), wheelchair robots, rehabilitation robots (Burgar *et al*, 2002) and educational robots. Most of this physical interaction is to help reduce stress, fatigue and to increase human capabilities in regards to force, speed and precision. In general, to improve the quality of life. The crucial capability is the generation of supplementary forces to aid in overcoming the physical limits of a human (De Santis *et al*, 2008). The physical interaction in assistive robotics is not used to lower anxiety or reduce loneliness; the human-robot interaction is not social.

Figure 2.12 Robovie R3 http://www.roboticstoday.

Robovie R3 (Figure 2.12) is a half-sized humanoid robot developed by Vstone and ATR (Advanced Telecommunications Research Institute International), designed to assist the handicapped and elderly in everyday tasks. The robot can move around omnidirectionally, enabling it in assisting people to walk naturally. It can also hold a person's hand while moving up and down wheelchair ramps (Hornyak, 2010).

2.2. Socially Interactive Robotics

Socially interactive robotics (SIR) describes robots whose main task is some form of interaction (Feil-Seifer & Mataric, 2005). They can operate as assistants, peers or partners with the sole purpose and task of engaging people in social interaction. The term was first used by Fong (*et al*, 2003) to distinguish social interaction from teleoperation in human-robot interaction. Research in this area concentrates on "human social" characteristics such as expressing emotions, developing social competencies, using natural cues, etc. (Fong *et al*, 2003), focusing on vision and sound.

Figure 2.13: Roboceptionist https://sbs.arizona.edu/news/ university-arizona-partners-

The Roboceptionist (Figure 2.13) is based near the main entrance of a building at Carnegie Mellon University. A moving flat-screened monitor, displaying a graphical human face is mounted on a mobile base. It is an interactive robot capable of engaging with visitors and handling basic receptionist tasks such as locating telephone numbers and providing directions. Mechanical faces have numerous moving parts so designers chose a flat-screen face which is more reliable and easier to change. However, the greatest disadvantage of a graphical face is the lack of a physical embodiment a mechanical face has. The Roboceptionist is being used to study long-term relationships with users (Gockley *et al*, 2005).

KASPAR is a child-sized robot developed at University of Hertfordshire (Blow *et al*, 2006). Using minimally expressive face and gestures to communicate and interact with people it is used as a research platform to study human-robot interaction (Dautenhahn *et al*, 2009). KASPAR is working to help autistic children improve their social skills and with simple facial expressions, they can better understand him. Due to his size, they can relate to him as they would their peers. KASPAR was never designed to look cute (Dautenhahn *et al*, 2009) but he has an uncanny resemblance to Chucky from well-known horror movie Child's Play (see Figures 2.14 and 2.15), yet this does not frighten autistic children (Liu, 2011) nor does the disproportion of his head to his body.

Figure 2.14: KASPAR

http://www.herts.ac.uk/news-and-

Figure 2.15: Chucky from movie Child's Play

http://captstar1.deviantart.com/art/ch

2.3. Socially Assistive Robotics

Socially assistive robotics (SAR) is said to be the bridge between assistive robotics and socially interactive robotics (Cavallaro *et al*, 2014). The goal is to provide assistance to humans and to develop close and effective interactions with humans. It is used in hospitals and care facilities working alongside healthcare teams as a caregiver, promising to provide personalised day to day physical and cognitive support (Nestorov *et al*, 2014). They have also been used as a social mediator in autism and a therapeutic aid for children suffering from loss or grief. This is achieved specifically through social interaction without physical contact (Feil-Seifer & Mataric, 2005).

Pearl is the second generation of nursebots developed by Carnegie Mellon (Figure 2.16). With two main goals of reminding elderly people about their daily activities (eating, drinking, taking medicine) and helping them navigate their environment (Montemerlo *et al*, 2002). Pearls overall facial design is cartoon-like, expressing emotion through moving eyes and eyebrows and communicating via a touchscreen monitor (Nejat *et al*, 2009).

Figure 2.16: Pearl

http://cmtoday.cmu.e

2.4. Zoomorphic Robots

An increasing number of personal and entertaining toy robots are being designed to mimic living creatures. Robots are designed with a zoomorphic embodiment which is important in establishing a human-creature relationship (Fong *et al*, 2003). Human-creature relationships are simpler than human-human relationships and humans have lower expectations of realistic animal morphology, this makes avoiding the uncanny valley easier with zoomorphic designs.

Figure 2.17: Paro

http://www.paro.jp/english/

On the surface, Paro (Figure 2.17) is covered with white fur to create a soft natural feel (Wada & Shibata, 2007). Its appearance was designed using a baby harp seal as a model and was developed especially for therapeutic applications (Wada *et al,* 2004). Initially introduced in Japanese care homes as animal-assisted therapy. Studies have shown interacting with Paro, especially stroking it, results in a reduction in stress, anxiety and loneliness (Sharkey & Wood, 2014).

Figure 2.18: Probo

http://probo.vub.ac.be/Pics_Video/

Probo (Figure 2.18) is an intelligent robot that was developed at Vrije University in Brussels. Its design represents an imaginary animal based on four extinct species of elephants from the last ice age (Saldien *et al*, 2008). Probo is said to have a huggable appearance, due to the mechanics being surrounded by foam which gives it the feeling of a stuffed animal. It was developed as a research platform to study cognitive human-robot interaction with a specific focus on children. The head is fully actuated with 20 degrees of freedom with the capability of showing 7 facial expressions, has an interactive belly screen and an impressive moving trunk.

The Huggable (Figure 2.19) was designed to resemble an anthropomorphized fantasy animal, the teddy bear. It allows more freedom with the design of the behaviour as it is not limited to being based on a real animal. It features a full-body sensitive skin and mechanics allowing it to emulate touch behaviours such as nuzzling or hugging (Stiehl *et al*, 2006). Developed at the MIT Media Lab for healthcare, education, and social communication applications.

Figure 2.19: The Huggable (Stiehl *et al*, 2006).

Figure 2.20: AIBO http://www.sony-

AIBO was developed and produced by Sony as an entertainment robot (Figure 2.20). It was designed to resemble a dog and many of its movements during social interaction are dog-like. It has a hard plastic exterior and a wide set of sensors which include touch sensors. Studies showed the relaxation effects that are obtained from petting a real dog were never felt with AIBO (Wada & Shibata, 2007).

2.5. Conclusion

Social robots are being used in a wide variety of ways and as a result, the interactions between humans and robots become more complex. From the projects above, the research surrounds human-robot interaction and how it can help build a relationship with the human and how the robots react in certain environments. Within human-robot interaction, one main goal is the investigation of natural ways humans can interact with robots (Duatenhahn & Saunders, 2011).

Humanoid robots need to interact in a human-like way to gain a meaningful relationship, but achieving this while staying out of the uncanny valley has proven to be difficult. Even a robot with a high level of intelligence like Sophia still evoke those feelings of unease. With humans noticing subtle imperfections, a slight delay or a change in speed while gesturing alters the perceived intelligence, dropping Sophia into the uncanny valley.

The uncanny valley is avoided within human-creature relationships as they are less complex and have lower expectations than human-human relationships. This type of relationship also encourages non-verbal communication. Paro has demonstrated a reduction in stress, loneliness and anxiety in nursing homes from patients stroking him. He is covered in soft fur and has 7 actuators allowing movement in a number of axes. Also covered in fur The Huggable emulates nuzzles but the emotional implications of this touch are unknown.

KASPAR and Paro have both demonstrated that humans naturally seek interaction through touch (Silvera-Tawila *et al*, 2015), yet very little is known about how touch impacts emotion. The huggable appearance of Probo is not used as a tool in human-robot interaction. AIBO encourages humans to interact with it like a real dog, it visually looks like a dog but does it evoke the same emotions when stroked versus a real dog? The published descriptions of Sophia mentioned the skin is made from a material called Frubber which looks like real human skin by mimicking the arrangement of muscle to the skin but failed to mention how it feels. There have been great leaps forward with vision and sound but very little with touch, often no mention of touch at all.

The next chapter investigates the importance of touch within human development and social life. Explains how it can impact emotions within human-human interaction and describes The Haptic Creature, a device that uses touch as the method of communication.

3. AFFECTIVE TOUCH

Skin is the largest, oldest and most sensitive organ in the human body and is said to have been the first medium of communication (Juhani, 2014). Covered in 1000’s of nerve endings, the dermis is a layer of skin providing the sense of touch. The brain processes touch via two parallel pathways, one of which provides inputs such as vibration, pressure, texture and the second social and emotional information. A crucial element of early human development, emotional support and social bonding is affective touch.

Touch is used to share feelings and enhancing the meaning of other forms of communication, visual or verbal. Different cues can evoke human emotions and the sense of touch is said to be one of the most emotionally charged channels (Smith and MacLean, 2007). It can feel different based on the social context of the encounter (Linden, 2015). Even if the skin is being stimulated in the exact same way humans experience that touch differently depending on who it is coming from. It continues into adulthood when soothing, expressing power, flirting and playing (Eibl-Eibesfeldt, 1989).

With affective touch being both technically and socially difficult to study, the role it plays in the communication of emotion has received little attention compared vocal and facial displays of emotion (Stack, 2001). Two claims have been made regarding the role touch plays in emotional communication. The first being that touch intensifies emotional displays from the face and voice. Second is that touch communicates either negatively valanced pain or discomfort and positively valanced warmth and intimacy, this is thought to communicate hedonic values of emotion (Knapp & Hall, 1997).

Lederman (*et al,* 2007) carried out an experiment to test whether humans can recognise the six universal expressions of emotion (happiness, sadness, surprise, fear, anger and disgust) by touching a live face in both static and dynamic expressions. The results for the dynamic facial expressions of emotions showed a mean accuracy of 74% and 51% for static facial expressions of emotion. Results also proved that while anger, fear and disgust were less recognisable, happiness, surprise and sadness were highly recognisable.

