Intercorporeality with a Soft Telerobotic Incarnation.

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Abstract

This thesis is a post-phenomenological investigation into the use of soft robots as mediating bodies between humans that could unfetishise their imaginative figure of the stranger, in an event I call incarnation. Through my own encounters with Palestinians for the purpose of conflict resoluton and through readings of phenomenological and sociological studies, I determine the importance of the physical body, its fleshiness, nonlinearity and organic qualities for the construction of a meaningful and transformative dialog that can free us from stranger fetishism. Furthermore, I investigate the potential of nonhumanoid robotic avatars to liberate the interlocutors from prejudice and identity constraints. I propose the use of soft robots as a medium of re-embodidemnt that could factilitate massive scale physical incarnations, creating physical encounters between people who are unable to otherwise meet in person. As a proof-of-concet, a novel method for the production of soft robotic avatars is introduced, capable of bodily haptics, language translation and animalistic emotional expression, accompanied by a web based software platform for an easy development of applications. Using this method, *Hitodama*, a first prototype for a soft robotic avatar is produced. I perform an intial evaluation of the robot in an encounter between people of different cultures, using an example app in which they examine their bias and prejudice of one another. I analyze the results by conducting interviews with the participans, following the principles of interperative phenomenological analysis. Finally the broad potential of artistic craftsmanship to assist in political transformation is debated, reaching the conclusion that a scientific perspective could be applied not only to the creation of the piece, but also to the estimation of its societal effect.

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Introduction

Manifesto

"Man has to perform an act of incarnation, for he is dis-embodied (désincarné) by his imagination. What comes to us from Satan is our imagination" (Weil, 2002, p. 54). This intuition by French philosopher and political activist Simone Weil captures the core of this thesis and the underlying motives for the production of *Hitodama* - A soft robot for a mediated incarnation. My guiding principle is, and has always been since I was discharged from my military duty, the use of cutting edge technology for social well-being. Throughout my evolution as a developer, I slowly drifted away from paths of algorithmic rationality and abstract, alienated coding and into questions of meaning and existence. Following my Bachelor's degree in Philosophy of mind and Neurobiology, I have sought ways to transcend my institutionalized role of a programmer and apply the knowledge I have gained to challenge pressing issues of our society, and in particular, my own society in Israel.

Ever since its formation, Israel has been divided between two nations, Jews and Palestinians. Due to the events of the 1967 "six day war", and until this very day, most of the Palestinians reside under Israeli military occupation. Access restrictions enforced by the Israeli government prohibit the crossing of populations between the nations and inhibit the Palestinians' mobility. A 700-kilometer-long concrete barrier surrounds the "Green line" that separates Israel from the West Bank – the area that currently holds the largest population of Palestinians within the former mandatory Palestine that lies between the Mediterranean sea and the Jordan river. While the crossing of Israelis to the other side is, at best, frowned upon, and at worst institutionalized and encouraged in the case of settlements; the Palestinians endure stricter restrictions, not only across the West Bank, but also within it. Multiple checkpoints divide different areas of the land and force the Palestinians to face military control on a daily basis.

Growing up in a middle-class, liberal Israeli family, in Tel-Aviv of the 90s is a self-conflicting experience. The discourse oscillates constantly between hope for peace and prosperity to the despondence of war and carnage. The surrounding scenery changes quickly from a decadent lifestyle of beaches and high tech offices to a life amidst a war zone of missiles and suicide bombings. Throughout these changes, people are constantly immersed in media spectacles of tragedy that provoke our sensation of social unity; a sense that is reinforced by the nation wide military conscription and the omnipresent memory of the holocaust. From an Israeli liberal point of view, the conflict is associated both with guilt and resentment for the injustices toward the Palestinians, but also with necessity and a justification of self-defense against a lethal threat to the body of our nation. As a result of this strange mesh of emotions, one develops a self-contradictory and somewhat post traumatic image of the Palestinians: They represent, on one hand, a source of danger, and on the other, a marginalized and abused population. Their behavior is both condemned and justified, they are both terrorists and freedom fighters; they are to be reconciled with, but could not be fully trusted.

A phrase transition in my life occurred in the summer of 2012, when I landed on an opportunity to join a two-week conflict resolution workshop in Germany. The initiative, as started by an Israeli and a Palestinian who formed a relationship through mutual work, grouped young adults from both sides, carrying their hopes and doubts, to sit and talk together in one shared space. The participants in fact lived no more than a hundred kilometers away from each other, and yet, they were so infinitely apart in practical terms that the most reasonable place for them to meet was in a separate continent, 4000 kilometers away. Moreover, the two groups could not even meet during the journey to the Germany, because movement restrictions compelled the Palestinians in our group to take a detour through Jordan, rather than taking the shortest path through Israel's airport.

Since the conflict between the nations is very much situated in the land of Israel/Palestine, meeting at a relatively neutral and distant location was also constructive. As noted by Nietzsche (2001, p. 134) : "Egoism is the perspectival law of feeling according to which what is closest appears large and heavy, while in the distance everything decreases in size and weight". Albeit Germany plays significant role in the conflict with its great effect on the historical processes that lead to the formation of Israel as the home of the Jewish people, it was, nevertheless, easier for the parties to bridge the gaps without the unnerving presence of soldiers and the affect of this blood-soaked land.

Up until then, the closest encounter I have had with a Palestinian was an occasional crossing with a nearby "Israeli-Arab". This controversial term can be accounted for an attempt to sequester the national aspirations of the Palestinians that ended up under Israeli jurisdiction during the 1948 war for its independence (Peleg & Waxman, 2011, p. 26). To this day, the 1948 war marks both a national holiday for Israelis and a monumental catastrophe, or "al-Nakbah", for Palestinians, due to hundreds of thousands of them being driven out from their homes and becoming refugees in the neighboring countries. As for 1967 Palestinians that found themselves out of Israel's borders after its formation – they are currently living under either siege in Gaza or under military occupation in the West Bank. Naturally, my encounter with them has been strictly imaginative or digital – this was about to be my first physical encounter with the *Other*.

I remember the anticipation I felt as we arrived, in pouring rain, to our host institution "Jugendakademie Walberberg", a youth center and hostel in a remote village close to Cologne. The Palestinians were already waiting for us at the rendezvous point, waving their national flags, demonstrating unity. Upon meeting the embodied strangers face to face, I experienced what could be described not only as an emotional turmoil, but also to some extent a spiritual event. A vertical motion in which transcendental forces and ideas sedimented within a body, only so that they can once more coil up within themselves, and transcend along their historical contingency to emerge a true found *Logos* – the voice and ideas of the strangers in their corporeality. The *Other* was no longer a fetishized stranger, but a verified existence - Weil's intuition of incarnation was validated. After this event, I felt grounded, more open to difficult discussions and was able to obtain a sense of pain relief. It was as if the corporeal presence of the Palestinian in front of me had untangled and mended short-circuits that existed in my mind, and from then on, everything felt more natural.

At the end of the workshop in Germany, we were asked to think on how we can utilize what we had gained toward the upcoming future. At that moment, I felt a great sense of duty – I was to use my software engineering skills to bring about this event that I experienced to a massive scale, to enable conflict resolution for the masses until a critical point of the nonlinear system that is society is reached, and the democratic process is shifted toward peace-making. I did not consider at first that corporeity as such, is a crucial ingredient for this process. I simply aimed toward a free and expressive virtual encounter between conflicted strangers; whether through games, music, chatting or other forms of online communication. Now, however, I would like to contend that the virtual reality is insufficient for a true determination of history, and for a true transformation of the individual. Through the Merleau-Ponty's phenomenology and post-colonial theories of Sarah Ahmed, I would argue that a biomimetic embodiment is necessary for intersubjective dialectics that determine the style of our social existence. The physical flesh of our subjectivity in time and space, and our physical interaction with the other, demarcates our being in this world and form our social identity. This realization led me to pursue the technological solution for an efficient, mobile and expressive re-embodiment, a *techno-flesh*; one that can cross borders, separation barriers and facilitate events of incarnation when a physical encounter is not possible. I found the answer in the form of a soft Robotic re-embodiment, a modern-day incarnation, an Avatar for pain relief.

In this thesis, I establish a theorem regarding the importance of embodiment in social transformation; I then ask the question of whether a remote re-embodiment, a techno-flesh, could exhibit the same power for social dialectics as a direct encounter, and if not, how can we bring it as close as possible to the actual thing. I will outline my journey for constructing a telepresent soft robot that can serve as a mediator between subjects in conflict, knowing that I will first and foremost test it in the land of Israel and Palestine, but hoping that it can be applicable to any situation of conflict or other situations of social and physical gaps. The implementation is put to preliminary testing and is evaluated for future work. I invite the reader to join me on this journey of transcendent hope and corporeal suffering.

Thesis goals and method

The core question of this thesis is that of technological mediation. Despite the famous saying by post-phenomenoligst Don Ihde that "human activity from immemorial time and across the diversity of cultures has always been technologically embedded" (1990, p. 20), there is a vast spectrum of experiences that branch out of different technologies and different use cases of mediation. The saying is perhaps true in the broad sense of mediation, since we are always perceiving the world through matter, but it is not only the presence of the medium that matters, but also its style.

In any mediated interaction that is not a direct encounter in a shared physical space, a symmetry break occurs. The two conversing subjects are no longer sharing the same medium of communication as they would be if they were simply standing in front of each other; an experience gap is opened. The conditions of the two interlocutors could be quite similar, for example when two people are having a Skype call through their laptops, but in many other cases the situation can greatly vary, for example when one person is controlling a robot using their phone while the other is physically interacting with that robot. Thusly, if we want to consider the right medium for particular use case, we must look at the experience from three different perspectives: 1) In regards to the *receivers* communication at any given moment, How do they experience the presence of the *transmitter* with them in the same space? How much of the other side's corporeality is being perceived through the medium? For our use case, we would like the transmitter be incarnated, such that it could free the receiver of its fetish, prejudices and bias regarding the transmitter's body and identity. This aspect is discussed in the chapter titled **"Phenomenology of Incarnation"**. 2) In regards to *transmitters* of communication at a given moment, how much do they feel present in the remote location in their flesh? Do they have a sense of agency and ownership of their actions and do they feel freedom to express their core values? For our use case, the transmitter should feel comfortable discussing more intimate and even conflicted subjects as to generate empathy and obtain relief. This aspect is discussed in the chapter **"Phenomenology of re-embodiment"**. 3) In regard to mutual perspective of intercorporeality and multimodal communication, are there sufficient ways of expression for a meaningful encounter? Are there mechanisms of interaction and dialog that allow the interlocutors to bypass the hurdles of the medium and flow freely into conversation? This aspect is discussed in the chapter **Intercorporeality“**.

Once those aspects are determined, several choices of mediums are stacked up one against the other in a comparison chart, listing their advantages and disadvantages for the task from each of the research perspectives, finally explaining the selection of soft robotic telepresence as the medium of choice. In addition to the phenomenological analysis, more practical aspects such as accessibility and feasibility will be taken into account. With the chosen medium, the soft robotics research for *Hitodama* is presented, outlining the design choices and the production method for head, face, neck and arms along with phenomenological reflections. Finally, the user test is analyzed and the aesthetic implications are discussed.

Phenomenology of Incarnation

Stranger Fetishism and the Circulation of Emotions

We begin with a further investigation of the conditions that led to the above event of incarnation. As noted, prior to the encounter, I had nothing but an image of a Palestinian; the so called *Other*. An image that was fed by media, by conversations, by my own internal processes, none of which originated directly by a Palestinian, co-inhabiting my own time and space. I have developed a milieu of emotions toward this image that were by definition generalized and prejudiced, since they were oriented toward an abstract entity, a generalized identity. Moreover, these emotions tended to be posited on more extreme ends of the emotional spectrum, either being strongly negative or strongly positive.

This phenomenon is symptomatic to what is described by Sara Ahmed as "Stranger Fetishism". In her book *Strange encounters* she defines it as "a fetishism of figures: it invests the figure of the stranger with a life of its own insofar as it cuts 'the stranger' off from the histories of its determination." (Ahmed, 2000, p. 5). The epistemological gap of the stranger in its corporeality leaves an opening for an over-representation; a figure of our imagination that we endow with deep emotional value. Ahmed borrows the term "fetishism", both from a Marxist perspective of "commodity fetishism" and from a Freudian perspective of a phantasmic substitution.

Let us first examine the Marxist perspective. In *Capital: Vol I*, Marx explains his notion of commodity fetishism (Marx, 2015, p. 47). The fetishism lies in the Bourgeois's inability to discriminate between the commodity item's inherent and physical history - such as labor time, materiality and use, and its abstract value that is determined by the social relations of exchange: "A commodity is therefore a mysterious thing, simply because in it the social character of men's labour appears to them as an objective character stamped upon the product of that labour" (Marx, 2015, p. 47). When we assign a monetary value to a certain item, we in fact conceal the fact that this value is a result of a social and historical process, and it appears as if the value is an objective property of that item. Ahmed equates this process to the fetishization of the figure of the stranger. So in this case, the 'commodity object' that is tied to a material basis would be a corporeal person of some social identity, while the value that we assign to it is the abstract figure of the stranger. Much in the same way, we are prone to assign our prejudices, that are a product of social exchange, as actual qualities of a person. (TODO: Something about reification)

The Marxist analogy becomes even more interesting when we examine the economical circulation of emotions that are associated with the stranger. In her later book, *Cultural Politics of Emotion*, Ahmed identifies a relation between the circulation of abstract monetary value during commerce and the circulation of affect involving strangers in society (Ahmed, 2014, p. 45). In his discussion about the general formula of capital (Marx, 2015, p. 104), Marx explains the importance of the transition from the more simple form of trade: Commodity-Money-Commodity (C-M-C), to the more modern form of Money-Commodity-Money (M-C-M). In the former, more simple form, money is used only as an abstract mediator between two objects that are grounded in their materiality and use-value. For example one would sell their produced crop of corn to obtain money, which would then be used to buy cloths. However, in the latter form of M-C-M, the accumulation of abstract value is the end goal of the transaction, and since the only use of the money is to further accrue it, the process is endless.