Hertenstein (*et al,* 2006) carried out a study exploring the communication of emotion through haptics and discovered that humans could identify anger, disgust, fear, gratitude, happiness, love, sadness and sympathy from the experience of being touched on either the arm or body by a stranger, without seeing the touch. In the study, two strangers (an encoder and a decoder) in a room separated by a barrier, one which would prevent them from seeing each other, but could still reach one another through a hole in the barrier. The encoder was instructed to convey 12 different emotions by touching the decoder on the forearm, the decoder had to choose which emotion they thought was being communicated after each touch. Results showed that the decoder could interpret anger, fear disgust, love, gratitude, and sympathy via touch with accuracy rates ranging from 48% to 83%. The study showed self-focused emotions embarrassment, pride and envy or the emotion of surprise were unable to be communicated to strangers. Further research by Hertenstein (*et al,* 2009) allowed the touch to be anywhere on the body that was appropriate, not restricted to the forearm. The study concluded by increasing the number of emotions being interpreted to eight, adding happiness and sadness. This research challenges Knapp and Hall’s (1997) claims that touch exclusively communicates hedonic values of emotion or intensifier of emotions displayed from the face and voice.

An interesting pattern of gendered communication was found in a later study that re-examined the data collected by Hertenstein (*et al*, 2009) and Lederman (*et al*, 2007). Results showed that when both participants were male, anger was communicated above the expected rate. Happiness, on the other hand, was only communicated when both participants were female. The chances of sympathy being communicated relied on at least one of the participants being female (Eid & Osman, 2006).

In 2006 Coan *et al* ran a study confirming the interpretation of emotions is influenced significantly by the person receiving and the person giving the touch. In 2011 Thompson and Hampton ran a study comparing the ability of strangers and romantic couples when communicating emotions through touch. From the results both the romantic couples and strangers successfully communicated the universal emotions, however, self-focused emotions envy and pride were only successfully communicated by the romantic couples.

Studies found that haptic touch alone is not sufficient information to identify different emotions (Knapp & Hall, 2007), direct touch affect is one of many channels that helps decipher emotions. Within the same study carried out by Hertenstein (*et al,* 2009), 23 different types of tactile behaviour such as hugging, squeezing, shaking, etc. were identified. The results concluded that tactile behaviour alone was not enough in identifying distinct emotions. For example, stroking was used when communicating sympathy but also when communicating sadness or love. It found that duration and intensity of stimulus have to be controlled for improved judgment between emotions as well as the choice of tactile behaviour.

In a study to measure the physical properties of affective touch (Huisman & Frederiks, 2013), a wearable sleeve with a pressure sensitive input layer is used for a number of expressions of emotions such as gratitude, anger, fear etc. Results showed a significantly larger surface area was touched by participants to express happiness, anger and fear compared to when expressing gratitude, sadness and sympathy. It also showed that intensity of most of the emotions expressed was relatively equal. For sympathy, however, participants were observed to use more force when compared to anger, fear and gratitude. The duration between the touches when expressing happiness and love was longer than when expressing sadness. Disgust was also shown to have significantly shorter duration than happiness, love, fear and sadness.

Although, for sympathy, participants used significantly more force when compared to fear, anger, and gratitude. As for the duration between touches, anger had a significantly shorter gap duration than happiness and love. Disgust had a significantly shorter duration than fear, happiness, sadness and love.

Various confounding factors such as gender, relationship status, familiarity, social status, and culture have been shown in studies on social interaction through touch (Thompson & Hampton, 2011) (Hertenstein & Keltner, 2011). The ability of a human to interpret a haptic stimulus and recognise its corresponding emotion depends on more than the physical properties of the haptic stimulus. A foundation needs to be built and attributes such as interpersonal gender, relationships, synchronised visual and audio cues, etc. need to be considered for a more reliable touch-based emotion recognition.

3.1. The Haptic Creature

The Haptic Creature (formerly known as Hapticat) is an expressive animatronic lap-pet designed to study affective touch in human-robot interaction (Yohanan & MacLean, 2011). The creature interacts with the world primarily through the modality of touch and is composed of five major components: a body, two ear-like appendages, a breathing mechanism, a purring mechanism, and a warming element. The form of the body is intentionally organic and relatively non-zoomorphic, resembling a rugby ball. The first prototype was covered in polyester fleece with the motivation it was easier to construct, had a comfortable feel and a lower cost (Yohanan *et al*, 2005). In 2009 (Yohanan & MacLean), this was changed to synthetic fur for its pleasing feel and rough approximation to animal fur and a layer of silicon rubber was added beneath the fur to mitigate the rigid feel of the body.

The emotional model of the Haptic Creature is represented by an affect space adapted from Russel (1980 and *et al*, 1989). Figure 3.1 shows that the vertical dimensions represent the robot’s arousal, deactivated vs. activated, and the horizontal dimensions describe the robot’s valence, unpleasant vs. pleasant. The Haptic Creature has three levels of arousal; high, medium and low, each match with three levels of valence; negative, neutral and positive, creating nine key expressions (represented by diamonds in Figure 3.1). They drew from models of interaction between humans and animals as there is a wealth of non-verbal communication through touch.

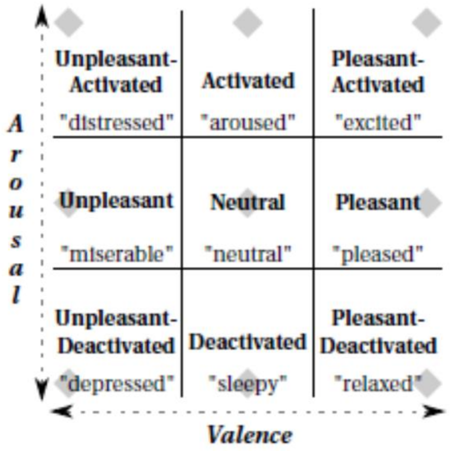


Figure 3.1: Yohanan & MacLean (20011). The Haptic Creature's affect space.

The two ears can vary in firmness, which can be felt when they are squeezed, and is defined by volume ranging from 0% - limp to 100% - stiff. Using the stiffness proportional to arousal level (low represents limp ears and high represents fully stiffened ears) the ears are exclusively used to convey arousal. The user study confirmed that the intended affect state was achieved when paired with the breathing rate.

Normalising the breathing rates to those of cats, dogs and rabbits the breathing mechanism conveys arousal with a breathing rate of 15 – 70 bpm. The breathing mechanism was also used to convey valance. The key to this was determined by the symmetry of breathing where equal durations for inhalation and exhalation signified positive valence and a quicker inhalation corresponded to negative valence. In domestic animals, the opposite is true, where the inhalation is notably slower when an animal is in a negative state. By moving away from the animal model Yohanan & MacLean (2011) chose to convey a quick outward motion from the ribcage striking the human's hand as a negative feeling. In the user study faster breathing rates corresponded to high arousal of 15-70 bpm. Equal durations of inhalation and exhalation corresponded to positive valance and quicker shallow inhalation corresponded to negative valance. Their results found 71% of participants rated breathing symmetry, 100% of participants rated breathing rate and 94% of participants rated depth as something they actively used to assess the emotional state of the Haptic Creature.

Whenever purring was present, the results showed participants ranking the arousal dimension much higher and for this reason, purring was used to only convey positive valence. However, their next study contradicted this when participants considered the purr to mean shaking or shivering. Some participants noted the increase in the intensity of the purr not only showed an increase in excitement in the Haptic Creature but also noted the strong intensity to represent unhappy or fearful emotions.

The heating element began with four settings; off, low, medium and high, after which it was decided to only use off and low as the others felt too warm. However, as it took several minutes for the heat to dissipate, when going from low to off, it was not used in their user study (Yohanan *et al*, 2005).

3.2. Conclusion

The implications of touch are only just emerging in human-human interaction. Research has shown anger, disgust, fear, gratitude, happiness, love, sadness and sympathy can be recognised through touch. Self-focused emotions such as embarrassment, pride and envy or the emotion of surprise have been proven to be more difficult to emulate in certain context; strangers versus romantic couples. It has also shown confounding factors such as gender, relationship status, familiarity, social status, and culture. With touch being one of the most emotionally charged channels, there is the added complexity of touch feeling different based on the social context and environment of the encounter. The duration, force and surface area needs to be taken in to account alongside the choice of tactile behaviour.

Human emotions are complex to emulate with only touch but there is a clear connection forming between touch and emotions. This is being slowly translated into human-robot interaction. Studies with AIBO showed that people petting it did not gain the same feelings as they gained from petting a real dog. Is this because it has a hard, cold plastic exterior? What you gain from the touch is not something that is soft and comforting, it is smooth and solid which compared to a real dog is a big difference. Probo is said to have a huggable appearance and when you touch it it is compliant, so when you hug it you sink as you would do when hugging a human or an animal. Does this make Probo feel more natural receiving positive emotions from humans? Stroking Paro can have a calming effect as it is covered in soft fur; it has 7 actuators which allow it to move in a number of axes. However, when Paro changes from static to moving, the initial movement can be startling.

Humans are almost never completely still, when human’s sleep they make very little movement and when they awake their movements are slow and sluggish. Breathing is a small movement but it makes you aware that something is alive and moving. Perhaps by starting robots with a gentle breathing emulation may reduce the startling effect people can sometimes have. Breathing was one of the main features in which the Haptic Creature successfully conveyed emotions. When purring was introduced it usually enhanced the emotion (mostly positive valance) but on some occasions, participants noted it also felt negative, for this reason, purring will not be part this thesis. While Yohanan & MacLean gave no touch-based reasoning when changing the outer covering from polyester fleece to synthetic fur, they did mention a silicon layer being added to soften the feel of the hard body. It is unclear if this impacted the feel of the breathing and purring as the materials varied in thickness. It is also unclear changes were made to the output of the respective mechanisms. This thesis will investigate if the outer covering is something that can affect the interaction.

To fully understand the impact touch has on human-robot interaction small steps need to be taken. Research from the Haptic Creature has shown the movement of breathing is something humans link closely to emotional state. Purring mechanisms and heating elements have yet to be fully understood in the world of touch. Each new mechanism changes the way the device will feel, potentially changing the emotion. For this reason, a simplified device was developed to focus exclusively on breathing and the texture, investigating what combination of texture and movement feels most natural to humans when interacting with the robot. This thesis will explain the changes in state and how the experiments will be carried out and will then present the results and the conclusions which were formed.

4. DESIGN, IMPLEMENTATION AND EXPERIMENTS

The main design factor during the design process was touch, investigating which combination of texture and movement felt the most natural. The form of the body is intended to be organic and minimalistic, keeping it non-zoomorphic and limiting the expectations of the participants but also focusing on the interaction rather than the form. The intention was to build a modular robot to accommodate the breathing mechanism and have the capability to add additional mechanisms such as temperature and purring for future research. Several shapes and sizes were produced to accommodate the additional mechanisms, however, this increased the notion of intelligence from the robot. For this reason, a smaller design was created to focus exclusively on breathing and external texture, the final form resembles an American football but in half (Figures 4.1 and 4.2).

Figure 4.1: Prototype polyester fleece

Figure 4.2: Prototype with synthetic fur

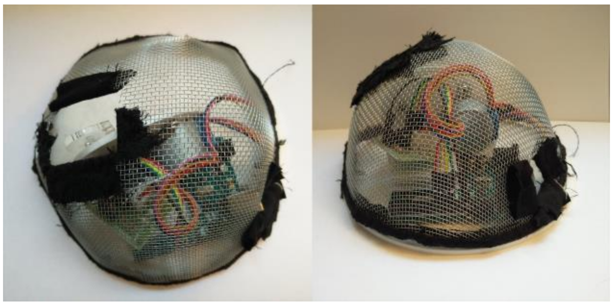
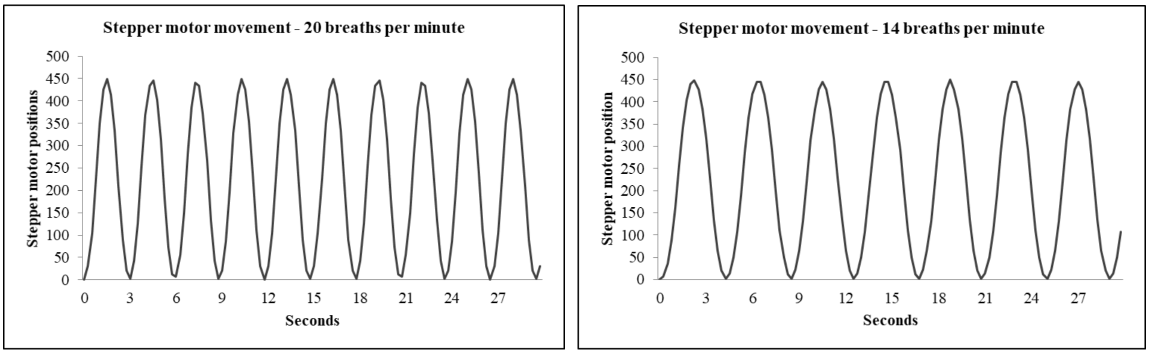


Figure 4.3: Prototype without cover

The internal structure needed to support the weight of two hands, yet still, allow some compliance while holding its shape. This was achieved by using a stainless-steel mesh (Figure 4.3). The breathing mechanism is a rack and pinion driven by a 5V stepper motor (28BYJ-48) programmed and controlled via an Arduino uno board (Appendix 3). The program has three motions, 1 sets the rate to 14 breathes per minute, 2 sets the rate to 20 breathes per minute and 3 stops the motor.



Graph 1: Left 20 breaths per minute, right 14 breaths per minute

There are two types of breathing; metabolic breathing is vital breathing which keeps humans alive and behavioural breathing is carried out voluntarily i.e. holding a breath. In 2008 Homma and Masaoka introduced a third type called emotional breathing which is carried out involuntary i.e gasping. In their study on anxiety and respiration, they found a positive correlation between anxiety and an increase in respiration rate. Relationships between emotions and respiration have shown more rapid breathing during an arousal state (Boiten, 1998). The Haptic Creature's user study showed participants rating breathing symmetry as something they actively used to assess an emotional state (Yohanan & MacLean, 2011). To eliminate any emotions elicited by a faster inhalation and slower exhalation, equal durations for both will be used. In the resting state, an average cat takes 15 – 25 breaths per minute, while an average dog takes 10 to 35 breaths per minute and an average human takes 14 – 20 breaths per minute. Using the above data, the device will emulate two breathing rates one to mimic human breathing at 14 breaths per minute and the other emulating a cat or a dog like breathing at 20 breaths per minute (Graph 1). Mammals depth of breathing and regularity continuously changes, and anything too regular could be unnatural. Keeping the breathing rates to a set number may result in participants feeling discomfort from the motion but it eliminates the implications surrounding breathing rates and emotions. The displacement created by the two breathing rates is 15 mm.

Figure 4.4: The two different covers. Left – synthetic fur. Right – Polyester Fleece

There are two outer shells, one has the feel of a pet like a dog or a cat using synthetic fur (black). The other is polyester fleece (yellow) which may not have a direct link to a pet but it is soft to the touch (Figure 4.4). Both covers have been designed to be put on and taken off the prototype swiftly and with ease. Please see Appendix 1 for video.

4.1. Experiments

The focus of the experiment was to determine what combination of texture and movement felt the most natural. Table 1 shows the 4 states the prototype will be in.

State	Texture	Breathing rate
1	Fleece	14
2	Fleece	20
3	Fur	14
4	Fur	20

Table 1: Showing the different States

The main goal is to determine what is the most natural combination of texture and movement but also to find out if the difference in thickness between the two covers affects the interaction. My reasoning was that thicker fur cover would mute the feel of the movement more than the thinner fleece cover, thereby providing a more life-like experience for the user. Another interest is to investigate what external covering is preferred. The following was hypothesised;

H1 - State 1 will feel more natural then State 2

H2 - State 3 will feel more natural then State 4

H3 - Overall State 3 will be chosen more than the other states

H4 - Overall State 2 will be chosen less than the other states

While this hypothesis may be obvious, it is the first step in creating a device which communicates exclusively through touch in a more natural and meaningful way. A slower even rate is common when in a resting state, hypothesis 1 and 2 will confirm that a rate of 14 breathes per minute will feel the most natural. Hypothesis 3 will determine if synthetic fur is the preferred choice over polyester fleece. Hypothesis 4 will answer the question how much does the thickness of the covering affect the movement.

Combination	State 2	State 3	State 4
State 1	1	2	3
State 2		4	5
State 3			6

Table 2: Matrix table showing the 6 different pairs

4.2. Methodology

There are four changes; two breathing changes and two external texture changes. To pair each state with one another a matrix table (Table 2) was used to identify six combinations. Participants will be asked to choose which of the two states feels the most natural. For example, combination 2 would be State 1 compared to State 3. To avoid any bias in the data collected, the order of the 6 combinations was randomised for each participant.