Thus, value, or circulated capital “suddenly presents itself as an independent substance, endowed with a motion of its own, passing through a life-substance of its own, in which money and commodities are mere forms forms which it assumes and casts off in turn” (Marx, 2015, p. 107). The same effect, Ahmed suggests, occurs when the imaginative figure of the stranger, and its associated emotions are circulated throughout society. Ahmed provides as an example the discourse surrounding asylum seekers in the UK. Leaders of the conservative party have created a frightening image of the asylum seeker, one that is not only “flooding” and “swamping” the nation, but is also disingenuous in their intention; faking the need for asylum in order to be able to reside in the country. This discourse is passed around, from speech to speech, from media report to office conversations, all while breathing life into the imaginative figure and accumulating affect, intensifying the associated negative emotions. The reason for this intensification is exactly that which enables the accumulation of capital; its disassociation with anything physical that can set its bounds. According to Ahmed “The impossibility of reducing hate to a particular body allows hate to circulate in an economic sense, working to differentiate some others from other others, a differentiation that is never ‘over’, as it awaits others who have not yet arrived. Such a discourse of ‘waiting for the bogus’ is what justifies the repetition of violence against the bodies of others in the name of protecting the nation” (Ahmed, 2014, p. 47). She notes that her analogy to Marx is limited, since her “argument does not respect the important Marxian distinction between use value and exchange value” (Ahmed, 2014, p. 45)“, yet it is imperative to recognize the metaphysical similarity between the two notions of circulation. In both, a lack of access to the worldly *flesh* of things, whether they are a stranger or a commodity, drives the emergence of an abstract image. The circulation of the image in society only intensifies its perceived reality, and the powers the projection of strong emotions toward that image.Once an individual of the targeted group, let us say a Muslim asylum seeker, is encountered, whether through media or in person, an event occurs which Ahmed refers to as”the ‘sticking’ of signs to bodies” (Ahmed, 2014, p. 13). The accumulated imaginary value that was intensified by circulation *sticks* to the body of the stranger and appears as if it is an inherent quality of that body.

The discussion on projection and stickiness leads us to the Freudian view of fetishism. Ahmed suggests that the “process of fetishisation involves, not only the displacement of social relations onto an object, but the transformation of fantasies into figures” (Ahmed, 2000, p. 5), she slightly backtracks in the corresponding footnote (Ahmed, 2000, p. 182), arguing that the Freudian model is less suitable, since it privileges the phallus (or lack thereof in women), as that which is being concealed and substituted by the fetishized object. It is however important to note that in Freud’s account for fetishism, it is described as “habitually present in normal love, especially in those stages of it in which the normal sexual aim seems unattainable or its fulfilment prevented” (Freud, 1953, p. 154). Once more is the tendency to ascribe emotional value to an object, as a substitution for a physical state that is non-accessible. We can observe a similar notion at the other end of the emotional spectrum when dealing with the “uncanny”. The term was first explored psychologically by Ernst Jentsch (1997), defined as an uneasy feeling of “psychical uncertainty” (Jentsch, 1997, p. 5) that arises when something unknown and foreign is encountered in correlation to something old and familiar, for example when we are uncertain if a certain character is a human person or an automaton. Freud expanded on that notion, claiming that the “uncanny is in reality nothing new or alien, but something which is familiar and old-established in the mind and which has become alienated from it only through the process of repression”, citing examples of repressed phenomena such as “animism, magic and sorcery, the omnipotence of thoughts, man’s attitude to death, involuntary repetition and the castration complex” (Freud, 1955, pp. 241–242). Nevertheless, there is a resemblance between the uncanny and fetishism. In both cases, a certain inaccessibility to the true nature of an object, a certain gap, serves as an incubator for repressed desires or fears toward that object. The conviction that positive and negative emotions are in many occasions interchangeable is also supported by Ahmed (2014, p. 50). She defines hate as a form of intimacy that is in fact predicated by love, citing Gordon W. Allport’s classic account *The Nature of Prejudice*: “a symbiosis and a loving relation always precede hate. There can, in fact, be no hatred until there has been long-continued frustration and disappointment” (Allport, 1954, p. 215). This is all the more supported by neuropsychological studies such as one performed by Zeki and Romaya (2008), showing that hate and love share overlapping neuropsychological mechanisms.

Whether it is fear, love, hate or any other emotion, the impossibility of truly knowing a subject may lead to figure abstraction and ultimately to fetishisation: an emotionally attached relation between us and an imaginative figure. Such a relation, as any highly emotional attachment, is prone to addiction and obsessiveness. Moreover, as we’ve seen, the figure can gain a life of its own and intensify once it takes part in social circulation. Surly, this effect is not simply triggered on any subject that is only partially known; it requires a starting point, an initial value, a birth of a figure. It could be a reported incident involving an asylum seeker, or a mysterious encounter with an attractive individual. If out relation to the abstract figure would remain in the transcendent realm, it wouldn’t have been a major cause for concern, but the relation is naturally cast back into a living subject, resulting in peculiar behavior at best and violence at worst. It remains to be asked, how does one “truly” know a subject? How do we “unfetishise” the stranger? As Marx’s example suggests, there may exist a pivotal role to physicality, to corporeality. Thinking about today’s virtual and digital methods of social interaction, how does a typical WhatsApp conversation contribute to social relations? It is well agreed upon (TODO: **REF**), that indications of the users’ status such as “typing” or “seen message”, create mystery and thus only incubate the fetishized figure, not to mention more enigmatic ways of knowing individuals such as through their social feeds. Yet it seems that even a direct Skype conversation is somewhat lacking (TODO: REF?). The exact cause is elusive, and perhaps only manifests unconsciously, but a virtual encounter always leaves some room for interpretations regarding individuals and our relation to them. Is it body language that we are missing? Some nuance of speech that is not transmitted accurately over the fiber optic cables? Or is it something even more fundamental? To illuminate the significance of the intercorporeal interaction, we turn to the phenomenology of Maurice Merleau-Ponty.

Flesh and Intercorporeality

How is the physical different from the virtual? How is the real different from the imaginary? These kind of questions quickly evolve into the most fundamental questions of *being* and Consciousness. Queries that have troubled man-kind in both east and west since the beginning of history. However, we are not simply looking for any perspective on the meaning of life and existence; we are looking for one that bestows special status to the physicality and embodiment of the human connection. One that investigates into the corporeality of the *Other* as a medium and a foundation of affect and knowledge, that incorporates the *Other* into *Being*. There is no better place to look than the phenomenology of Maurice Merleau-Ponty.

Phenomenology is a discipline of philosophy that is firstly attributed to Edmund Husserl, but spans a wide range of thinkers and methods (Smith, 2018). Husserl defines it as a “science of essence”, pertaining to the a priori intuitions of consciousness and experience (Husserl, 1982, p. XXII). The discipline of phenomenology can be seen as a historical development which stems from the intuitions of the greatest thinkers of western philosophy such as Descartes and Kant; the intuition that if we are to know anything about the world, it has to start with our conscious experience and its intuitive structures. Merleau-Ponty joins this project with his most widely acclaimed work *Phenomenology of Perception* (Merleau-Ponty, 2013). In this work he reminds us that any pure conscious experience is nevertheless an act of the body, that perception is a bi-directional interaction of our body with the world, inhabiting time and space. This implies that “learning”, and even “thinking” are all intentional bodily actions upon the world, and should be investigated as such. According to Merleau-Ponty, insofar as we develop as a body, the range of possibilities is gradually “sedimented” into our physiology, and we become habituated, adjusted to the world that surrounds us. This is not a solipsistic act, since we always co-develop our social identity in concordance with other inhabitants of the world. Despite being written in the 1940s, this approach is relevant today even in regards to modern neuroscience, especially to researchers that inspect the brain as a self-organized non-linear dynamic system that dissipates into the open environment. One of those researches was Walter J. Freeman, a scientist of *Neurodynamics*. In his book *How Brains Make Up their Mind*, Freeman argued that the brain operates as a self-organized complex system of nerve cells, that is arranging its “attractor landscape” in concordance with the outside world. Input from the outside environment triggers this dynamic system into a trajectory of patterns that determines our behavior. Freeman cites Merleau-Ponty numerous times, asserting his intuition of bodily perception and assimilation of the world’s structures. (Freeman, 2000, pp. 125–127). An even more radical scientific manifestation of Merleau-Ponty's theories can be found in theories of *Quantum Neurodynamics*, that portray the brain as a dissipative quantum field that melds with the external world. Quantum neuroscience researcher Giuseppe Vitiello refers to the "openness of the brain to the external world" as dissipation (Vitiello, 2007); Merleau-Ponty uses very similar phrasings in his theories, maintaining his focus on the entire body, rather than just the brain. Such thought is linked to even more modern theories, for example regarding the roles that gut microbes play in shaping our behavior (Dinan, Stilling, Stanton, & Cryan, 2015). The intuitive investigations of Merleau-Ponty are proven to be scientifically sound even decades after they were written. (TODO: Write about Enactivism).

In final published works of Merleau-Ponty: *The visible and the Invisible* (1968), a work that is incomplete due to his untimely death at the age of 53 and was published posthumously, and *Eye and Mind* (1964, p. 159), an essay about aesthetics and metaphysics, Merleau-Ponty starts laying down his own ontology - the ontology of *flesh*. He critiques previous ontological interrogations of existence and begins to divulges his own theory, placing a great emphasis on how our relationship with the *Other* is crucial to our understanding of metaphysics; after-all, it is the basis for our existence as social beings. The underlying question, however, is still one of *knowing*. What exists? What is true? How do we make the logical leap from being immersed in a vivid experience of life, to devising positive facts about our world, ourselves and others? Merleau is critical of "philosophies of reflection", primarily referring to those of Descartes and Kant that could be considered as forms of Idealism. The proverbial *Cogito* - "I think there for I am", intuitively shifts our attention to the world of *thought*. We cannot directly know and access the world outside of our body, except through the mediator of thought. Through reflection and logical analysis, we deduce whether our experience is that of perceiving the real outside world, or that of imagining. By examining the consistency of change in our inner world, in relation to our actions and our body, we assert the geometrical rules of the world. Our interaction with the world is passive; we consume light that is coming from things, and organize it according to our logical structures. What does that suggest regarding our relation to others? "If then the others are thoughts, as such they are not behind their body which I see — they are, like myself, nowhere; they are, like myself, coextensive with being, and there is no problem of incarnation". Reflection is thus "the simple transposition of the incarnate subject into a transcendental subject and of the reality of the world into an ideality" (Merleau-Ponty et al., 1968, p. 31). Hence, intuitively we disregard the others in their physicality: "there is no intermundane space, there is only a signification 'world' " (Merleau-Ponty et al., 1968, p. 53). In *Eye and Mind* Merleau-Ponty argues that painting is the ultimate manifestation of *Being* in all its depth. A Cartesian view of vision however, is insufficient in its understanding of the world around us: "A Cartesian does not see himself in the mirror; he sees a dummy, an 'outside,' which, he has every reason to believe, other people see in the very same way but which, no more for himself than for others, is not a body in the flesh." (1964, p. 170). From these writings it is clear that this form of idealism is perilous, because it encourages the reduction of individuals to thoughts, of actions to signs and of bodies to images. Such a view may lead Sarah Ahmed's notion of fetishisation of the *Other*.

Idealism has another fundamental flaw in its logic, and that is its circularity - the fact that the rules of perception and the relation between subject and object, are defined using the same logical constructs that they induce. How could we formulate the relation between ideas and things, when all we have is our pure experience that has no inherent logic of subject and object? What is the primal a priori basis for the notion of space? Who is the circumscribed "I" that thinks therefore it exists? These logical loops sprouted other philosophies of experience, such as *Being and Nothingness*, the title of Jean Paul Sartre's essay on ontology (Sartre, 2012). Sartre recognizes that our subjective experience is in fact all there is, this *Being* that we endure encompasses everything and leaves no room for a subject or object. What then remains to our subjectivity is merely a vessel for *Being* - a *Nothing*, a negation of everything. We are solely a "a fissure that deepens in the exact measure that it is filled" (Merleau-Ponty et al., 1968, p. 53). Sartre states that "man is the being through whom nothingness comes to the world" (Sartre, 2012, p. 24), referring in fact to our freedom of choice. The ability of the human consciousness to create a distance from the totality of *Being*, to "secrete a nothingness which isolates it" (Sartre, 2012, p. 24) and to act for itself, is Sartre's idea of freedom. Nevertheless, Merleau-Ponty reminds us that our concrete body, our thoughts, our subjectiveness, those are all still parts of a *Being* that lies at a close distance to the nullified self. Where, then, is the place of the *Other* in such *Being*? It is clear that if *Being* is everything, then my body and situation share the same *Being* as the *Other*'s body and situation, an intermundane space is emerging. But more than a cooperation, the interaction with the *Other* is a vortex that drains into my nothingness: "The experience of the other's gaze upon me only prolongs my inward conviction of being nothing, of living only as a parasite on the world, of inhabiting a body and situation". (Merleau-Ponty et al., 1968, p. 62). The *Other* is there, reaching me, touching me, but I cannot reach its essence, it is transcendent. For me, there is only one nothingness and that is my own, my own freedom. I can only view the *Other* as a superficial clone of myself. This type of analysis, Merleau-Ponty states, "makes of the other an anonymous, faceless obsession, an other in general" (Merleau-Ponty et al., 1968, p. 72). As explained by Jack Reynolds (2014, p. 134), Sartre is accused of ignoring "the way in which otherness is always intertwined with subjectivity". This inscrutable gap between the *Other*'s will and the flesh of the world pushes us once again into the chasm of fetishism. In one of the footnotes in *The Visible and the Invisible* (Merleau-Ponty et al., 1968, p. 81), Merleau-Ponty notes a more general problem in what he names "philosophies of the negative", such as the one posed by Sartre: they tend to refer to to the problem of *the* other and not *an* other; "a non-I in general". This generality is exactly the type of abstraction that Sarah Ahmed is problematizing in her work. The connecting thread between *Stranger Fetishism* and the philosophical critique of Merleau-Ponty is our ability to view the *Other* as a subjectivity in the flesh, as a body whose consciousness is interconnected to our body, perhaps only then we can truly respect the other's alterity, inspect its nuances and perceive our interactions without prejudice. Merleau-Ponty defines this as _intercorporeality"_.

The final chapter in *The Visible and the Invisible*, titled *The Intertwining-The Chiasm*, is Merleau-Ponty's last and only attempt to devise a positive ontology of the world, the ontology of *flesh*. Albeit the thoughts end abruptly, this chapter and its surrounding notes and essays lay a foundation to a vast array of contemporary philosophy. Ironically, as a prerequisite to the ontology Merleau-Ponty asks us to give away our primal need for absolute logical truth, for a *thesis*. To retreat the Bird's eye view of idealized logic, to live in the moment. Any attempt for logical truth would be sucked into an enveloping *Being*, leaving only a void *Nothingness* at the core. Instead, he proposes a dialectic that is an endless interrogation, void of significations "We are not asking ourselves if the world exists; we are asking what it is for it to exist" (Merleau-Ponty et al., 1968, p. 96). It is futile to try and freeze the notion of *Being*, because we are an inseparable part of it. The world that we are trying to resolve is perceived only by us, a body that is part of that world. "The effective, present, ultimate and primary being…offer themselves therefore only to someone who wishes not to have them but to see them, not to hold them as with forceps, or to immobilize them as under the objective of a microscope, but to let them be and to witness their continued being" (1968, p. 101).