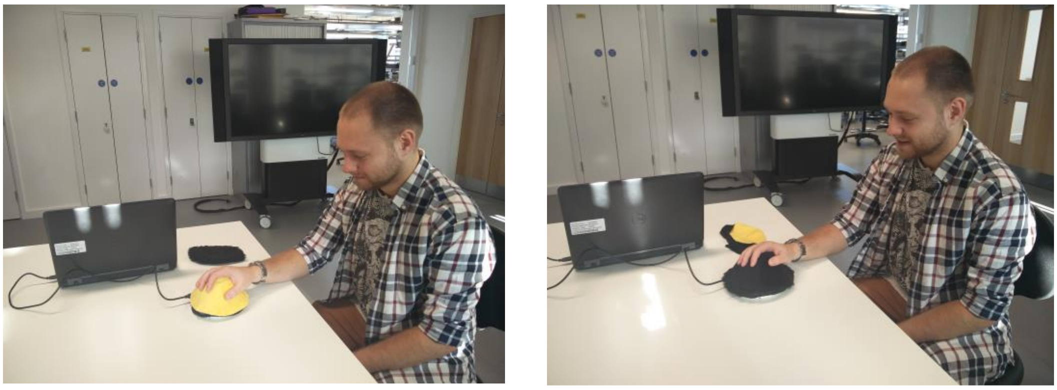


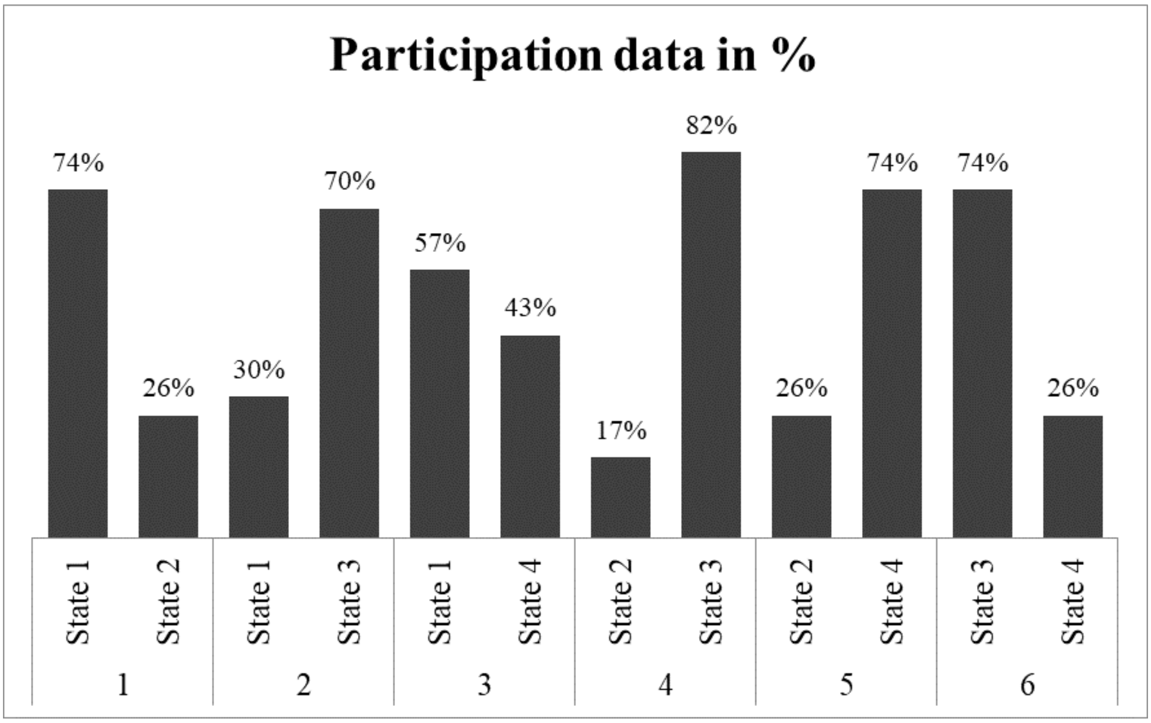
Figure 5.1: Experiment

There were 23 participants (8 females and 15 males), a mixture of staff and students from Middlesex University (age range 16 – 58 years old), were used in this experiment. Recruited via email, the participants had some knowledge of robotics but none had seen or interacted with the prototype before. The experiment was conducted in a laboratory (Figure 5.1). On the desk were the prototype and a laptop. Upon arrival, participants sat with the prototype in front of them and were asked to get into a comfortable position. A short explanation of the nature of the research was given. Participants were told to view the prototype as a living being with no specific ties to gender or species. They were then told the prototype has six different combinations and from each combination, they would have to choose which felt the most natural (Table 2). The participants were not given instructions on how to interact with the device they were free to choose their own exploration strategy. They were not limited by time to make a decision but after a minute, participants were prompted if they were ready for the next state in the combination or if they had made their decision. Once they were ready for the next state, the motor is set to position 3 (refer to the program in Appendix 3), and this is when the cover was changed if needed and the next motion was set.

The change in states was manually changed via a program. All results were recorded on a spreadsheet. The timing of interaction was noted ± 2 seconds and whether participants used one or two hands to interact with the prototype.

4.3. Results

The experiment was carried out to identify what combination of texture and movement feels the most natural. Data shows (Appendix 2) that out of the 6 combinations combination 4 (State 2 and State 3) had the biggest difference with 82% of the participants choosing State 3 and only 17% choosing State 2. Participants were divided with combination 3 with State 1 and State 4 being chosen 43% and 57% respectively. Please refer to Graph 2.



Graph 2: Results from experiments

Hypothesis 1 is supported with State 1 feeling more natural to 74% of the participants over State 2.

Hypotheses 2 is supported with State 3 feeling more natural with only 26% of participants choosing State 4.

Hypothesis 3 and 4 are fully supported as overall State 3 was chosen above all other states and State 2 was chosen the least out of the other states.

The data from the experiment showed the combination of the covers and breaths per minute proved to make enough of a difference for the feeling to change when compared to another combination. The most natural breathing rate from the data recorded proved to be 14 breaths per minute, with States 1 and 3 feeling the most natural to participants. The synthetic fur texture felt the most natural with 2 out of 3 participants choosing State 3. When developing the hypothesis, the thickness of the covering was also taken into consideration. From the data, we can see it plays a much bigger role in what felt natural. As predicted, the faster breathing rate combined with the thinner polyester cover felt more unnatural to participants over any other state. State 2 was chosen the least by participants and had the lowest average time of interaction across all the participants. The thicker fur cover and slower breathing rate had a higher percentage and a higher average time of interaction during the experiments. Participants felt State 3 is the most natural combination of movement and texture with State 1 being a close second.

What is unexpected, and maybe more interesting, is the high percentage of participants who unexpectedly chose States 2 and 4 as feeling more natural. It would seem obvious that participants would find State 3 more natural when compared to State 2 however 17% of the participants proved otherwise and 26% of the participants chose State 4 over State 3. The thought behind their choice is unclear and the order of the combinations may shed some light. In some cases, when the prototype was set to 14 breathes per minute for the previous two states participants chose State 2, 20 breathes per minute, as the most natural. The unfamiliarity of the movement might have felt more natural to them. As previously mentioned humans find regular motion unnatural as mammal’s depth and regularity is in continuous change. The change in motion may have affected that unnatural feeling to something more natural. In other cases, the covering on the prototype was synthetic fur for the previous two states participants chose State 2, polyester fleece. This could mean the texture does change the feel of the motion and in some cases making it feel the most natural.

4.4. Conclusion

The main purpose was to focus on the combination of movement with texture and how this would impact the interaction. The experiment proved to be successful with the most natural combination being the synthetic fur with a respiration rate of 14 breaths per minute. The high percentage of participants choosing the unobvious states is still somewhat unexplained. Combination order and the regular breathing rate may have something to do with this. It could also have been the way in which the experiments were conducted as participants could see the cover change. Keeping the illusion of intelligence is also important even when the prototype is somewhat simplistic. The change in program was done in the view of the participants. They could all be reasons for the unusual choices, shedding light on the potential errors which need to be taken into consideration moving forward.

Physical movements that mimic nature combined with different textures can change if something feels natural or not. This was a focused experiment not considering vision or sound as part of the interaction. The level of the prototypes intelligence perceived by the participants was low as expected due to the form of the prototype, so for it to not respond in any intelligent way was accepted. Participants made comments as to the emotional state of the prototype without being prompted and while this was not scientifically collected as data it was still noted.

Combination 6, where the cover is the same but the change is in the breathing rate, participants described the prototype to be sleeping when in state 3. Combination 2 where the texture changes and the breathing rate stays the same, participants described the prototype to be excited when in State 1.

This opens the path to continue experimenting with different breathing rates to identify the perceived emotions and whether or not the texture enhances the interaction. This would then follow with more mechanisms being introduced like purring, as in Paro and the Haptic Creature. The lack of feedback from the prototype was accepted by participants as it showed very little intelligence during the interaction. The evolution of the prototype would need to include some sort of feedback from the prototype to respond appropriately to human touch and for the humans to interpret that touch to emotions.

The next chapter presents a vision for the next stage in research. It will begin with explaining the changes to the current breathing mechanism based on the feedback received from the participants and a change in shape to accommodate additional mechanisms. This will follow with an explanation and reasoning for the additional mechanisms and intelligence to the prototype so it can respond to touch.

5. FURTHER WORK

5.1. Design

The design of the device worked well for the application it was being used for and has shown proof of concept for affective touch. One main issue that was brought up by more than one participant was the noise from the motor and gear mechanism. This needs to be upgraded to a closed-air system to inflate and deflate a balloon. Alternatively, as touch is the main form of communication, participants can wear ear muffs to avoid this distraction.

Although, while the visual appearance was not being used as a form of communication, it still needs to link to the embodiment of the prototype and a neutral colour for the cover needs to be used. The intention was for participants to use both hands to get the full impact of the movement and texture, 26% of participants interacted with the prototype with only one hand. This may be due to the size of the prototype. The overall shape of the prototype will be elongated in the y-axis and the shape will resemble an egg (Figure 7.1), creating a larger surface area and increase internal space for the additional mechanisms and the battery.

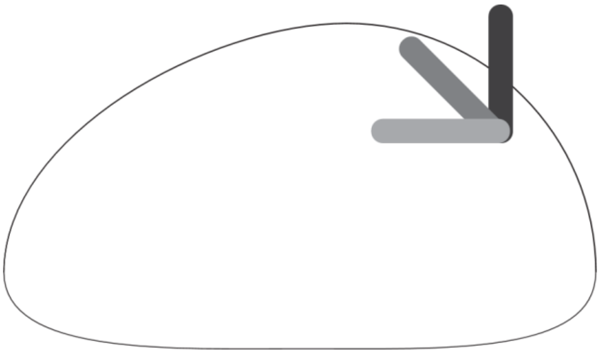


Figure 7.1: Profile of the new shape, showing the range of the 'ears' in varying gradients of grey

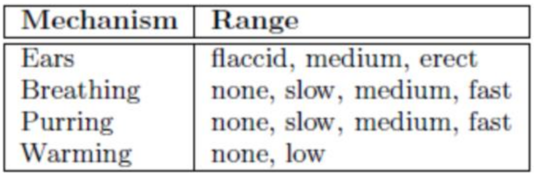
Currently, the prototype is tethered to a laptop via a USB, to supply power to the Arduino board and to control the change in states in the device. The next generation will have enough space to accommodate an external power supply in the form of a battery. An additional Arduino board will be added to allow wireless control of the prototype, allowing the facilitator of the experiments to be in a separate room from the participants.

5.2. Mechanisms

An additional movement will be added to enhance the communication, with ears. Though the first sense linked to ears is hearing, they can also be used as a means of expressing one's emotions in some animals. The position of the ear can convey information, orientation, rigidity and angle. Ears can be stroked or grasped providing another form of physical interaction and haptic feedback. The compliance of the ear needs to be as close to the compliance of a dog's ears. In dogs when the ears are completely flat it can be a sign of fear or sadness and when they are up and slightly forward it is a sign of aggression. The control of the ears will be achieved via a servo motor but within the mechanism, there will be a spring to allow the ears to be compliant when pressure is applied.

Purring can be heard within the prototype and can also be felt when in contact with the prototype. This provides haptic feedback to the human but also provides acoustic feedback. A 10 mm diameter and 2.7 mm thick vibrating mini motor disc will be used emulating purring. Different housing mounts will be tested to see which amplifies the vibration the best and it will initially be enclosed in the centre of the prototype. This is to investigate how purring can be perceived. Cats purr when they are content and also as a sign that they are in pain.

Pilot studies will need to be carried out to determine when the vibration feels too strong as the studies in the Haptic Creatures shows this can change the perceived emotion from positive to negative. This will also shed light on how other mechanisms affect the way purring is perceived. In the Haptic Creature study, participants felt purring represented unhappy or fearful emotions. The combination of the ears and purring may impact the desired reaction. Table 3 shows the various ranges used in the original Haptic Creature. Using the same terminology Table 4 shows the ranges of the developed mechanisms.



Mechanism	Range
Ears	flaccid, medium, erect
Breathing	none, slow, medium, fast
Purring	none, slow, medium, fast
Warming	none, low

Table 3: Yohanan *et al* (2005) Ranges for Hapticat mechanisms

Mechanisms	Range			
Ears	Flat	Medium	Erect	
Breathing	None	Slow	Medium	Fast
Purring	None	Slow	Medium	Fast
Temperature	None	Cold	Warm	

Table 4: Range of mechanisms

Physical temperature plays an important role in human-human interactions by sending interpersonal warmth information such as trust (Nie *et al*, 2012). Research in the neurobiology of attachment (Insel & Young, 2001) has further supported the link between temperature sensation, feelings of psychological warmth and trust. In 2008, Williams and Bargh carried out a study where participants who briefly held a cup of hot coffee perceived the personality of the target person as significantly warmer than those who had briefly held an iced cup of coffee. Physical temperature, or warmth, translates into emotional warmth because of the human-likeness (Nie *et al*, 2012). Without being aware of it, participants were affected by the physical temperature they experienced. This influenced impression of and prosocial behaviour toward the target person.

In 2014, Cabibihan *et* al carried out an experiment to research the desired thermal and mechanical characteristics of an artificial hand. Participants were asked to select which samples, out of 16 artificial skin samples, they felt were similar to human skin. Ranging from 22 degrees Celsius to 37 degrees Celsius the samples had a surface temperature gradient of 5 degrees. The ambient room temperature was 21 degrees Celsius and the selected temperatures ranged from 27 degrees Celsius to 32 degrees Celsius. For the artificial skin to be perceived as life-like the results showed a soft rubber material with a surface temperature of 28.4 degrees Celsius is critical.

In 2012 Nie (*et al*) suggested that increased physical warmth would increase feelings of warmth during human-robot interaction. In the study, participants were randomly assigned one of three experimental conditions: warm ‘human touch’, cold ‘human touch’ and no ‘human touch.’ The results indicated warm ‘human touch’ participants had a higher degree of perceived friendship towards the robot then no ‘human touch’ participants. Warm ‘human touch’ also indicated higher levels in perceived trust levels than cold ‘human touch’ and no ‘human touch’. To achieve the warm ‘human touch’ the researcher used a thin hot pad which kept the robot’s hand at a temperature of around 40 degrees Celsius. In the cold ‘human touch’ no change was made to the original robot, participants held the original mechanical hand of the robot, the temperature was not noted. The researchers hypothesised that due to the psychological gap between an immersive human touch and the mechanical appearance and behaviour of the robot, the warm ‘human touch’ may produce a negative reaction. This was evident in the results when the no ‘human touch’ participants had lower levels of fright from the robot then the warm ‘human touch’ participants.

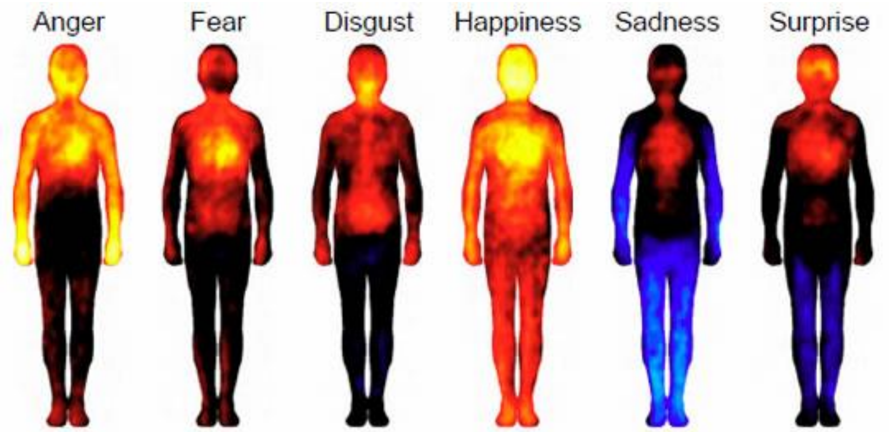


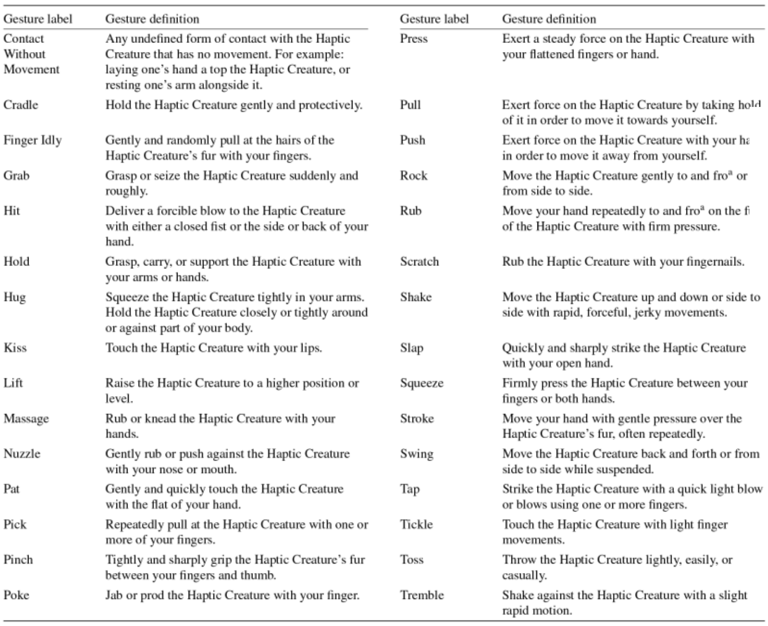
Figure 7.2: Body maps reveal areas in the body where certain sensations may increase or decrease for a given emotion. http://www.npr.org/sections/health-shots/2013/12/30/258313116/mapping-emotions-on-the-

A heating element will be placed in between the metal mesh and the outer covering to emulate body heat. The average core body temperature is 37°C and there is a correlation between temperature and emotions (Figure 7.2). All six emotions will not be tested, but the theory behind a warm temperature and the correlation to the emotion of happiness will be compared to the correlation between colder temperatures and sadness. Initial pilot studies were carried out with a heating element to determine if a temperature change of 14°C to 20°C was detectable. This was to see if varying temperatures across a surface can be felt. However, the change in temperature was not impactful enough and in some cases, similarly to the Haptic Creature, it took a long time for the heat to dissipate from the heating element when dropping to a lower temperature.

The circuit was changed for the next pilot study to include bi-directional control, allowing the heating element to be cooled down to lower temperatures by reversing the polarity. This change in temperature had a more successful result, the temperature difference was enough to be recognised. From this, the heating element will have three states; no temperature, warm and cold. Further testing needs to be carried out to determine the time it takes the heating element to change from pre-set temperature to the new desired temperature and to determine when it has reached no temperature. The heating element also needs to be tested with the external covering to understand how much heat the material will hold and at what point it will feel uncomfortably warm to humans. In initial testing, the heating element proved to be inconsistent and required a relatively long time to cool down after use. Further research and pilot studies are required before final parameters are set.

5.3. Interaction

The device needs to be able to respond. This can be done by adding a touch sensor on the surface of the device eliciting a response depending on the interaction with the robot. There are many types of touch interactions that convey affective or social content. For humans, handshakes are a form of greeting and poking is used to get someone's attention but can also be perceived as aggression. Petting is a calming gesture for both participants, while anger can be displayed with a slap. Many more examples exist. In 2012 Yohanan and MacLean identified a 30-item human-animal touch dictionary (Table 5). They began with literature sources form human-human touch, human-human affective touch and human-animal interaction, culminating in three gesture lists. They then removed gestures relying on hands/fingers and lips/mouth as they were deemed inappropriate and unsuitable. Using this as a reference 5 key emotional gestures were selected (Table 6). These gestures were selected as the hand movements required are very distinctive and the reactions allow the investigation of purring and how affective it can be in communicating emotions.