Our recognition of the world stems from the fact that we are of it, the seer is also visible. Our body perceives under the same rules that the universe operates, all made of the same *flesh*. Of course, we maintain our *invisible* state, our private experience of colors, sounds and feelings, but that experience is directly attached to the same flesh, and is a direct result of our body's openness to the world. Then, every action we take or idea we conceive is a physical response of our body to the world. The conception of an idea is nothing but "coiling up or redoubling" (1968, p. 114) of the bodily experience. It is out body sensing, then modifying itself, learning something new, only to once again open up and interact with the physical world, whether it is by speaking out or any other act. This is a somewhat of a general abstraction to John Dewey's "Learning by Doing" (1923): According to the theory of *flesh*, even reading a book would be an active physical movement upon the world in which our eyes touch the pages of the book as we sense reactive force with our entire body: "between my body looked at and my body looking, my body touched and my body touching, there is overlapping or encroachment, so that we must say that the things pass into us as well we into the things" (Merleau-Ponty et al., 1968, p. 123). Could an increased exertion of the body lead to an increased capacity of learning? A 2012 study by the Finnish national board of education reviewed the recent research on the subject and concluded that this is indeed the case, noting that "motor and cognitive skills would appear to develop hand in hand, because the same mechanisms of the central nervous system are responsible for controlling both motor and cognitive skills in parallel" (Syväoja et al., 2012). We are interested, however, not only in the learning and assimilation of simple facts such as Newton's law of mechanics, but also in the internalization of social meanings such as the image of the stranger or the acquisition of new behavioral patterns in society.

For Merleau-Ponty, our interaction with another human being is what validates our existence in this world, in the *flesh*. It provides us the recognition that we are visible as much as we are seeing. This recognition is based, according to Merleau-Ponty on a primordial intuition that we all all of the same *flesh* in the same universe, that our actions are undeniably seen by another as much they are seen by us. He makes the bold statement that the subjective experience of another is not completely hidden from us, because it is physically manifested in our shared space: "it suffices that I look at a landscape, that I speak of it with someone. Then, through the concordant operation of his body and my own, what I see passes into him, this individual green of the meadow under my eyes invades his vision without quitting my own, I recognize in my green his green" (Merleau-Ponty et al., 1968, p. 142). This recognition opens before us the entire universe of intersubjective being, since by transitivity we are all seen and touched by one another: "What is open to us, therefore, with the reversibility of the visible and the tangible, is— if not yet the incorporeal— at least an intercorporeal being, a presumptive domain of the visible and the tangible, which extends further than the things I touch and see at present." (Merleau-Ponty et al., 1968, p. 143).

This conviction could be interpreted in a weaker or a stronger sense. In the weaker sense, it lays the foundation to social aspects of contemporary cognitive science disciplines such as enactivism and embodied cognition, as well as philosophical concepts as Performativity. Research in those fields asserts that we define and express our social identity through bodily interactions with others - Through acting, reenacting and resonating to the physical actions of others. For example, the phenomenon of *mirror neurons*, although much more complex than the popularized interpretation of its name, is still being researched today and is exemplifying models of how the perception of bodily actions by another resonates within the correlating areas of our own motor cortex (Craighero, 2014). Another notable example comes from a phenomenon known as social rhythmic entrainment - It describes how people bond through synchronized movements, whether they are dancing together to the rhythm of music or or even walking at the same pace (Stupacher, Wood, & Witte, 2017). In the stronger sense, however, intercorporeality is not only our social, epistemic backbone, but our metaphysical one as well. It is constitutive to our sense of existence and our faculty of perceiving reality. This notion might explain why losing our social meaning may feel like a violation of our own existence. It also deepens role of physicality in our own subject of matter, the encounter with the fetishized stranger. If the bodily interaction with another is so significant that it reaches into the core of our being, it must be necessary for any kind of transformation to occur in our belief systems. In an interview with Dr. Yael Berda, an Israeli sociologist and political activist who focuses her work on the intrinsic social mechanisms of the West Bank occupation, she described her experience of crossing the separation barrier (Litman, 2018). According to Dr Berda, in order to relieve ourselves from our instinctive fear of the Palestinians, we must undergo a physical experience of crossing to the other side, because the fear is in the body. This sentiment is affirmed by Sarah Ahmed, who analyzes fear as dynamics of shrinkage and expansion of bodies: "fear works to restrict some bodies through the movement or expansion of others." (Ahmed, 2014, p. 69). For Ahmed, fear has an element of demarcation, effectively determining which bodies pose a threat and which bodies are under threat. It is then no surprise that Dr Berda, and myself included experienced such a transformation and relief simply through physical movement. The movement in itself was an act of liberation.

Now that we have determined the importance of corporeity for a transformative and meaningful social encounter, we must ask the question of whether an event of incarnation, i.e the physical grounding of an encounter with a body that previously existed only as a fetishized image of the stranger, can be mediated using technology. Such a mediation would clearly cause attenuation - A reduction and an abstraction of the subject's corporeality into a different set of signals. On the flip side, it would allow us to increase the accessibility of encounters, to perform them on larger scales and perhaps even to grant more freedom to the interlocutors as a result of the mediating layer serving as a protective shield. In essence, we wish to try and replicate as much as possible of Merleau-Ponty's concept of *flesh* when it is mediated by technology. The term *techno-flesh* was coined by Peter-Paul Verbeek, one of the pioneers of postphenomenology, as part a keynote he presented at Tel Aviv university (Verbeek, 2016). Postphenomenology, a discipline originally founded by American philosopher Don Ihde, seeks to explore the relations between humans and technology from a phenomenological perspective. We would turn our focus now to research in this field that may help in our quest for achieving techno-flesh.

Postphenomenology and techno flesh

In a work by Aud Sissel Hoel and Annamaria Carusi Merleau-Ponty's writings are analyzed in an attempt to extract his views on technology in relation to his ontology of flesh (Rosenberger & Verbeek, 2015, p. 73). According to Hoel and Carusi, the basis for Merleau-Ponty's view on technology lies within his general critique of what he refers to as an operationalist view on science, as outlined in "Eye and Mind" (Merleau-Ponty, 1964). Merleau-Ponty denotes the mistake in viewing the products of science as a representational reality, external to the things themselves and isolated from the bodily perceptive processes that conceived them. He compares that to painting, which he asserts is a direct manifestation of our intertwined experience of perception. The incorrect view on science is traced back to Descartes "whose theory of vision fails to recognize the internal complicity between vision and world" (Rosenberger & Verbeek, 2015, p. 78). However, Merleau-Ponty does not criticize Descartes' theory of a virtual mathematical space in itself, but only the operational way of thinking about that space as an ontological truth. His solution through flesh, according to Hoel and Carusi, is what differentiates the theory postulated in *Phenomenology of Perception* and his later writings. In *Phenomenology of Perception* Merleau-Ponty articulated the role of the body in raw sensory perception, but was unable to account for the creation of conceptual meanings, leaving us with a withstanding dualism of body and thought. With flesh, however, ideas, concepts, perception and matter are all of acting under the same fleshy medium. For this, Hoel and Carusi have "coined the term the "measuring body" to emphasize the "in-each-otherness" (Ineinander) of the material and ideational aspects of mediation" (Rosenberger & Verbeek, 2015, p. 79). A measuring body is anything that participates in a system of interaction in the common space of our universe. Since it operates within the same flesh, it exhibits what Merleau-Ponty refers to as a general style of being (Merleau-Ponty et al., 1968, p. 109) that can be recognized by any and intertwined with any fleshy agency. This includes both perception and ideation, but it is accentuated that in accordance with Jakob von Uexküll's notion of *Umwelt* (Von Uexküll, 1982), one that was also favored my Merleau-Ponty, each measuring body exists operates and transforms under its own world of meaning while still participating as a part of a bigger whole *interworld* (Hoel & Carusi, 2018, p. 16). The metaphor of *circuit* is also used to describe the "space of mutual and co-constitutive interactions" (Hoel & Carusi, 2018, p. 11).

How do tools and technologies participate in this fleshy circuit? Hoel and Carusi refer us to Merleau-Ponty's discussion on 'technical objects' in *Eye and Mind* (Hoel & Carusi, 2018, p. 20). While Merleau-Ponty's discussion focuses on the mediating and reflexive properties of paintings, he mentions them to be at the same category of tools and other techniques of the body that "outline and amplify the metaphysical structure of our flesh" (Merleau-Ponty, 1964, p. 168). For Merleau-Ponty, a painting is unlike a thing of all things that is observed passively by a viewer. A painting contains the embedded carnality of the painter and is constantly enacting the private experience of its creator in a dialog with the viewer. Nevertheless, we cannot overlook the fact the creator's body is seen as a point of origin, albeit being an ever-changing body schema that is in dialog with its environment, it is still recognized is the agency of the painting. It is there where Sissel and Carusi wish to take it further: "We further develop his idea of the body as a 'measure' of things by granting symbolisms and tools the status of 'measures' in their own right, that is, as 'agencies' with their own relative autonomy" (Hoel & Carusi, 2018, p. 23). Technology is seen as a "generative mediator" operating within and producing its own contingent dimensions: "For each modification new dimensions of the world open up, new ranges of possible modes of measuring and being measured" (Hoel & Carusi, 2018, p. 21). Thus, this goes beyond the decentralization of agency and into the decentralization of observation; the tools and technologies we create manipulate a shared space of perception. Sissel and Carusi recognize this approach resonates with contemporary posthumanist and new materialist approaches such as those of Karen Barad (2007) and Rosi Braidotti (2017). Such approaches open up the possibility of a mediated flesh, insofar as they recognize the interconnectedness of bodies and thoughts and the capacity for corporeality, and thus also intercorporeality, to be manifested remotely. However, they also risk the flattening of any experience to one variation in flesh, losing the meaning of a difference in form and function. We require a deeper investigation into mediation to determine its nature in social interactions.

Let us take a step back from the expanded conclusion regarding measuring bodies and focus on our scenario of mediated encounters between people. Clearly, not all mediations are one and the same and not all technological tools are utilized in a similar fashion. We are looking for a solution to a re-embodiment of the fetishized stranger; an incarnation that could carry the fleshy nature of the subject's body, along with its own mediating measures, and facilitate a relief from prejudice through communication. It would be worthwhile to return to Merleau-Ponty's analysis of painting in *Eye and Mind*, since this would be his most highly regarded example of mediated corporeality. Merleau-Ponty refers to an epitomizing discussion with French artist Auguste Rodin (Auguste Rodin, 2012, p. 34), analyzing the movement of a galloping horse in a painting by Théodore Géricault (see fig. 1).

Figure 1: "The 1821 Derby at Epsom" by Théodore Géricault, 1982. Retreived from Wikipedia (https://en.wikipedia.org/wiki/The_1821_Derby_at_Epsom). In the public domain.

Merleau-Ponty asks the following question: "When a horse is photographed at that instant when he is completely off the ground, with his legs almost folded under him—an instant, therefore, when he must be moving—why does he look as if he were leaping in place? Then why do Géricault's horses really run on canvas, in a posture impossible for a real horse at the gallop?" (Merleau-Ponty, 1964, p. 185). The answer if provided by Rodin: "It is the artist who is truthful, while the photograph is mendacious; for, in reality, time never stops cold". Even though the horse is painted in a position that is illogical, the movement is well transmitted from the artist's expression into the painting. Not only the movement, but the also the intention of the artist; Merleau-Ponty concludes: "Painting searches not for the outside of movement but for its secret ciphers, of which there are some still more subtle than those of which Rodin spoke. All flesh, and even that of the world, radiates beyond itself" (Merleau-Ponty, 1964, p. 186). It becomes clearer that an accurate mediation of flesh should embody not only the source's movements, but also their inner intentions, their creation and experience of the world. For example, compare a Skype call to a collaborative music jam. The Skype video transmission undeniably incorporates communicative features of the transmitter such as their voice and facial expressions, but it also loses part of the flesh. One difference between a digitally sensed representation and a painting or a musical composition is the passivity of the medium. With a camera, the transmitters are not actively involved in the creation of the resulting image, they are sensed by it, but the image forms on its own. It does not emerge from their flesh. Indeed, from a perspective of new materialism and measuring bodies, the camera sensor is very much intertwined with the source's flesh and should capture all of its qualities, but the difference lies in what Hoel and Carusi ascribe to flesh as "its formative role as productive negativity", alluding to Sartre's notion of secreted nothingness. Productive negativity is the reversible quality of flesh - the power to shift between phases as when one hand is touching the other and we shift between the perception of touching and the perception of being touched. The gestalt effect of our consciousness as a willful phase shift occurs and makes Noboyuki Kayahara's spinning dancer change direction (Parker-Pope, 2008). In short, it is the emergence of meaning that is actively created by a subject.

In this moment we are faced with a crossroads - We need to choose one of two strategies. Do we a) Focus on producing better and greater sensors, that are able to not only catch the most intrinsic and subtle fleshy qualities of the subject, but also represent them in an authentic manner, or b) Create more expressive tools that allow the subject to consciously and willfully express their own flesh, as artists do with painting. Granted, option (b) requires more effort from the interlocutors to be in touch with their inner qualities and to learn new and creative forms of expression, while option (a) defers the work to the technology, allowing the users to be more passive in communication. *Mindfulness* is a form of inner-self connection that could be used to improve self-expression. Numerous researchers have shown that mindfulness could have health and social benefits such as stress reduction (Grossman, Niemann, Schmidt, & Walach, 2004), greater empathy (Walker & Mann, 2016) and success in education (Leland, 2015). It is then apparent that opting for (b) could be beneficial for society while option (a) has a risk of doing the opposite. Moreover, in (b) the expressing subjects have a direct and controlled connection to the communication medium, allowing them learn and adapt to it, while in (a) there is an inherent barrier between the productive negativity of the subject and the medium, making adaption harder and more reliant on the technology. With this in mind we can move forward to considerations of the materiality and form for the medium of incarnation.