Gesture label	Gesture definition	Gesture label	Gesture definition
Contact Without Movement	Any undefined form of contact with the Haptic Creature that has no movement. For example: laying one's hand a top the Haptic Creature, or resting one's arm alongside it.	Press	Exert a steady force on the Haptic Creature with your flattened fingers or hand.
Cradle	Hold the Haptic Creature gently and protectively.	Pull	Exert force on the Haptic Creature by taking hold of it in order to move it towards yourself.
Finger Idly	Gently and randomly pull at the hairs of the Haptic Creature's fur with your fingers.	Push	Exert force on the Haptic Creature with your ha in order to move it away from yourself.
Grab	Grasp or seize the Haptic Creature suddenly and roughly.	Rock	Move the Haptic Creature gently to and fro[a] or from side to side.
Hit	Deliver a forcible blow to the Haptic Creature with either a closed fist or the side or back of your hand.	Rub	Move your hand repeatedly to and fro[a] on the f of the Haptic Creature with firm pressure.
Hold	Grasp, carry, or support the Haptic Creature with your arms or hands.	Scratch	Rub the Haptic Creature with your fingernails.
Hug	Squeeze the Haptic Creature tightly in your arms. Hold the Haptic Creature closely or tightly around or against part of your body.	Shake	Move the Haptic Creature up and down or side to side with rapid, forceful, jerky movements.
Kiss	Touch the Haptic Creature with your lips.	Slap	Quickly and sharply strike the Haptic Creature with your open hand.
Lift	Raise the Haptic Creature to a higher position or level.	Squeeze	Firmly press the Haptic Creature between your fingers or both hands.
Massage	Rub or knead the Haptic Creature with your hands.	Stroke	Move your hand with gentle pressure over the Haptic Creature's fur, often repeatedly.
Nuzzle	Gently rub or push against the Haptic Creature with your nose or mouth.	Swing	Move the Haptic Creature back and forth or from side to side while suspended.
Pat	Gently and quickly touch the Haptic Creature with the flat of your hand.	Tap	Strike the Haptic Creature with a quick light blow or blows using one or more fingers.
Pick	Repeatedly pull at the Haptic Creature with one or more of your fingers.	Tickle	Touch the Haptic Creature with light finger movements.
Pinch	Tightly and sharply grip the Haptic Creature's fur between your fingers and thumb.	Toss	Throw the Haptic Creature lightly, easily, or casually.
Poke	Jab or prod the Haptic Creature with your finger.	Tremble	Shake against the Haptic Creature with a slight rapid motion.

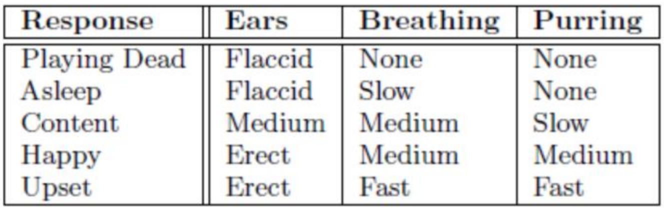
Table 5: Yohanan and MacLeans (2012) Touch dictionary.

Stroke	Moving hand gently over the prototype body/ear
Pat	Gently and quickly touching the body with the flat of the hand
Slap	Quickly and sharply strike the prototype with open hand
Poke	Jab or prod the prototype with a finger
No Touch	Prototype left untouched

Table 6: 5 key emotional gestures

Current technologies within touch sensors rely heavily on force alone and cannot detect a light touch. This can cause problems detecting the different gestures with similar hand pressures. PARO and AIBO use FSRs alone to identify touch and the Huggable uses Force Resistive Sensors (FSR) in conjunction with temperature sensors and capacitive sensors. FSR's are sensors that allow you to detect physical pressure, squeezing and weight. The sensor does not work well on curved surfaces, nor can they detect light touches. A combination of FSR's and piezo resistive fabric pressure sensors will need to be piloted to see which combination gives the best results. One of the reasons for choosing the key emotional gestures was the difference in hand movements required for each gesture. The sensors would need to differentiate between a quick touch with a flat hand as against a prod with a single finger, which is a change in surface area. The next step for the sensors will be to differentiate between a stroke and a slap. Both require an open flat hand but the duration and pressure will be different. Table 7 shows the mechanisms settings for responses used in the original Haptic Creature. Using the same terminology Table 8 shows the mechanism settings for responses for the device. This opens the scope of the investigation to the impact of purring and ears from positive to negative valance.

An experiment will be carried out to evaluate the effectiveness of the prototype in conveying emotion through touch. A 'Wizard of Oz' type response will be used, where the prototype would have human controller observing the human-robot interaction and controlling the device to respond accordingly. It is important to ensure the controllers are hidden from the participants so it appears the prototype is responding autonomously. Answering the following questions: Can the prototype communicate the pre-set emotional responses to the participant? Do the pre-set emotional responses match the expectation of the participant? Does communicating via touch elicit stronger emotional responses from the participant?



Response	Ears	Breathing	Purring
Playing Dead	Flaccid	None	None
Asleep	Flaccid	Slow	None
Content	Medium	Medium	Slow
Happy	Erect	Medium	Medium
Upset	Erect	Fast	Fast

Table 7: Yohanan *et al* (2005) Hapticat mechanism settings

	Breathing	**Purring**	**Temperature**	**Ears**
Stroke	Slow	Medium	Warm	Medium
Pat	Medium	Slow	Warm	Medium
Slap	Fast	None	Cold	Erect
Poke	Fast	Slow	Cold	Flat
No touch	None	None	None	Flat

Table 8: Robot responses to tactile stimulation

6. CONCLUSION

Touch plays a prominent role in communicating emotions and it is said to be the most natural way of communicating emotions for humans. There is a big gap in the social robotics community in using touch as a form of communication, this may be because we are yet to fully understand the implications touch has on emotions in both human-human interaction and social human-robot interaction. Human-human interaction studies are slowly emerging with a focus on the analysis, design, and evaluation of systems that can capture, process, or display emotions through the sense of touch. They have proved that humans can detect emotions through the sense of touch but have brought up confounding factors such as gender, relationship status, familiarity, social status, and culture. There is the added complexity of touch feeling different based on the social context and environment of the encounter.

A human-human relationship within social robotics is a difficult thing to replicate. A human-creature relationship allows us to bend the rules in interaction without dipping into the uncanny valley. Robots being designed with the aim of investigating affective touch, need to work in conjunction with other sensors to decipher emotions. Emotions are not singular, they are not evoked via one sense alone as they are created by different layers of senses working together. More than just haptic stimulus is required, a foundation of stimulus working in conjunction with different senses is necessary to create a more reliable touch-based emotional recognition.

The main purpose of this thesis was to begin the process of designing a device to communicate with humans using touch by understanding how texture and combination can affect the way something feels. Physical movements that mimic nature, and combined with different textures, can change whether something feels natural or not. It was a simplified device focusing exclusively on breathing and the texture. The results showed the most natural combination being the synthetic fur with a respiration rate of 14 breaths per minute.

There were some unexplainable results with participants choosing unobvious states. Although, the simplification of the experiment and the study may have caused the unusual results. This was a focused experiment without considering vision or sound as part of the interaction. The level of intelligence perceived by the participants was low as expected due to the form of the prototype, so for it to not respond in any intelligent way was accepted. Still, participants made comments as to the emotional state of the prototype without being prompted, describing State 3 as sleeping and State 1 as excited.

It is possible that the ongoing research into human-human interaction is helping scholars understand the complexities of human emotions and may provide valuable insights that can be harnessed for human-robot interaction. The development of the prototype will further the investigation of breathing rates combined with the other mechanisms to identify if texture enhances the interaction. This may also shed some light on the unusual choices in the results from this experiment. To fully understand the impact touch has on human-robot interaction small steps need to be taken and fully explored. It is my hope this work will be the start of a new area of research that will change communication methodologies within social robotics and be the catalyst behind developing a more meaningful human-robot interaction.

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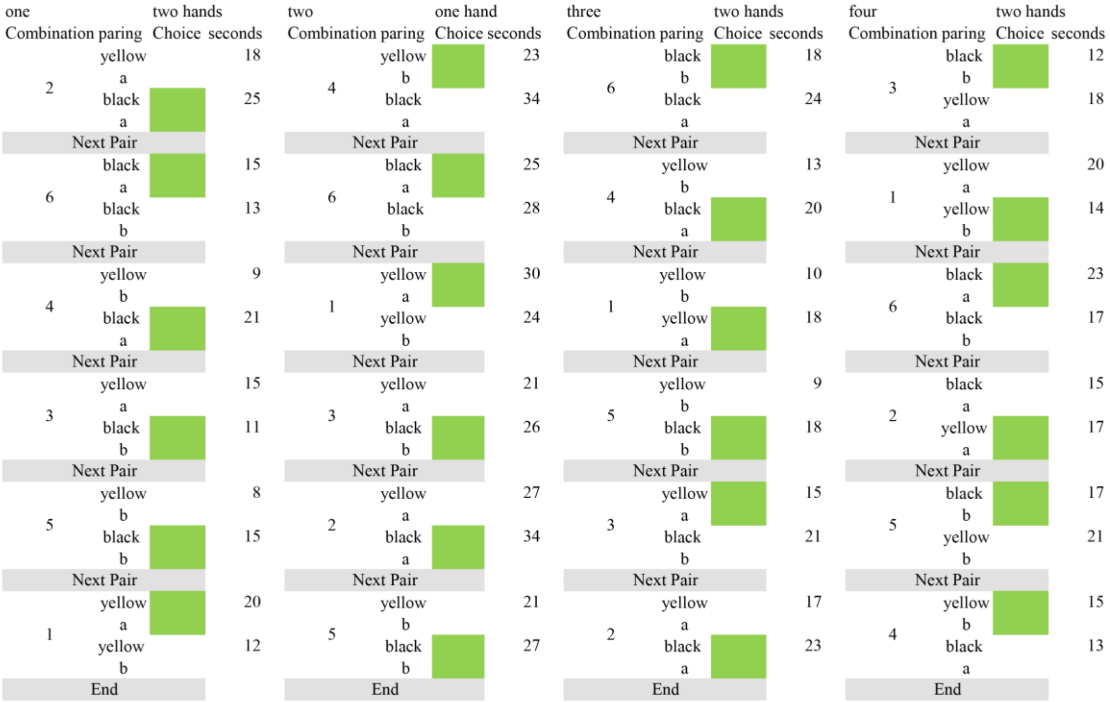
8. APPENDIX

1. https://youtu.be/wGOJgVRkm4o - the video shows the movement the breathing mechanism does and how the program controls the different settings.

2. Images below show screenshots from the data collected from 23 participants. Column 1 shows the order of the combinations. The next column shows order of states. Third column shows the chosen state. Last column indicates the duration of time it took the participant to decide.



one		two hands	
Combination	paring	Choice	seconds
2	yellow a		18
	black a	🟩	25
Next Pair			
6	black a	🟩	15
	black b		13
Next Pair			
4	yellow b		9
	black a	🟩	21
Next Pair			
3	yellow a		15
	black b	🟩	11
Next Pair			
5	yellow b		8
	black b	🟩	15
Next Pair			
1	yellow a	🟩	20
	yellow b		12
End			

two		one hand	
Combination	paring	Choice	seconds
4	yellow b	🟩	23
	black a		34
Next Pair			
6	black a	🟩	25
	black b		28
Next Pair			
1	yellow a	🟩	30
	yellow b		24
Next Pair			
3	yellow a		21
	black b	🟩	26
Next Pair			
2	yellow a		27
	black a	🟩	34
Next Pair			
5	yellow b		21
	black b	🟩	27
End			

three		two hands	
Combination	paring	Choice	seconds
6	black b	🟩	18
	black a		24
Next Pair			
4	yellow b		13
	black a	🟩	20
Next Pair			
1	yellow b		10
	yellow a	🟩	18
Next Pair			
5	yellow b		9
	black b	🟩	18
Next Pair			
3	yellow a	🟩	15
	black b		21
Next Pair			
2	yellow a		17
	black a	🟩	23
End			

four		two hands	
Combination	paring	Choice	seconds
3	black b	🟩	12
	yellow a		18
Next Pair			
1	yellow a		20
	yellow b	🟩	14
Next Pair			
6	black a	🟩	23
	black b		17
Next Pair			
2	black a		15
	yellow a	🟩	17
Next Pair			
5	black b	🟩	17
	yellow b		21
Next Pair			
4	yellow b	🟩	15
	black a		13
End			

five		one hand	
Combination	paring	Choice	seconds
1	yellow		23
	b		
	yellow	🟩	32
	a		
Next Pair			
4	black	🟩	34
	a		
	yellow		17
	b		
Next Pair			
3	black		25
	b		
	yellow	🟩	26
	a		
Next Pair			
5	yellow		19
	b		
	black	🟩	21
	b		
Next Pair			
6	black	🟩	36
	a		
	black		24
	b		
Next Pair			
2	yellow		27
	a		
	black	🟩	32
	a		
End			

six		two hands	
Combination	paring	Choice	seconds
3	yellow	🟩	28
	a		
	black		36
	b		
Next Pair			
6	black	🟩	31
	a		
	black		27
	b		
Next Pair			
4	yellow		21
	b		
	black	🟩	34
	a		
Next Pair			
5	black	🟩	25
	b		
	yellow		19
	b		
Next Pair			
2	yellow	🟩	27
	a		
	black		35
	a		
Next Pair			
1	yellow	🟩	21
	a		
	yellow		15
	b		
End			

seven		two hands	
Combination	paring	Choice	seconds
3	black	🟩	34
	b		
	yellow		28
	a		
Next Pair			
6	black		28
	b		
	black	🟩	37
	a		
Next Pair			
4	black	🟩	29
	a		
	yellow		23
	b		
Next Pair			
2	yellow		27
	a		
	black	🟩	19
	a		
Next Pair			
1	yellow		18
	b		
	yellow	🟩	21
	a		
Next Pair			
5	yellow		18
	b		
	black	🟩	24
	b		
End			

eight		two hands	
Combination	paring	Choice	seconds
6	black		29
	b		
	black	🟩	32
	a		
Next Pair			
5	black		27
	b		
	yellow	🟩	28
	b		
Next Pair			
1	yellow	🟩	21
	a		
	yellow		24
	b		
Next Pair			
2	yellow		19
	a		
	black	🟩	27
	a		
Next Pair			
4	yellow		14
	b		
	black	🟩	21
	a		
3	yellow		24
	a		
	black	🟩	16
	b		
End			

nine		one hand	
Combination	paring	Choice	seconds
2	black		34
	a		
	yellow	🟩	37
	a		
Next Pair			
1	yellow		25
	b		
	yellow	🟩	32
	a		
Next Pair			
4	black	🟩	30
	a		
	yellow		22
	b		
Next Pair			
3	black	🟩	36
	b		
	yellow		29
	a		
Next Pair			
6	black	🟩	28
	a		
	black		26
	b		
5	black	🟩	25
	b		
	yellow		22
	b		
End			

ten		two hands	
Combination	paring	Choice	seconds
5	yellow		17
	b		
	black	🟩	24
	b		
Next Pair			
1	yellow		13
	b		
	yellow	🟩	21
	a		
Next Pair			
3	yellow	🟩	19
	a		
	black		26
	b		
Next Pair			
2	yellow		21
	a		
	black	🟩	27
	a		
Next Pair			
6	black	🟩	21
	b		
	black		29
	a		
4	black	🟩	23
	a		
	yellow		19
	b		
End			

eleven		one hand	
Combination	paring	Choice	seconds
6	black		34
	a		
	black	🟩	29
	b		
Next Pair			
5	black	🟩	24
	b		
	yellow		19
	b		
Next Pair			
3	yellow	🟩	29
	a		
	black		24
	b		
Next Pair			
1	yellow	🟩	31
	a		
	yellow		19
	b		
Next Pair			
4	yellow		14
	b		
	black	🟩	19
	a		
2	black	🟩	28
	a		
	yellow		25
	a		
End			

twelve		two hands	
Combination	paring	Choice	seconds
1	yellow	🟩	31
	a		
	yellow		26
	b		
Next Pair			
4	black	🟩	37
	a		
	yellow		19
	b		
Next Pair			
6	black		28
	b		
	black	🟩	21
	a		
Next Pair			
5	black	🟩	26
	b		
	yellow		15
	b		
Next Pair			
3	yellow	🟩	23
	a		
	black		20
	b		
2	yellow		24
	a		
	black	🟩	19
	a		
End			

thirteen		two hands	
Combination	paring	Choice	seconds
2	yellow a	🟩	26
	black a		31
Next Pair			
1	yellow b		23
	yellow a	🟩	21
Next Pair			
6	black b		29
	black a	🟩	33
Next Pair			
3	black b	🟩	26
	yellow a		24
Next Pair			
5	yellow b		19
	black b	🟩	21
4	black a	🟩	29
	yellow b		17
End			

fourteen		two hands	
Combination	paring	Choice	seconds
3	yellow a	🟩	28
	black b		31
Next Pair			
5	black b		27
	yellow b	🟩	25
Next Pair			
4	yellow b		19
	black a	🟩	34
Next Pair			
1	yellow b	🟩	21
	yellow a		19
Next Pair			
2	black a	🟩	21
	yellow a		24
6	black a	🟩	31
	black b		22
End			

fifteen		two hands	
Combination	paring	Choice	seconds
4	black a	🟩	31
	yellow b		19
Next Pair			
3	black b		27
	yellow a	🟩	24
Next Pair			
1	yellow a		22
	yellow b	🟩	21
Next Pair			
2	black a		27
	yellow a	🟩	20
Next Pair			
5	black b		26
	yellow b	🟩	19
6	black b		21
	black a	🟩	19
End			

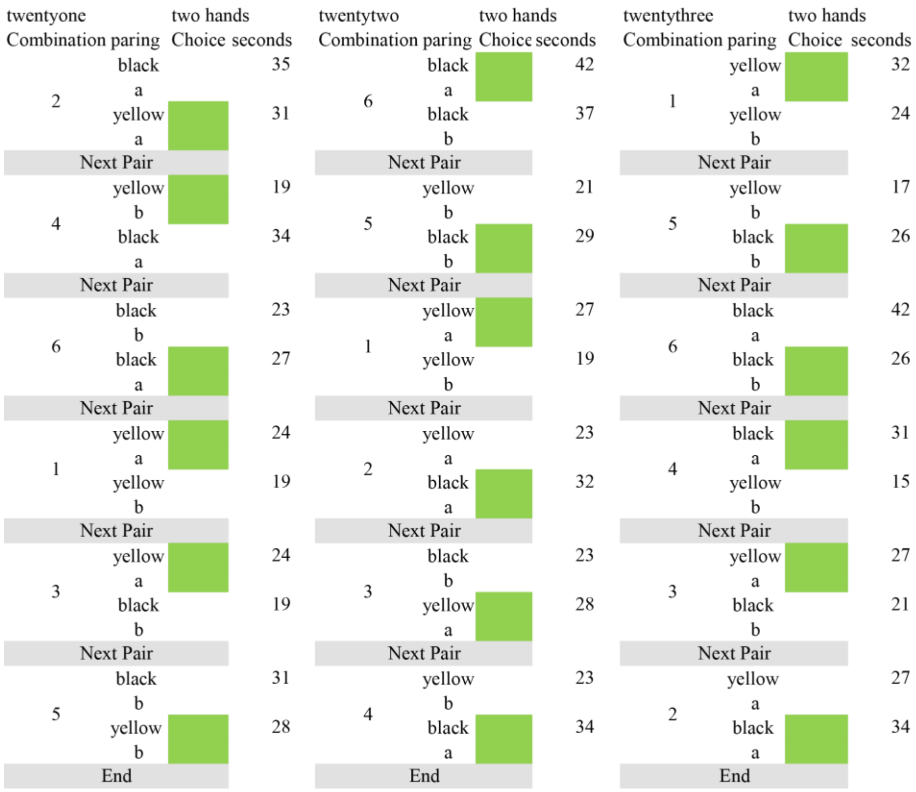
sixteen		two hands	
Combination	paring	Choice	seconds
3	yellow a	🟩	30
	black b		36
Next Pair			
2	yellow a		33
	black a	🟩	37
Next Pair			
6	black a		25
	black b	🟩	34
Next Pair			
5	black b		29
	yellow b	🟩	26
Next Pair			
1	yellow a		28
	yellow b	🟩	24
4	yellow b	🟩	19
	black a		31
End			