Materiality of Flesh

Merleau-Ponty describes flesh as “a certain manner of being” (1968, p. 115), as well as an essence or style of existence in time and space. This does not refer to some objective science of the universe such as the laws of quantum physics and general relativity. Instead, it is the essence of nature as it appears through our bodies; the laws of the universe as they are experienced, only later to be abstracted and induced through the ideation of math and physics, a pronounced physical act on its own right. In the previous chapter we have determined that an optimal medium for the transfer of a corporeality has to be expressive, but what about the materiality of that medium? While a painting may be best for capturing the visual corporeity of a subject, it is clear that Merleau-Ponty’s concept of flesh encapsulates other senses as well, and in fact he sees vision and all other senses as a particular type of touching: “We must habituate ourselves to think that every visible is cut out in the tangible, every tactile being in some manner promised to visibility, and that there is encroachment, infringement, not only between the touched and the touching, but also between the tangible and the visible” (1968, p. 134). Nevertheless, in his description of flesh, and in particular the description of intercorporeality, Merleau-Ponty assigns a special status to tactile sensing. When describing the reversibility of flesh, the power to shift our attention from touching and being touched, and when describing our body’s relation to things that exists beyond it. Merleau-Ponty articulates the difference between touching a thing, experiencing it from the standpoint of our body, and touching another, which we pre-reflectively recognize to be another sensing body: “For the first time also, my movements no longer proceed unto the things to be seen, to be touched, or unto my own body occupied in seeing and touching them, but they address themselves to the body in general and for itself (whether it be my own or that of another)…the body no longer couples itself up with the world, it clasps another body, applying [itself to it] carefully with its whole extension, forming tirelessly with its hands the strange statue which in its turn gives everything it receives” (1968, p. 144).

There is a special and immediate reciprocity that is associated with touch and bodily gestures; it is when our actions and intentions toward another are met with a direct response, when are physical presence and its affect on other bodies is most accentuated. Numerous researches have shown great correlation between physical contact and the cognitive development of sociality. It was shown that maternal-newborn contact has a long-term effect over a child’s physiological organization and cognition (Feldman, Rosenthal, & Eidelman, 2014) and that tactile interactions are constitutive to all of our social bonds (Goodwin, 2017). However, before going deeper into the intercorporeality of touch, let us consider its materiality. In our context, the term *materiality* is in accordance with N. Katherine Hayle’s definition of “the physical qualities that present themselves to us” [TODO: ref]. We cam regard materiality as phenomenological, rather than a scientific, analysis on the properties of matter. Archaeologist Lambros Malafouris follows the footsteps of phenomenology and new materialism, and with his vocational perspective, introduces a comprehensive framework for a body and matter based cognition dubbed the “Material Engagement Theory” or MET (Malafouris, 2013). While Malafouris does not directly address notions such as telepresence and re-embodiment, he does refer to the essential role of material properties in the emergence of meaning when using tools, focusing on activities such as clay making and knapping: “form is not imposed from the outside; it is, rather, brought forth or revealed from the inside. What we call”form” exists as a surface property rather than a static mental event. It exists where the projective mind meets the material at hand (stone, clay, or metal). More important, “form” is always “informed” by the properties of the material to which it gives shape.” (2013, p. 177). This view on tools and technology bodes well with postphenomenology, and indeed Malafouris and Don Ihde have produced a joint publication discussing the role of material cognition in creative processes (Ihde & Malafouris, 2018).

Despite the intuitive interface between MET and postphenomenology, a scant amount of research in those disciplines was dedicated to the understanding of how different material properties in modern technologies affect our cognition and modes of engagement. Perhaps this is due to the fact that the vast majority of our engagement with contemporary technologies of mediation involves gazing on flat display and interacting with them using limited touch gestures. One study by Blazquez Cano et al (2017) found increased user engagement on a touch display when shopping for fashion, but there have not been extensive inquiries into the dialectics between the human body and our devices for daily use. However, when seeking a technologically mediated experience that is more physical, and involves ample material engagement, it is apparent that the field of robotics could provide an answer. Robots come in different shapes, forms and materials, and our interaction with them has more physical depth. When considering the difference between the Cartesian view on reality and the richer, more corporeal notion of flesh, it is clear that interactive display fall in the former category while robotics have the potential to deliver a flesh experience of mediation. It is left to inquire about the various materialities of robots and their efficacy for a medium of incarnation.

While in industrial roots, the only consideration for material properties has been the capacity of the material to perform a desired function, three emerging technological fields are placing more emphasis on materiality. Firstly, the field of *wearable electronics*, consisting of functional garments, clothes and accessories that blend textile-based materials with electronic circuits, secondly, the field of *social robots*, that aspires to conduct intimate and harmonious interaction between humans and robots, and thirdly, the field of *bio robotics* that uses robotic actuators to perform medical operations on the human or animal body. As emphasized by Fortunati (2003) and Katz (2017), the underlying thread between these two trends is an attempt to unify the human body with information and communication technologies, or ICTs; to bring them closer and closer until the borderlines between the artificial and the organic vanish completely. As an umbrella term for robotics that use soft materials, the term *soft robotics* is now widely accepted [TODO: ref]. Elda Danese studies the cultural implications of the appearance of such "soft machines" [TODO: ref]. She notes how the elasticity of wearable electronics allows them to conform and adjust to underlying structures, granting the capability of the machines to adapt to the environment and the human body. She also notes how the use of soft materials in android robots is "altering their metallic and geometric qualities to achieve more empathetic, naturalistic form" (2015, p. 130). Interestingly, soft material technologies are being used not only to produce devices that try to mimic biological mechanisms and appear organic, but they are also producing futuristic forms, that while exhibiting flexible properties, still carry a post-human or non-human form. This is apparent not only in fashion-tech as noted by Danese (Danese, 2015, p. 137), but also in media art, as exemplified by Jonas Jørgensen, who both studies and utilizes soft robotic technology for artistic purposes. He notes that "soft robots are more often bio-inspired than biomimetic. That is, rather than being copies or technical remediations of biological mechanisms aimed at exact replication they extrapolate these,following their virtual lines of flight" (2017, p. 5).

Thinking about soft robots through the perspective of flesh, it is evident that soft materials have a better capacity to interact and synchronize with the human body and the environment. They are ontologically closer to the material properties of the human body and are more receptive of its intentionality and expression. Further more, there is another important quality of soft materials that should not be overlooked, especially in the context of flesh, and that is their style of movement. In a paper by Guy Hoffman of the Media Innovation Lab at IDC, Israel (2014), a convincing argument is outlined as to why we should pay more attention to movement, rather than just form, where designing robots, citing a body of research concerning non verbal acts and gestures in humans. From the point of view of phenomenology, this argument appears natural, as movement of the body is at the core of perception and in some cases even consciousness [TODO: Ref?]. We would dedicate more thought to matters of body language in the chapter about intercorporeality, but let us consider the role of materiality in movement.

Why is it that some materials seem to move in a style that appears more organic and more lifelike than others? We might think that an organic substance simply has more degrees of freedom, more plausible conformations and states of movement. But yet, some machines have an astoundingly complex inner mechanism with countless degrees of freedom [TODO: ref some clockwork thing?], yet on our view they do not portray the same materiality as organic entities. The answer may present itself when we consider the *linearity* of movement. If there is one repeating quality in natural processes, it is the self-organization of fractal-like patterns that emerge out of a complex dynamic of inter-connections [TODO: ref, strogatz!]. If there is one quality that defines those patterns, it is their nonlinearity. Organic substances and systems move in a style that is at the same time deterministic and predictable, but also non linear [TODO:

examples]. As for animal movement, the neuromuscular system itself exhibits nonlinear properties [TODO: Ref]. In the world of robots, even if an anroid's arm is covered with a soft material, when the android moves its joints, the linearity of the underlying servo motor is apparent. The software could even try to imitate nonlinearity by shifting the speed of the motor between steps, but the underlying discrete and linear materiality would uncover itself from beneath the flesh. That is not the case with soft robots made of silicone rubbers, textiles and other stretchable materials. Those materials have an inherent nonlinear dynamic style of movement. Even the most basic form of soft movement, a pneumatic system controlling the inflation of a party balloon, the movement seems more organic than that of the most expensive android robot. We have determined the importance of soft materials for an engagement with the flesh of a perceiving body, we can now summarize the logos of incarnation.

TODO: Can organic material be not uncanny.

The Logos of Incarnation

TODO: Positive incarnation VS negative reification / fetishim - Tulpa? TODO: Ranciere logos TODO: Form and fetish for robot TODO: The logic of incarnation

Phenomenology of Re-embodiment

Agency and Ownership

The term *re-embodiment* is used by postphenomenoligists such as Besmer (Rosenberger & Verbeek, 2015, p. 55) and Dolezal (2009) to denote a mediated experience in which a subject assumes another body, physical or virtual, in a remote location. A previous term used for similar experiences was *telepresence*, first coined by in 1980 by Marvin Minsky, who applied it to remote object manipulation applications and their teleoperation systems (Campanella, 2000). However, as Dolezal notes, telepresence is normally used to describe a functional scenario in which the remotely manipulated environment is real and does not apply to virtual environments. Insofar as the experiences of virtual reality, avatar gaming and robotic telepresence have a common phenomenological nature of assuming control over another body, they can be grouped together under the term of re-embodiment. How about a Skype conversation? We would be inclined to assume that this is not a form of re-embodiment, since although the users assume a form in a remote location (on somebody else's computer screen), they have no control over that environment and cannot manipulate it; they have no *agency*. But is that true? Imagine I was to shout so loudly during a Skype call that my voice broke a wine glass in a remote location, or that time the creators of South Park had trolled everyone's Alexa devices using remove TV screens (Lockett, 2017). A sense of agency could be achieved even with a minimal effect on the remote environment. A more clear example of a

Skype call that adds agency would be wheel based telepresence robots such as the ones produced by Beam (Patel, n.d.). In a virtual reality game, despite the fact that the environment I am manipulating is completely virtual, I still have sense of agency in that environment which contains my remote body.

The nuances of re-embodiment become more apparent when considering not only the notion of agency, but also that of *ownership*. Galagher (Gallagher, 2000, p. 15) distinguishes between agency and ownership such that agency is the "sense that I am one who is causing or generating an action, for example, the sense that I am the one who is causing something to move", while ownership is "sense that I am the one who is undergoing an experience". A lack of ownership could have moral implications on re-embodiment. According to Dolezal "Dissociation from ownership, induced by a lack of presence, has many ethical and epistemological implications and, furthermore, has phenomenological consequences in which the subject feels alienated from the actions he or she is performing" (2009, p. 218). Dolezal denotes an artwork titles "Legeal Tender" (Paulos, 1996) as the "first publicly accessible telerobotic website, where users, after agreeing to take full responsibility for their actions, could destroy or deface two allegedly real 100USD notes." (2009, p. 210). This action is criminal act in the United States, yet In a study done by Dreyfus it was found that "most participants in the experiment responded that they did not believe that the notes and the experiment were real, and hence did not feel as though they were placing themselves under any risk" (Dreyfus, 2000). This poses major concerns for more serious telepresence applications such as telesurgery, where a doctor uses a remotely controlled robot to operate on a patient's body. If a doctor does not feel present during the operation, their sense of accountability could be hindered, risking the patient's health (Dolezal, 2009, p. 211). An even more terrifying example comes from the world of remotely operated war drones. One study of drone killing in Pakistan between the years 2004 and 2009 found an usual amount of civilians that were killed by drones, citing the emotional and physical distance as one cause: "A 20-something Christian Air Force pilot living with her two children in suburban Las Vegas who views a monitor to locate her targets would seem to be as distant as a one can be from targets in rural, Muslim Pakistan. Television and YouTube video of drone pilots on the job reveal a set-up that looks very much like video game. These factors and others likely contribute to the high death rate among unintended targets" (O'Connell, 2009, p. 9).

According to Dolezal, the key factor that enables a sense of ownership is *proprioception*: the "kinesthetic and somatic sensations that permeate the body and give information regarding position, posture and movement" (2009, p. 219). Proprioception constitutes our *body schema*, a pre-reflective subconscious mapping of our body that allows us to act in the environment without explicitly thinking of each step and being aware of every movement. An emblematic highlighting the significance of proprioception is the case of IW, a man who has lost his of proprioceptive feedback due to injury (Gallagher & Cole, 1995). Despite the loss of this inner sense of the body, IW was not paralyzed and was able to re-learn how to operate in the world, however this learning was in a painstaking process in which IW had to forcefully map his intentions to the changes in his body; he had “lost the experience of body invisibility, which characterizes the normal and healthy experience of movement” (Dolezal, 2009, p. 219). Such an experience naturally entails a sense of detachment and alienation from ones own actions.

Phenomenoligists have shown how in the normal situation when the proprioceptive system intact, tools and technology could also be incorporated directly into our body schema. Merleau-Ponty’s famous example of the blind man’s stick defines the stick as “an extension of the bodily synthesis” (Merleau-Ponty, 2013, p. 176) and Don Ihde provides the examples of the eyeglasses - a relation in which “the technology becomes maximally ‘transparent.’ It is, as it were, taken into my own perceptual-bodily self experience thus: (I-glasses)-world” (Ihde, 1990, p. 73). However, as enunciated by postphenomenoligists, the experiences of telerobotics, avatar-based gaming and virtual reality are notably different from closely integrated tools and technologies such as the blind man’s stick and eyeglasses. Firstly, it is a matter of feedback - in order for the tools to be integrated into our body schema, there needs to be an immediate and consistent sensory feedback between the actions of our ‘original’ body and the mediated environment. Dolezal argues that the “coincidence of proprioceptive sensations to visual feedback of motion is the mechanism that induces a sense of ownership of action” (2009, p. 219), citing research by Martin (1995) and an experiment by Cole, Sacks and Waterman (2000). In the latter experiment, participants were controlling a robot from the driver’s seat in a mixed reality environment at the Johnson Space Center in Texas, experiencing immersive visual feedback to their actions from the robot’s camera. At one point the sense of ownership was sufficiently high to make participants worry when a heavy object was about to fall on the robot’s leg (Cole et al., 2000, p. 167).

While visual feedback that is concomitant to bodily proprioception is important for a sense of ownership, it may not be enough. Besmer argues the following regarding the transparent withdrawal of the controlling interface in robotic re-embodiment: “this second withdrawal is distantly different from the way in which bodily co-located tools and equipment—such as the blind man’s cane—recede from focal awareness to become integrated into the body schema. There is a decisive difference here, for bodily co-located tools become integrated into the body schema by offering robust tactile feedback and thereby participating in somatic proprioception. This is often not the case with remote robotic machinery” (Rosenberger & Verbeek, 2015, p. 61). Besmer suggests that the experience of robotic re-embodiment is more similar to IW’s case of a lack of proprioception than to the usage of blind man’s stick. Besmer argues that the same problem applies for virtual avatars in a simulated game - While the controlling technology may become transparent, especially in immersive environments, without proper haptic feedback that sufficiently transmits the sense of tactile nature of the remote environment, the avatar would always be at an infinite distance from the body.

Let us assume that mixed reality and telerobotics technology would eventually advance to a degree that they could transmit a high resolution experience to all senses of the controller. Dolezal's intuition is that "even the most seamless experience of high-fidelity telepresence will remain qualitatively different from that of engagement with one's immediate surroundings" (2009, p. 221). However, delving deeper into the difference between mediums, it is apparent that there is still a fundamental gap between a completely virtual reality experience and a telepresence in a remote environment. If we consider the possibility of techno flesh, there is an incommensurable difference in the dialog between the remote body and the environment. In the case of of a virtual environment, the environment is entirely simulated by software, while in the case of remote presence the environment is of this world. Notwithstanding the fact that the effect of the environment is eventually sensed and transmitted by an apparatus, a sensor that is placed in the world is still more far immersed in the flesh than a simulation. Having said that, there have been arguments, most notably the one by Bostrom (Bostrom, 2003), that we are likely to already be living in a universe that is simulated, but insofar as scientists are still struggling to grapple with the question in light of infinite micro and macro scale of the universe (Beane, Davoudi, & J. Savage, 2014), and insofar as we might not even be capable of dealing with that question because we are subjected to our own cognition of the world, the gap between the universe and our current knowledge of simulation holds firmly. A virtual reality experience takes us one step closer to the dualistic Cartesian-Lockian model of representational knowledge that is separated from our body, and such a model would have a greater risk of reifying our contrived images of one another, turning them into reality.

TODO: Ownership and how it is easy to press the virtual buttons even if it hurts the robot

TODO: Materiality paragraph

Re-embodied imagery

In Donna Haraway's seminal work *A manifesto for cyborgs, science and technology* (2006), she depicts a utopic techno-feminist vision of cyborgs - machine/organism hybrids that are freed not only of their military-capitalist creators, but also from sociological and biological constraints such as gender, race, sex and a need for reproduction. She wants us to transition from *body imagery* - An embodied conceptual cage that determines our world view and our political language, into *cyborg imagery* - A reconstitution of bodies and discourse "on the basis of seizing the tools to mark the world that marked them as other" (2006, p. 33). Nowadays, one might say that this vision is slowly realizing, with the advent of of social media as the de facto form of communication, virtual realities as a standard space for gatherings and technological modifications for the body becoming more and more prevalent. However, as Haraway noted, the confusion of boundaries with the help of technology calls for a skillful responsibility in their reconstitution: "is it not just that science and technology are possible means of great human satisfaction, as well as a matrix of complex dominations (2006, p. 39). Phenomenons such as cyber-bullying, public-shaming and virtual sexual harassment [TODO: ref?] prove that point exactly. We can now start to think not only about body imagery, but on *re-embodied* imagery: The effect that re-embodiment has on our world view and dispositions. This effect could be divided into two main categories: a) The effect on our social cognition that is due to the disassociation of agency and ownership. b) The effect of avatar's nature on our image of self and in turn our cognition.

As the previous chapter suggests, and as most likely any one of us has experienced, a reduced ownership in re-embodiment allows us to not feel as accountable for our actions as in face-to-face communication. This leads to two outcomes, a positive and a negative: a) responsible

TODO: Gender Neutral voice TODO: My cognitive science presentation. TODO: Also about the visual appearance in VR anecdote in Dolezal.

Intercorporeality

Multimodality and Social Semiotics

We would not be doing justice to phenomenology if we analyzed the experience of technological mediation between humans merely from the fixed perspectives of each side. While it may be true that every communication act ultimately funnels into the individual, subjective experience of the interlocutors, some aspects of the experience cannot be defined by a simple one-directional relation between the environment and the subject. Instead, it is a dialectical process in which the final experience emerges from the modes of dyadic interaction. In face to face communication, the majority of meanings are created using common language and through bodily gestures. When using a technological medium, however, some modes are of communication are no longer available, some morph into different styles, while other completely new modes of interaction appear. An analytical framework that is useful for investigating various modes of communication and their role in social meaning-making is the framework of *multimodality*, particularly in the light of social semiotics. As defined by Gunther Kress (2009), multimodality analyzes the different modes of interaction that are in play, while social semiotics deals with the specific meanings that emerge in specific situations. In-line with phenomenology, Kress suggests that we move away from more virtual definitions of communication such as language and grammar and focus on the materiality of meaning making - the specific modes and affordances of our body and senses: "the focus on on materiality offers the possibility of seeing meaning making as embodied - as in our bodies: a means of getting beyond separations of those other abstractions, mind and body, or affect and cognition" (2009, p. 83).

However, the robustness of mediated and re-embodied intercorporeal relations and their potential to exist through technology has been doubted by researches such as Dolezal (2009, p. 222), Dreyfus (2000) and Stone (1991). Insofar as the experience one feels when communicating with a remote or incarnated medium is that of disassociation and alienation, that feeling becomes two-fold when applied to the most delicate and significant aspects of intercorporeality.

Dolezal argues that "Physical contact and proximity between human subjects constitutes an important qualitative aspect of intersubjective relations that may never be obviated by technological mediums" (2009, p. 222). Dreyfus makes an even stronger argument, declaring "tele-intimacy" as an oxymoron - "because any sense of intimacy must draw on the sense of security and well being each of us presumably experienced as babies in our caretaker's arms. If so, even the most sophisticated forms of telepresence may well seem remote and abstract if they are not in some way connected with our sense of the warm, embodied nearness of a flesh-and-blood human being" (2000, p. 16). Both Dreyfus and Stone (1991, p. 13) refer to fact that a re-embodied body does not withstand physical risk to its composition, and therefore loses depth in the mediated interaction.

There indeed is no denying the potency of an immediate and imminent physical interaction, but we should also try to avoid romanticism, and without forgetting the Cartesian risk of losing our bodies in virtual flatness, consider the multimodalities of mediated intercorporeality and the affordances of various mediums.

Verbal Langauge

Elizabeth Keating has studied various groups that are using different forms of telepresence as their daily means of communication [TODO: REF]. She met with engineers who had to cooperate with people living in different locations around the world to achieve a single task, and also with gamers who were actually sitting together in one physical space, but were operating in a separate virtual environment where the avatars only shared an inter-virtual space, as opposed to the intermundane.

One key aspect in communication is that of language its own modalities of verbal content, tone of voice and bodily movement. In a seminal research by Albert Mehrabian in 1971 [TODO: REF], it was stated that in determining the credibility of a particular person during verbal interaction, only 5% of the impression is accounted to the actual content that is uttered by that person; 55 percent is accounted to body language and 38 percent is accounted to the tone of voice. While this paradigm has since been challenged by researches such as Phillip Yaffe [TODO: REF], the important role of bodily signals during verbal communication is unquestionable. As Keating notes, in situations where interlocutors are mediated by a technology "no shared metalanguage exists for them to talk about the role of bodies and how they mean in interaction (the engineers use the short hand descriptor "face-face" to mean the whole body). The movement and contrastive properties of eyes, the flexibility of the face to convey attitudes and emotions, the mobility of the hands to organize talk and manipulate objects, the sense of touch, the seemingly "natural" attitudinal displays of the limbs, and the body's relation to others' bodies" (2017, p. 305). However, technology also opens up new modalities and possibilities of communication, some of which may be used to mediate over the gaps that were initially opened in exchange for the increased range and mobility.

In Keating's study of the engineers group, she found that they adapted to the lack of bodily interaction by "shifting to other modalities…they used spoken or written language instead of embodied signals" (2017, p. 313). However, the use of language was not always constructive; when the engineers used language to describe more of their internal and logical state, such as the sentence "Are you ready to start", or "Do you want", more clashes and misunderstandings emerged, but when they used language in a more descriptive matter as in "I've got it open" the conversation flowed more easily. Additionally, when the engineers used language to query for feedback that is normally captured by gestures such as nodding, gaze and facial expressions, as in asking the other engineers by name whether they were following the discussion, they were able to facilitate better (2017, p. 315). In the case of the gamers, similar adaptions were observed by Keating, despite the fact the mediated environment was completely virtual. The gamers adapted to technological challenges by "carrying on a constant narration to others about aspects of embodied behaviors happening on screen that can't be seen by all players" (2017, p. 316). Using a constant flow of action-perception utterances such as "I see it", "I hear it" and "I'm doing it", as well as more specific descriptions of bodily states such as "I'm asleep" or "I'm immobilized". Albeit the situation of the gamers is qualitatively different than that of the engineers, insofar as the gamers were using language to describe their own mediated subjective state in a virtual environment, the shared element between the two scenarios is the use of different modalities through technology to make up for ones that are lost. While we may assume that nothing could beat the directness of the gaze and the touch, it is not to be ruled out that other active, expressive modalities as a substitute.

As the power of language in mediated situations is now stated, we could examine the current modalities of language and voice that are enabled by contemporary technology. In regards to speech, there are three main scenarios in which a synthesized speech could be beneficial in a dyadic conversation where no autonomous artificial intelligence entities are involved: a) As previously mentioned, voice alteration technologies allow us to alter our embodied imagery, such as having a gender-neutral voice or an alternative avatar from a fantasy world, b) Speech synthesis allows a person to be able to speak even in cases when a certain physical impairment hinders their natural voice, or c) Real time translation technology allows us to speak in languages that we never acquired. In cases (b) and (c) where we might opt for maintaining the original characteristics of our voice but augment it with certain capabilities, technology has the capacity to learn and mimic a personalized voice using recording data (Mills, Bunnell, & Patel, 2014). In case(a) we might opt for a completely new and fresh voice, and in that field companies are now competing on creating the most expressive and natural sounding artificial voice (Xue, Zhu, An, & Xie, 2018). Most of the contemporary technologies for speech synthesis now use deep neural networks in one way or another, a technology that is growing rapidly, accelerating the development of speech synthesis to unimaginable levels.

Emojis

A more recent modality that is associated with language is the use of *Emojis*. Emojis are a set of icons for the use of text based communication, standardized by the unicode consortium ("Unicode Emoji," 2019). They allow us to express certain emotions or situations in text, adapting over the aforementioned gaps in mediated expression. Emojis were found to correlate with human sentiment (Novak, Smailović, Sluban, & Mozetič, 2015), are studied by psychologists to analyze human behavior (Kaye, Malone, & Wall, 2017) and are even suggested to be used in scientific literature to add additional expressiveness to academic texts (O'Reilly-Shah, Lynde, & Jabaley, 2018) 😲. The use of emojis is an accessible and open method for expressing elaborate meanings just by using text messaging; the medium could then translate the emoji to other modalities, whether by just displaying it on a screen, or by appropriating sound, movement and other physical elements.

Emotional expression

TODO: Darwin

Body Langauge

An emphatically meaningful, yet highly elusive element of intercorporeality comes from our body language: Meaningful because despite Merleau-Ponty's claim that speech and even ideation are acts of the body, the directness of bodily gestures provide a clear connection between social identity and the flesh that envelopes them, elusive because a large number of these acts are picked up only by our subconscious and because the line between the authentic and the uncanny is sometimes invisibly thin.

Interestingly (as cited in Keating, 2017), blah

One area where body language and its affects on our psychology has been studied extensively is dance choreography, in particularly that of modern dance. Dance appears as an attempt to extract elements of bodily interaction from our daily social lives, and present them in an accentuated, distilled form. Sevdalis and Keller summarize a range of research papers articulating the connections between modern dance movements and our social cognition (2011).

TODO: Keating face to face focus on the lower part, and more highlights about body/gaze

ody/gaze.

TODO: From the end of Dolezal TODO: Recap Meyer / Keating TODO: Dialogism? TODO: Laban style TODO: Hapticl sociality TODO: Ruth Feldman

Mediation chart

The following chart blah

Medium	Incarnation	Re-embodiment	Accesbility	Feasibility
Bananas	2.0	4.0	2.0	5.0
Apples	3.0	1.0	3.0	5.0
Oranges	3.0	1.0	3.0	5.0
Melons	3.0	1.0	3.0	5.0
Plumes	3.0	1.0	3.0	5.0

Caveats

Technological bias

HITODAMA : Overview

The word "Hitodama" is Japanese for "Human spirit". HITODAMA is a post-humanoid, soft robotic avatar designed to contain a remotely controlling human consciousness and re-embody it in a non-human form while still maintaining some anthropomorphic features. The main use case for HITODAMA is mediation between distant and/or conflicted cultures that normally do not encounter one another, such as the idiosyncratic case of Israel and Palestine.

The design of HITODAMA has undergone several iterations and modifications before reaching its final form (see figs. 2, 3). The goal was to create a soft telerobot that can put the outlined philosophical theory to the test, providing an intercorporeal experience and enabling multiple modalities, all while using a modular and flexible software and hardware platform. Working with limited resources, a modular approach ensures that as much knowledge and products could be reused later for future iterations and ensuing research. This chapter outlines the primary inspirations and aesthetic references for the design as well as an analysis of related work, followed by an overview of the main features: its physical properties and logical subsystems.

It is important to note that although HITODAMA's design includes a moving and sensing tail, it was **not implemented** for this Master's thesis due to time and resource limitation. The tail is nevertheless shown here on the design specification in order to visualized the complete form of the conceived prototype.

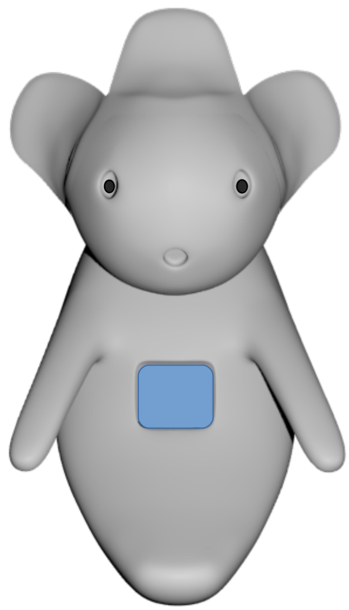

Figure 2: HITODAMA : Concept model.