seventeen		one hand	
Combination	paring	Choice	seconds
3	yellow a		26
	black b	🟩	22
Next Pair			
6	black b		19
	black a	🟩	28
Next Pair			
1	yellow b		20
	yellow a	🟩	24
Next Pair			
5	black b		27
	yellow b	🟩	22
Next Pair			
4	black a	🟩	25
	yellow b		17
2	yellow a		22
	black a	🟩	24
End			

eighteen		two hands	
Combination	paring	Choice	seconds
5	black b	🟩	34
	yellow b		27
Next Pair			
1	yellow a		28
	yellow b	🟩	30
Next Pair			
6	black b	🟩	29
	black a		41
Next Pair			
2	black a		29
	yellow a	🟩	25
Next Pair			
3	yellow a		19
	black b	🟩	23
Next Pair			
4	yellow b		19
	black a	🟩	27
End			

nineteen		two hands	
Combination	paring	Choice	seconds
4	black a	🟩	34
	yellow b		21
Next Pair			
2	yellow a	🟩	27
	black a		25
Next Pair			
3	black b	🟩	20
	yellow a		23
Next Pair			
1	yellow b		19
	yellow a	🟩	24
Next Pair			
5	yellow b		16
	black b	🟩	26
Next Pair			
6	black a	🟩	28
	black b		23
End			

twenty		one hand	
Combination	paring	Choice	seconds
2	yellow a		28
	black a	🟩	39
Next Pair			
6	black b		28
	black a	🟩	25
Next Pair			
5	black b	🟩	28
	yellow b		22
Next Pair			
1	yellow a		34
	yellow b	🟩	21
Next Pair			
3	black b		26
	yellow a	🟩	21
Next Pair			
4	yellow a		18
	black a	🟩	22
End			



twentyone		two hands	
Combination	paring	Choice	seconds
2	black a		35
	yellow a	🟩	31
Next Pair			
4	yellow b	🟩	19
	black a		34
Next Pair			
6	black b		23
	black a	🟩	27
Next Pair			
1	yellow a	🟩	24
	yellow b		19
Next Pair			
3	yellow a	🟩	24
	black b		19
Next Pair			
5	black b		31
	yellow b	🟩	28
End			

twentytwo		two hands	
Combination	paring	Choice	seconds
6	black a	🟩	42
	black b		37
Next Pair			
5	yellow b		21
	black b	🟩	29
Next Pair			
1	yellow a	🟩	27
	yellow b		19
Next Pair			
2	yellow a		23
	black a	🟩	32
Next Pair			
3	black b		23
	yellow a	🟩	28
Next Pair			
4	yellow b		23
	black a	🟩	34
End			

twentythree		two hands	
Combination	paring	Choice	seconds
1	yellow a	🟩	32
	yellow b		24
Next Pair			
5	yellow b		17
	black b	🟩	26
Next Pair			
6	black a		42
	black b	🟩	26
Next Pair			
4	black a	🟩	31
	yellow b		15
Next Pair			
3	yellow a	🟩	27
	black b		21
Next Pair			
2	yellow a		27
	black a	🟩	34
End			

3. Components used; 28BYJ-48 stepper motor, ULN2003 driver and Arduino Uno. The programme below is specifically for the 28BYJ-48 stepper motor (see figure 8.1 for the circuit). A library (<AccelStepper.h>) needs to be downloaded and added to the Arduino library folder. The definition of the pins is shown in the beginning of the program. Void setup sets the position of the motor to 0. Void loop is the main program. This is where using the serial monitor you can send numbers to the program. Depending on which number is inputted (1, 2 or 3) the respective program is initiated. Number 1 initiates void Breathing14(). Number 2 initiates void Breathing20(). Number 3 initiates void off (). Within each void the speed and acceleration is set for the desired state. void sendData(int val) prints the motor position every second. This was used to create Graph 1.

```
#include <AccelStepper.h> // include library
#define FULLSTEP 4
#define HALFSTEP 8
// motor pins
#define motorPin1  4     // Blue   - 28BYJ48 pin 1 //define pins
#define motorPin2  5     // Pink   - 28BYJ48 pin 2 //define pins
#define motorPin3  6     // Yellow - 28BYJ48 pin 3 //define pins
#define motorPin4  7     // Orange - 28BYJ48 pin 4 //define pins
// Red    - 28BYJ48 pin 5 (VCC)
```

```
#define motorPin5  8     // Blue   - 28BYJ48 pin 1 //define pins
#define motorPin6  9     // Pink   - 28BYJ48 pin 2 //define pins
#define motorPin7  10    // Yellow - 28BYJ48 pin 3 //define pins
#define motorPin8  11    // Orange - 28BYJ48 pin 4 //define pins

void setup() { //Move stepper to position 0
  stepper1.setMaxSpeed(1000.0);
  stepper1.setAcceleration(550.0);
  stepper1.setSpeed(600); //motor speed
  stepper1.moveTo(0);  // this is where you set the position of the motor

  stepper2.setMaxSpeed(1000.0);
  stepper2.setAcceleration(450.0);
  stepper2.setSpeed(600); //motor speed
  stepper2.moveTo(0);  // this is where you set the position of the motor
  Serial.begin (9600); // initialise serial communications at 9600 bps:
}

void loop() {
  char option; // Converts a value to the char data type
  while (Serial.available() > 0) { // 3 options. 1, 2, and 3. When 1 is entered in the serial monitor Breathing14() will be initiated. When 2 is entered in the serial monitor Breathing 20() will be initiated. When 3 is entered in the serial monitor Void Off() will be initiated.
    option = Serial.read();
    if (option == '1') { // 14 bpm will be set
      Breathing14();
    }

    if (option == '2') { // 20 bpm will be set
      Breathing20();
    }

    if (option == '3') { // stop moving will be set
      off();
    }
  }
  if (stepper1.distanceToGo() == 0)
```

```
    stepper1.moveTo(-stepper1.currentPosition());
  if (stepper2.distanceToGo() == 0)
    stepper2.moveTo(-stepper2.currentPosition());

  stepper1.run();
  stepper2.run();

 // int tracking = stepper2.currentPosition();
// tracking = map (tracking, 225, -225, 0, 450);
//   sendData(tracking);
}

void Breathing14() { // set speed and accel to 14 bpm


  stepper1.setMaxSpeed(1000.0);
  stepper1.setAcceleration(800.0);
  stepper1.setSpeed(800); // motor speed
  stepper1.moveTo(225);  // this is where you set the position of the motor

  stepper2.setMaxSpeed(1000.0);
  stepper2.setAcceleration(400.0);
  stepper2.setSpeed(400); // motor speed
  stepper2.moveTo(-225);  // this is where you set the position of the motor

}

void Breathing20() { // set speed and accel to 20 bpm
  stepper1.setMaxSpeed(1000);
  stepper1.setAcceleration(800.0); //motor speed
  stepper1.setSpeed(800);
  stepper1.moveTo(225);  // this is where you set the position of the motor

  stepper2.setMaxSpeed(1000);
  stepper2.setAcceleration(800.0); //motor speed
  stepper2.setSpeed(800);
  stepper2.moveTo(-225);  // this is where you set the position of the motor
```

```
}

void off () { // default position no movement.
  stepper1.setMaxSpeed(1000.0);
  stepper1.setAcceleration(700.0);
  stepper1.setSpeed(600); //motor speed
  stepper1.moveTo(0);  // this is where you set the position of the motor

  stepper2.setMaxSpeed(1000.0);
  stepper2.setAcceleration(700.0);
  stepper2.setSpeed(600); //motor speed
  stepper2.moveTo(0);  // this is where you set the position of the motor
}

void sendData(int val) // prints the motor position on the serial monitor every second.
{
  unsigned long timeStamp = millis();
  Serial.print('H'); // unique header to identify start of message
  Serial.print(",");
  Serial.print(timeStamp);
  Serial.print(",");
  Serial.print(val);
  Serial.print(",");
  Serial.print('\n');
 }
```

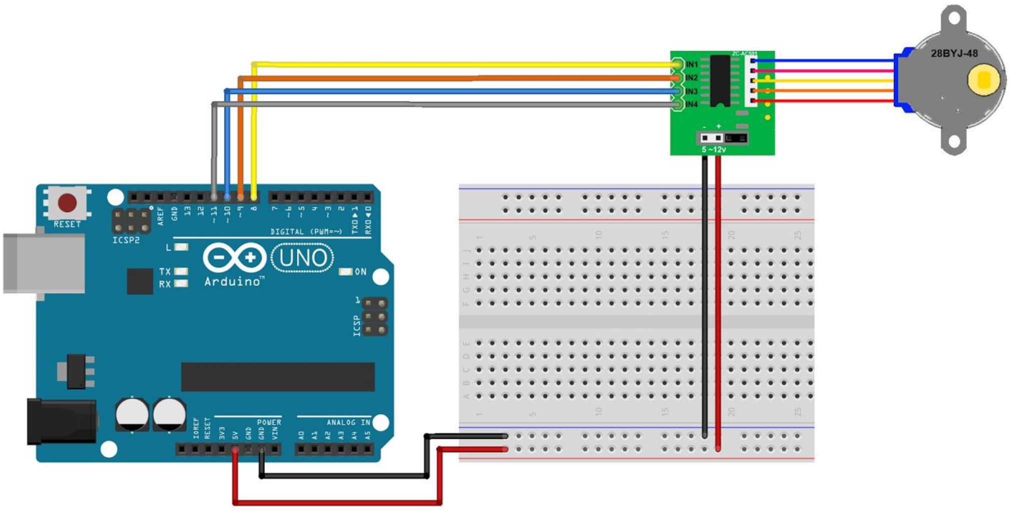


Figure 8.1: Image of circuit. Stepper motor to the motor board to the Arduino uno.