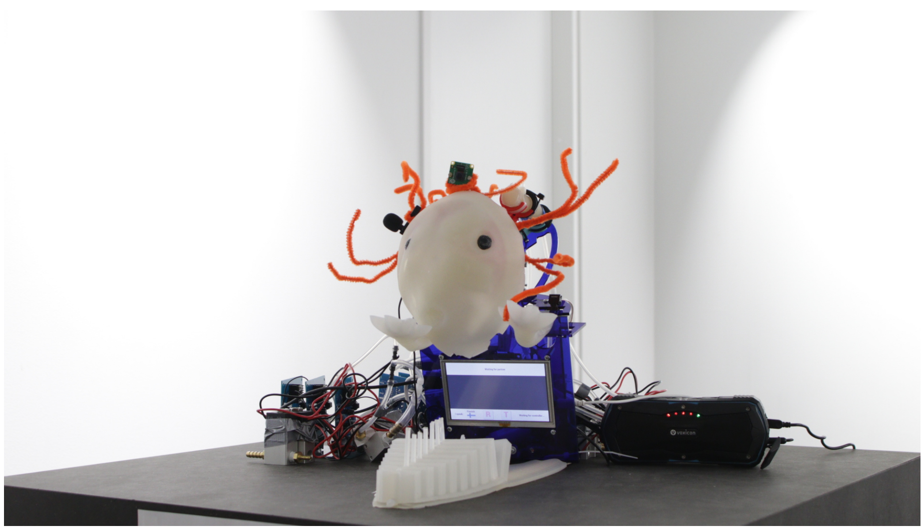

Figure 3: HITODAMA : Final prototype exhibition.

Related works

Aesthetic references

Shape - Hitodama - 人魂

The Kanji combination of the word hitodama is comprised of 1) 人 - Human and 2) 魂 - Soul or spirit. The term comes from ancient Japanese folk as part of Japan's vast folk culture of supernatural spirits and demons, also dubbed Yōkai (妖怪) (Goodman & Refsing, 1992, p. 83). The hitodama is the soul of a human as it leaves the body, much like re-embodiment could be seen as an act in which the human soul departs from its body and is then resituated in a new, robotic vessel.

The image of hitodama frequently appears in Japanese culture, ranging from 18th century art in Toriyama Seiken's book of demons: *Konjaku Gazu Zoku Hyakki* to the Nintendo game series *Yo-kai Watch* that features fighter cats equipped with supernatural powers and bearing hitodama symbols (see fig. 4). The hitodama shape resembles a cloud-like fire and is accompanied by a swirling tail. It is believed that the source for this form could have come from observations of shooting stars or of gas clouds that emerge out of human corpses. The swirling, fluid shape of hitodama spirits suits the curling and nonlinear nature of soft robotics, thus HITODAMA's shape is also inspired by this entity. A free vector icon of Hitodama by TopeconHeroes(2019) was chosen as the logo of the project (see fig. 5).

Figure 4: On the left: Hitodama from the Konjaku Gazu Zoku Hyakki by Toriyama Sekien. Retreived from Wikipedia (https://en.wikipedia.org/wiki/Konjaku_Gazu_Zoku_Hyakki). In the public domain. On the right: Komasan from Yo-kai Watch. Retreived from Yo-kai watch Wiki (https://yokaiwatch.fandom.com/wiki/Komasan)

Figure 5: Hitodama icon. Retreived from http://icooon-mono.com/11150-人魂のアイコン素材

Face - Kodama (木魅)

The Kodama is another form of Yōkai from old Japanese folk, described as a divine spirit that inhabits trees once they become more than a hundred years old (Papp, 2010, p. 14). The spirits may reside inside the tree without being seen, but may also present themselves in particular forms when encountered, such as the form of an old man in Toriyama Seiken's book of Yōkai (see fig. 6). In the Japanese classic *Tale of Genji*, the body of the princes Ukifune who attempted to drown herself, magically appears in the forest and is likened to a Kodama by the prelate of Yokawa (Caddeau, 2004, p. 11). In modern Japan, old trees that are said to contain Kodamas are revered and must not be cut down. A ceremonial rope known as *shimenawa* is tied around the tree to mark the presence of the spirit (Bigelow, 2009, p. 61).

Figure 6: "Kodama" (木魅) from the Gazu Hyakki Yagyō by Toriyama Sekien. Retreived from Wikipedia (https://en.wikipedia.org/wiki/Kodama_(spirit).

Kodama was popularized, however, by anime director Hayao Miyazaki. In the feature film *Princess Mononoke* (1997), the protagonists encounter a group of small forest spirits with glowing white skin and grey eyes. The style diverges from the original depictions, but according to Papp "Miyazaki's Kodama is a derivative of the yōkai Ninmenju (人面樹, Face Sap), which is another form of a tree spirit" (see fig. 7). The Ninmenju (sometimes referred to as jinmenju) "do not talk but they tend to laugh and when they do, they fall off the tree" (2010, p. 14).

An interesting characteristic of Kodama is the blend between the human, the natural and the supernatural. Miyazaki's Kodama are abstract nonhuman beings, yet they possess a human-like face, making them more relatable than a completely nonhuman entity. The intertwining of tree, spirit and human is an epitome to the Japanese culture of blending the human life force with nature. In one of the folk tales about Kodama, the tree spirit takes on a human form in order to meet a human it fell in love with (Katsumi, 1990, p. 335, as cited in Wikipedia). This blend is something to be sought after when designing an avatar. Finding the balance between the posthuman freedom (or the cyborg imagery as Haraway puts it) and Merleau-Ponty's pre-reflective relatedness to another human is the challenge HITODAMA attempts to tackle. Thus, the design of HITODAMA's face is mainly inspired by Miyazaki's kodama.

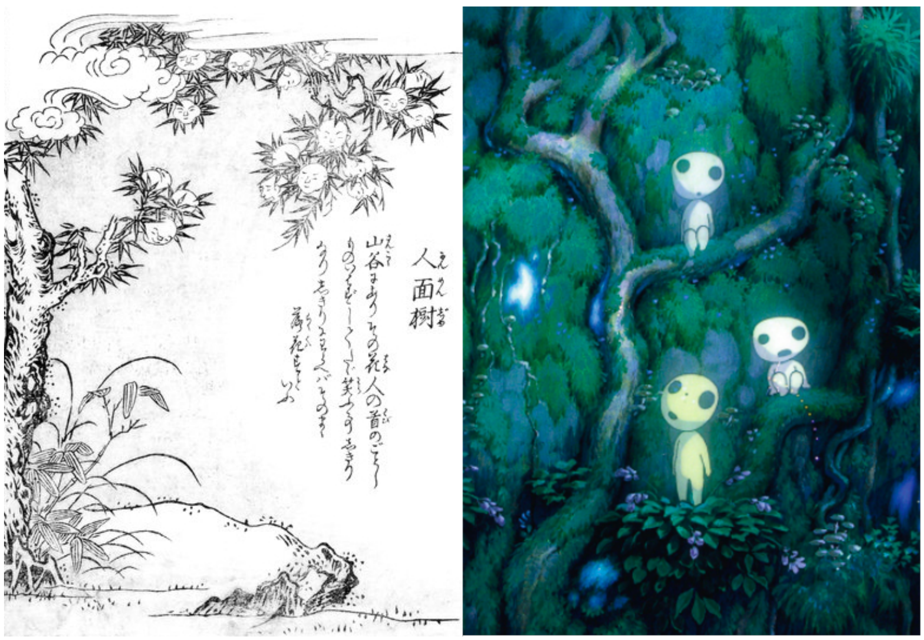

Figure 7: On the left: The jinmenju as illustrated by Toriyama Sekien. Retreived from Wikipedia (https://en.wikipedia.org/wiki/Jinmenju). In the public domain. On the right: Still from "The Princess Mononoke".

Axolotl

The axolotl is a Salamander, native only to the freshwater lakes of Chalco and Xochimilco in Mexico and is considered an endangered species. It lives inside water, not above, and is characterized by short limbs, a somewhat anthropomorphic face and a unique set of fiery red-orange gills on its head (see fig. 8). The axolotl is extensively studied by scientists due to its rare and exceptional biology: According to research the axolotl lives "perpetually in the embryonic state, a phenomenon called neoteny. It remains in the larval form even as it becomes a sexually mature adult. For this reason, it consists of embryonic cells that are capable of regenerating a foot, a limb, and even parts of its brain or spine. It does this without the production of scar tissue" (Tate, 2010).

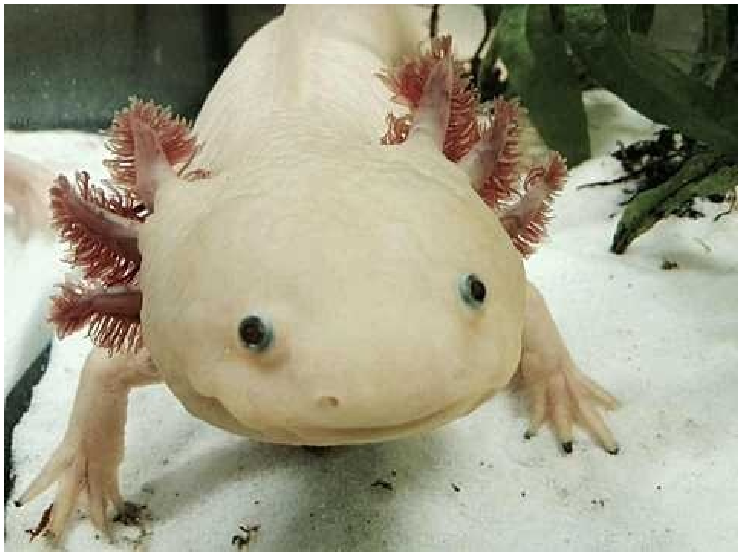

Figure 8: "An axolotl in captivity" from user th1098. Retreived from Wikipedia (https://en.wikipedia.org/wiki/Axolotl). In the public domain.

The axolotl is also a part of Aztec mythology in stories about the god Xolotl: the canine twin of Quetzalcoatl, the serpent god of wind and air (Tate, 2010, p. 518). Aptly, the story of the axolotl involves Xolotl's failed attempt to escape death. After it was decided that Xolotl and other gods would have to sacrifice themselves to bestow movement upon the sun, Xolotl tried to escape by transforming himself into different entities: First into types of canes and plants and finally into an axolotl, but all of the attempts failed and Xolotl died. It is unclear what information the Aztec had on the axolotl, but it is likely that they knew about its special regenerative abilities. It is also possible that the Aztec falsely believed the axolotl transforms itself into a tiger salamander because of their similar features, or because they were actually able to artificially induce the transformation as an extreme stress reaction (otherwise it does not happen) (Tate, 2010, p. 514).

Undoubtedly, the axolotl was used as a symbol for the flow of life between different organisms on earth and the earth itself and its motifs such as the gill stalk seem to appear in various arts and crafts as early as the Ayotla phase of the Tlatilco culture of ancient Mexico in 1200BC (Tate, 2010, p. 524). Even more so, Tate suggests that the ancient people of the Ayotla phase cleverly identified the connection between the regenerative, eternal larva form of the axolotl and the multipotent nature of the human embryo. Some symbols of the two co-appear in various crafts (2010, p. 528) and it is believed the Olmec people have studied embryonic evolution through observations of human gestation (Tate, 2008). Thanks to the theory of evolution, we now know that humans share plenty of genetic traits with other organisms, including amphibians, and that the early embryonic forms and larva embody those similarities insofar as they are visible before later differentiating into species-specific organs.

HITODAMA's body was not initially inspired by the axolotl, and was designed solely according to the aforementioned Japanese cultural tropes of spirits and ghosts. However, once the first prototype came out, people began likening it to the axolotl which motivated further research. Indeed, the properties and cultural heritage of the axolotl were found to be suitable for re-embodiment. The regenerative, almost immortal aspects of the axolotl allude to the eternal and transformative nature of a robotic re-embodiment. Furthermore, the resemblance of the axolotl to the human embryo as well as to Kodama suggests that a key enabler to the creation of a neutral yet anthropomorphic avatar may lie within the earlier stages of evolution, where some human traits are already developed and recognizable, but some are not yet visible. Donna Haraway completes the final piece of the puzzle when she discusses the regenerative aspects of cyborgs: "I would suggest that cyborgs have more to do with regeneration and are suspicious of the reproductive matrix and of most birthing. For salamanders, regeneration after injury, such as the loss of a limb, involves regrowth of structure and restoration of function with the constant possibility of twinning or other odd topographical productions at the site of former injury. The regrown limb can be monstrous, duplicated, potent. We have all been injured, profoundly. We require regeneration, rebirth, and the possibilities for our reconstitution include the utopian dream of the hope for a monstrous world without gender" (Haraway, 2006, p. 38).

TODO: Ishiguro's telenoids are embryos?

Material principles

HITODAMA is a soft robot made mostly from silicone. Silicone was chosen as the main soft element due to its robustness in movement, durability, nonlinear actuation and organic feel. However, HITODAMA also contains rigid materials such as a plastic backbone and metal screws. The material choices follow a simple governing principle: Any element of the body that **actuates movement** or **participates in tactile interaction** must be made from **soft materials**; movement and touch are the most critical modalities for an experience of intercorporeality. Other elements that act only as **structural support** are **made of plastic** and are connected either mechanically or with metal screws.

For the process of silicone casting, molds were experimented with a variety of materials: including PLA, polyurethane, metal, metal, acrylic and machineable wax. The molding materials are specified in the detail in the corresponding sections for each component.

Soft silicone

Two types of silicone are used following a simple principle:

1. *Smooth-On Ecoflex 00-30* (Smooth-On, 2019b): This softer material is used as outer skin that feel natural to touch and flexes easily. It is also

used for actuation of facial expressions since they are based on simple surface level balloon-like inflation.

2. *Smooth-On Dragon Skin 30* (Smooth-On, 2019a): This material is more rigid and offers higher kinetic performance for pneumatic actuation while still maintaining silicone's organic nonlinear style. It is used to create the underlying artificial muscles in HITODAMA's body.

Additionally, the Smooth-On Sil-Poxy silicone glue (Smooth-On, 2019c) was used for securing silicone tubes to actuators
and fixing occasional wounds.

Plastics

3D printed components were printed with PLA on consumer grade printers from Ultimaker and Lulzbot, while some components were printed with resin on a Formlab printer. Lasercut components used standard Acrylic glass.

Subsystems

HITODAMA's features can be divided into three separate subsystems: 1) Motor subsystem. 2) Sensor subsystem. 3) Digital I/O subsystem.

Motor subsystem

HITODAMA is pneumatic soft robot based on inflation of silicone actuators. Table tbl. 2 provides an overview of the different actuators and their function, accompanied by a visual mapping of the actuators (see fig. 9). A more detailed specification of each actuation will be specified in dedicated sections.

Table 2: Actuators in HITODAMA's motor subsystem

Body part	Type of actuator	Function
Neck	Fiber reinforced : linearly extending	Head yaw to the right
Neck	Fiber reinforced : linearly extending	Head yaw to the left
Neck	Fiber reinforced : linearly extending	Head pitch upwards
Eyes	Mounted inflatable actuator X 2 **	Face inflation above eyes
Cheeks	Mounted inflatable actuator X 2 **)	Face inflation below eyes
Mouth	Mounted inflatable actuator	Face inflation in mouth
Arms	Fiber reinforced : bending X 2 **	Arm bicep bend upwards
Tail*	Fiber reinforced : bending	Tail curve upwards

* The tail was not fully implemented and was not incorporated into the final prototype.

** Two separate actuators are joined as a single air chamber connected by a single splitting air tube.

Terminology wise, the term *Chamber* is used to described a pneumatic cell guarded by one inlet valve and one outlet valve. Different *actuators* could be joined using pneumatic splitters into one *chamber*.

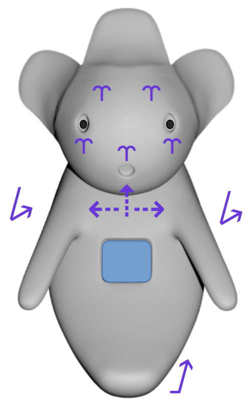

Figure 9: HITODAMA: Motor subsystem

Sensor subsystem

HITODAMA uses pressure sensing embedded into the silicone body on three different locations (see fig. 10): .

1. Left palm.
2. Right palm.
3. Tip of the tail*

* The tail actuator was not fully implemented and was not incorporated into the final prototype.

The sensor are able to detect when the body is being squeezed, as well as the amount of pressure exerted.

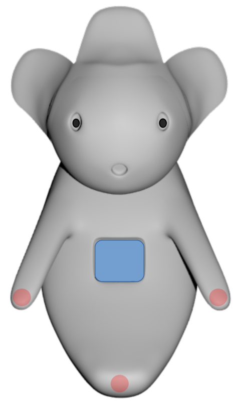

Figure 10: HITODAMA: Sensor subsystem

Digital I/O subsystem

HITODAMA employs web based digital I/O components that provide additional interaction functionality (see fig. 11). They include:

1. Camera: vision input.
2. Touch display*: visual output.
3. Microphone: audio input.
4. Speaker: audio output.

* The touch functionally of the display was not used in the final prototype.

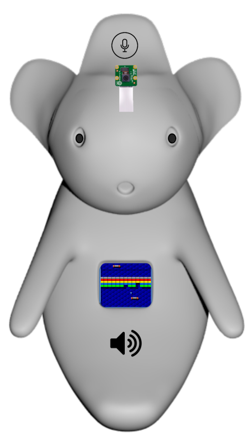

Figure 11: HITODAMA: Digital I/O subsystem

Face and head

Design

Appearance

Based on the face of Kodama, HITODAMA's head was designed with the help of Anderson Sudario in Kyushu University, Tomimatsu group (see fig. 12).

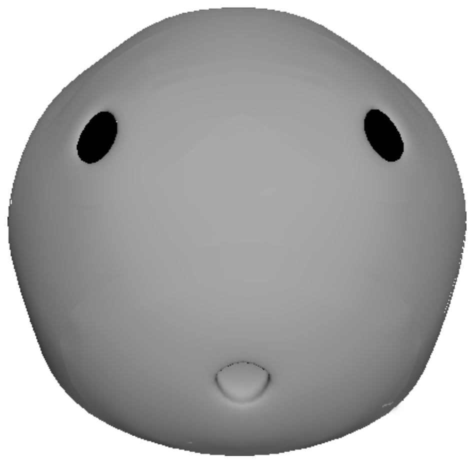

Figure 12: HITODAMA: Face model, with the help of Anderson Sudario.

Plastic Backbone

Following the general material principle, the head is supported by a plastic backbone (See fig. 13) that houses two types of soft components: 1) Facial skin that stretches along the circumference of the head. 2) Facial expression actuators that are housed inside the expression system.

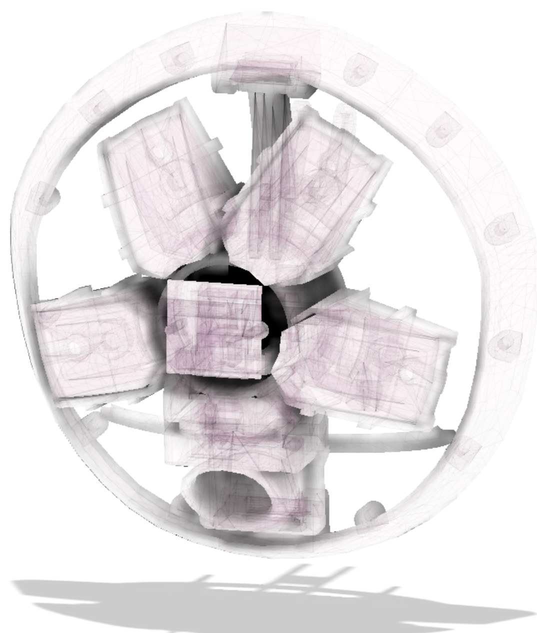

Figure 13: HITODAMA: Face plastic backbone, with the help of Anderson Sudario.

Modular expression system

For the purpose of researching and testing bio-inspired and organically actuating facial expressions, a novel system is presented. The system consists of a base rigid structure with multiple modular extensions that enclose the soft pneumatic actuators (see fig. 14). The enclosures can be freely added, removed and rotated within the upper 180 degree range of the face until the desired expression is achieved. Once inflated, the actuators are restricted by the enclosures such that they expand only toward the face and protrude a part of the skin, creating a facial expression (see fig. 15).

Additionally, an enclosure for a mouth actuator is added into the structure. The enclosure is printed using NinjaFlex flexible filament (NinjaTek, 2019) to further refine the movement of the mouth.

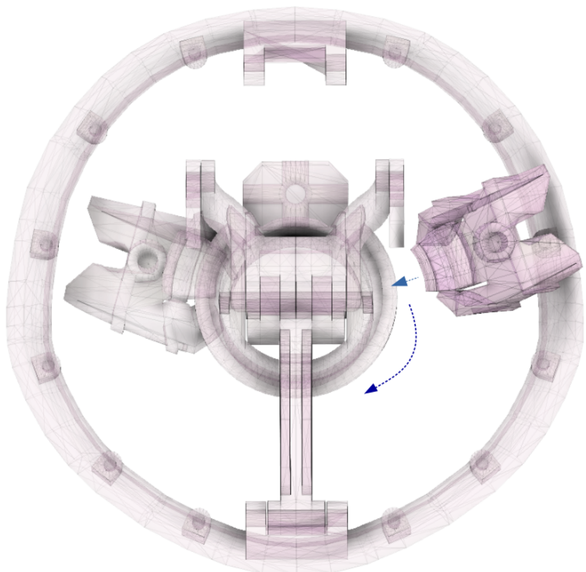

Figure 14: HITODAMA: Face modular expression system.

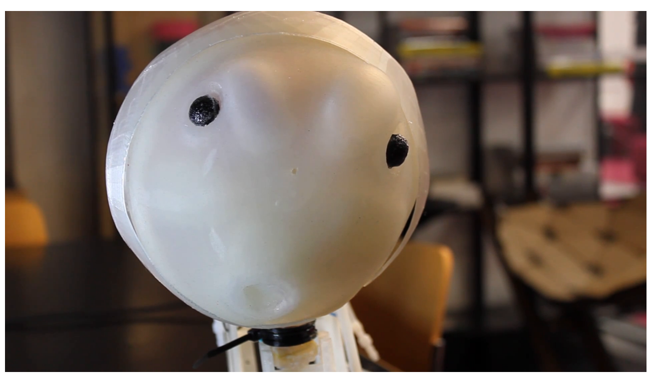

Figure 15: HITODAMA: Face modular expression example.

Method

Face skin

Casting of the skin was performed by 3D printing a PLA mold consisting of both the negative and positive forms of the face, and pouring Ecoflex 00-30 silicone in between the two parts (see fig. 16). The parts were then clamped together, allowing excess silicone to escape through the margins (see fig. 17).

Upon releasing the cured silicone, the mold had to be broken, possibly due to insufficient use of release agents during casting.

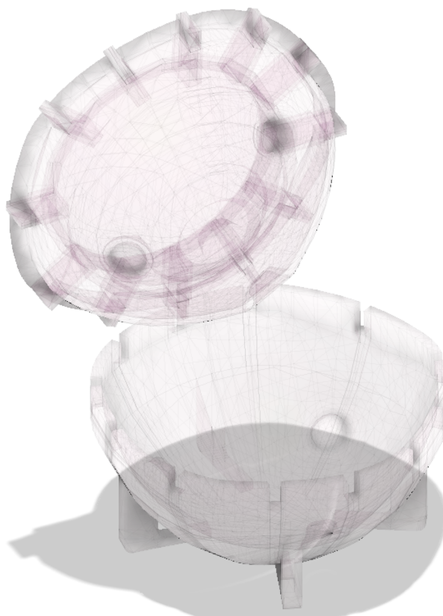

Figure 16: HITODAMA: Face mold, with the help of Anderson Sudario.

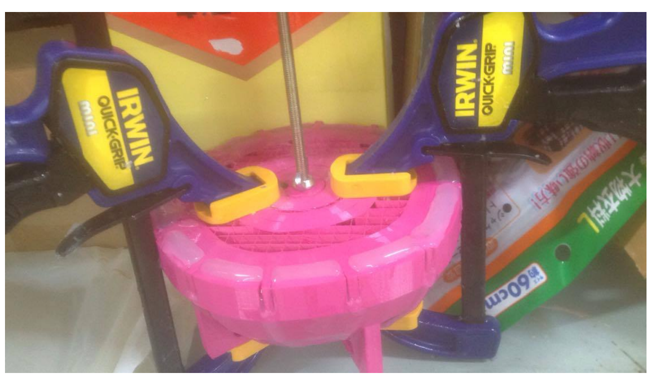

Figure 17: HITODAMA: Face mold clamping, with the help of Anderson Sudario.

Face actuators

Two types of face actuators were developed: 1) Modular actuator: an inflatable shaped that can be freely attached, detached and rotated around the face. 2) Mouth actuator: an actuator that fits distinctively into the mouth area. Molds were printed for both types using PLA (see [fig:face-actuators]).

The actuators were then attached into the 3d printed head backbone; two actuators above the eyes, two below the eyes and one mouth actuator. The location of the modular actuators was continuously tested and refined to achieve different expressions.

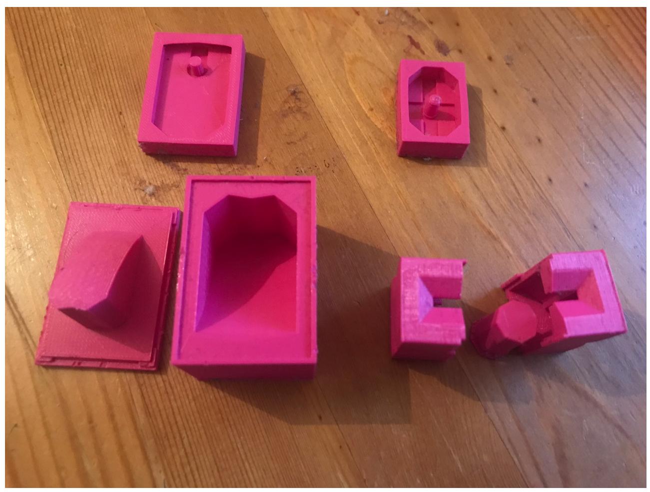

Figure 18: HITODAMA: Face actuator molds, with the help of Anderson Sudario.

Actuation

The face actuators were connected to the pneumatic system while having the two actuators above the eyes sharing an inlet, as well as the two actuators below the eyes. All together three different inlets were used for face actuation in the final prototype, namely “eyes”, “cheeks” and “mouth”.

Neck

Design

Movement

The neck is designed to grant four degrees of freedom (pitch and yaw) to HITODAMA’s head and was designed with the help of Joaquin Aldunate. The neck also provides structural support for the head, making sure it does not spontaneously tip or tilt over when idle. The movement is carried out by three linearly extending silicone actuators that are positioned in a triangular structure. The actuators are gripped by the rigid backbone support structure, shifting it as they extend (see fig. 19). When the right actuator extends, the head moves in the bottom-left direction, when the left actuator extends, the head moves in the bottom-right direction and when the bottom actuator extends, the head moves upwards. The combination of these triangular movements is sufficient for obtaining four degrees of freedom.

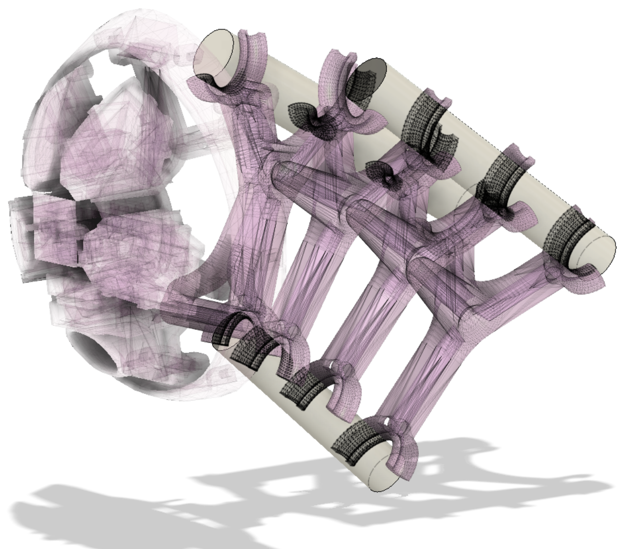

Figure 19: HITODAMA: Neck actuators, with the help of Joaquin Aldunate.

Plastic backbone

The neck backbone is made out of four triangular grippers that enclose the silicone actuators. The grippers are loosely connected to one another, allowing them to freely move in all directions, dictated by the extension of the actuators, without tipping over completely. The final gripper contains a handle that is attached to HITODAMA's head (see fig. 20).

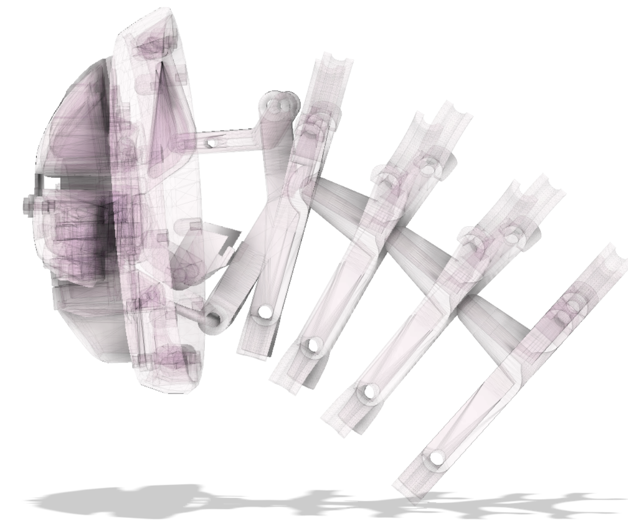

Figure 20: HITODAMA: Neck to head connection, with the help of Joaquin Aldunate.

Method

Fiber reinforced actuators

The linearly extending actuators are largely based on the work of Kevin C. Galloway of the Wyss institute in Harvard university (2013), but fiber-reinforced actuators have been around since the early 90s, when they were presented by soft robotics pioneer Koichi Suzumori (1991), now head of the Suzumori-Endo lab at the Tokyo institute of technology. The method was later disseminated by Harvard through the open source online toolkit: "Soft Robotics Toolkit" (Toolkit, 2019), contributing a great deal to the popularity and accessibility of soft robotics. Several changes were made in the neck actuators compared the original method by the Wyss institute, mainly: 1) The shape of actuator has changed to a whole cylinder instead of a half-cylinder to increase the structural stability of the neck. 2) The molds were modified for easier release, as well as designed for an injection casting method instead of pouring, for a minimizing the amount of bubbles.

The casting process follows a standard three primary step procedure:

1. Casting a Dragon Skin 30 muscle actuator tube around a metal cylinder. The spiral markings on the mold produce guiding notches for wrapping the fiber on the next step.
2. Wrapping the cured muscle with expansion restricting kevlar fiber in a double helical form and casting an Ecoflex 00-30 soft skin around the muscle.

3. Removing the metal cylinder, capping the actuator and inserting an air tube reinforced with silicone glue.

A customized mold set was designed and 3d printed for the procedure and a metal cylinder was prepared using a lathe machine. One mold creates a 1mm thick layer of Dragon Skin 30 around the metal cylinder (see fig. 21), while the second mold creates a 1mm thick layer of Ecoflex 00-30 around the Dragon Skin 30 tube (see fig. 22). The molds were designed with several mechanisms that aid in the release process. First, notches on both ends allow the insertion of a screwdriver to separate the parts. Second, holes for screws at the top enable the use of screws to pull out the top part.

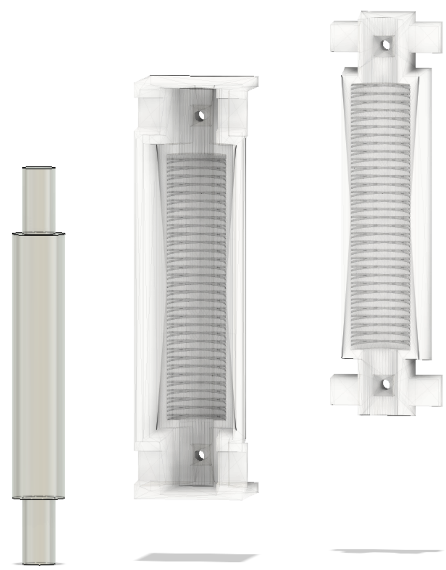

Figure 21: HITODAMA: Extending neck actuator, first mold, with the help of Joaquin Aldunate.

Figure 22: HITODAMA: Extending neck actuator, second mold, with the help of Joaquin Aldunate.

For the casting procedure, two more holes were built into the molds, one on each side. The silicone is injected using a syringe, from bottom to top, while the mold is tilted upwards (see fig. 23). This allows the bubbles to escape from the upper hole, leaving the remaining silicone bubble free. For this method it is important to always prepare about two times as much silicone as the mold require, insofar as the excess silicone is used drive the bubbles outside of the mold.

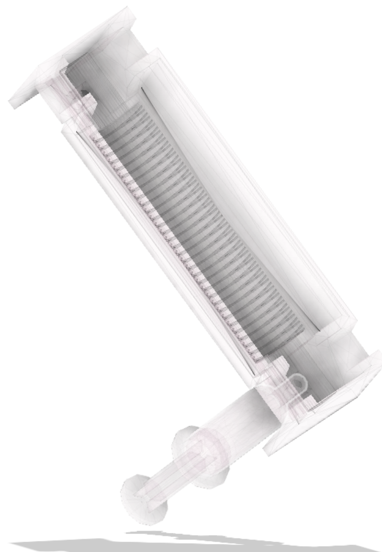

Figure 23: HITODAMA: Injection technique to the neck actuator.

Once the second step is done and the outer skin silicone cures, the metal cylinder can be removed. As shown on the soft robotics toolkit (Toolkit, 2018), the best method is to have One edge of the cylinder held in a clamp while Isopropyl alcohol is injected between the silicone and the cylinder; then the silicone can be smoothly removed from the rod by pulling it away gently.

The final step is capping both ends of the actuator by placing the silicone tube inside a cup filled with 20g of Dragon Skin 30. The inserted edge is wrapped around in gaffer tape to prevent excess silicone from sticking to the edge of the tube. Once both ends are capped, one end is punctured using a screwdriver or drill-bit, a silicone tube is inserted and glued with Sil-Poxy silicone.

Backbone

The backbone grippers are 3d printed, fit together and then reinforced using zip-ties (see fig. 24). One zip tie goes through the center of all grippers to reinforce the adhesion of one gripper to another, then each gripping handle is fit with zip-tie to grab a hold of the actuator.

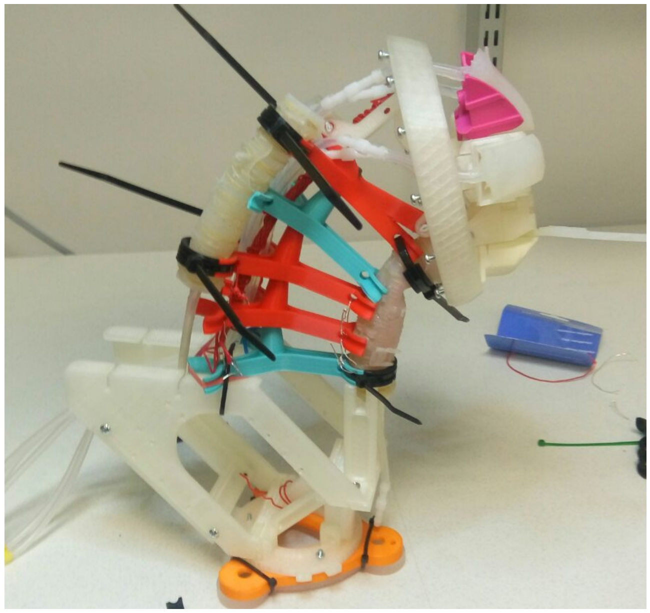

Figure 24: HITODAMA: Neck backbone ziptie reinforcement.

The backbone is then attached to head using the built in connection. The neck does not hold by itself, extended forward without being connected to a body structure that pulls the weight back. The body structure is detailed in the final section.

Actuation

The actuators all have separate inlets and are operated individually (see fig. 25). The rate and style of turn is controlled using control parameters to the release and inflation of air; this is detailed further in the section regarding the pneumatic system. A double spiral wrapping on the actuators with no restriction in the axial expansion direction ensures that the actuators only elongate, without changing their tubular form.

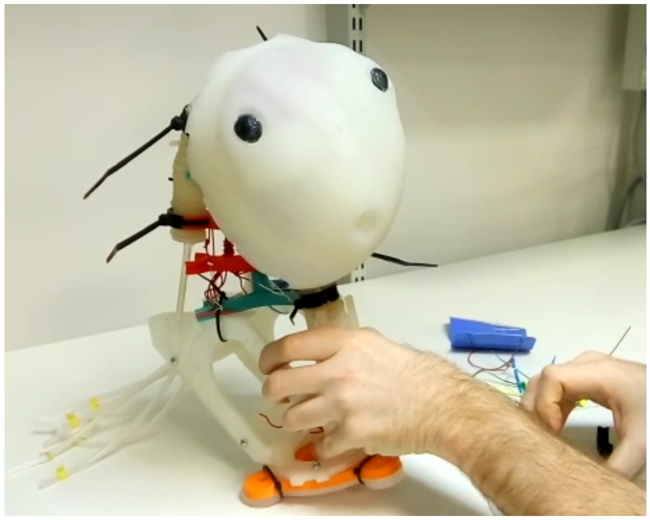

Figure 25: HITODAMA: Neck test, with the help of Joaquin Aldunate

Arms - Standard method for sensing soft body parts.

Design

Towards a standard method

The creation of HITODAMA's arms includes lessons learned from two years of experimenting with soft robotics, and is an attempt to standardize the creation of high performing, durable, cost efficient and environmental friendly soft body parts that are also touch and pressure sensitive. The method was designed with the help of Joaquin Aldunate.

The design builds upon the three step process used for the neck's fiber reinforced linearly extending actuators: 1) Casting of an elastic artificial muscle tube with high performance silicone (Dragon Skin 30), 2) Wrapping the tube with restraining fibers and casting a soft skin around it (Ecoflex 00-30), and 3) Capping the actuator and attaching a silicone tube air inlet. However, the new design offers considerable improvements over the previous line of actuators: Firstly, the molds are now synthesized using subtractive manufacturing with CNC milling rather than 3d printed additive manufacturing. 3d printed molds that are produced layer by layer, however thin the layers may be and whatever coating materials are used, are unable to reach the level of surface smoothness that one may get in subtractive synthesis. A non-smooth mold surface results in a non-smooth product that is difficult to release and vulnerable to injury. Secondly, the skin mold now supports any custom shape, as long as it is not too big to be actuated by the inner muscle. This allows us to design the form of the soft body part independently of the actuating muscle. Thirdly, the design takes into account the requirement of pressure sensitive sensing built into the actuators and offers a simple method to embed pressure sensors into silicone. Finally, the designs aims for cost efficiency and sustainability by opting for a custom machineable wax material rather than expensive and potentially toxic rigid plastics.

Movement

HITODAMA's arms act as the main physical control interface between the controller and interlocutor; the signal is sent by squeezing the hands of the arms and can be used on a variety of applications.The soft movement offered by the arms is that of bending, giving the impression that the robot body is opening its arms toward the user or closing them in a way that the control becomes inaccessible (see fig. 26). This gives the controllers some power over the interaction, allowing them to decide when the interface can or cannot be touched.

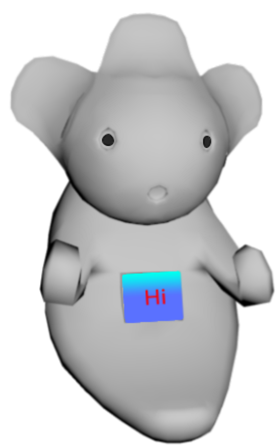

Figure 26: HITODAMA: Arm bend.

Sensing

The sensing is centered on the arm's palm, allowing users to squeeze it to pass a signal (see fig. 27). Different signals can be passed when both palms are squeezed simultaneously or individually, and depending on the time pressed. Additionally, the amount of pressure exerted on the palm can be measured, allowing refined control over variable reactions.

Figure 27: HITODAMA: Palm squeeze.

Method

Machineable wax

The method for producing machineable wax follows the one posted online by the Leeds hackerspace (Hackerspace, n.d.): paraffin wax is mixed with recycled LDPE plastic pellets in a 1:4 ration; four parts of plastic per one part of wax. The parts are mixed together in a consumer grade deep fryer and wax based crayon color is added for appearance (see fig. 28).

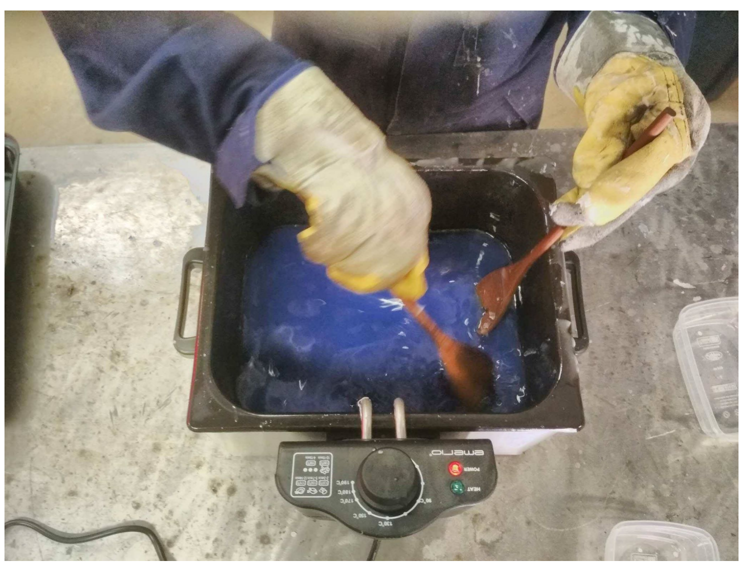

Figure 28: Machineable wax mixing.

Once the mixture is uniform, it is poured into a metal pan and left to cool and dry for the day (see fig. 29). It can then be removed from the mold and used to on the CNC milling machine (see figs. 30, 31).

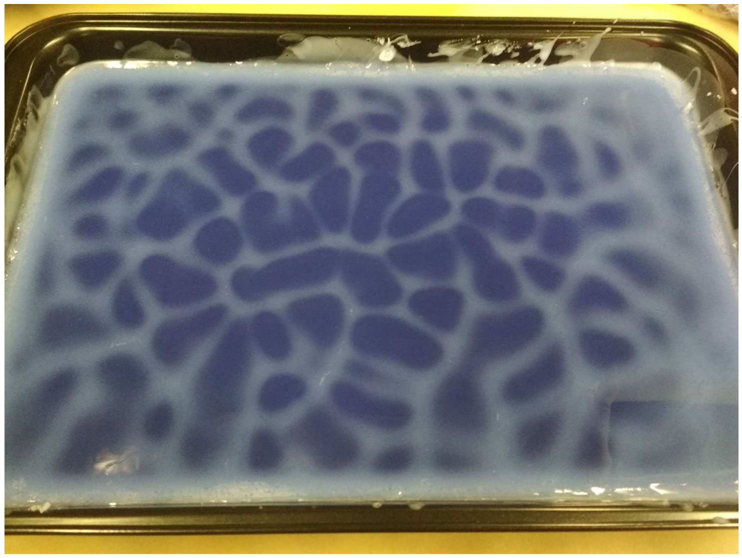

Figure 29: Machineable wax, interesting patterns are formed during the cooling process.

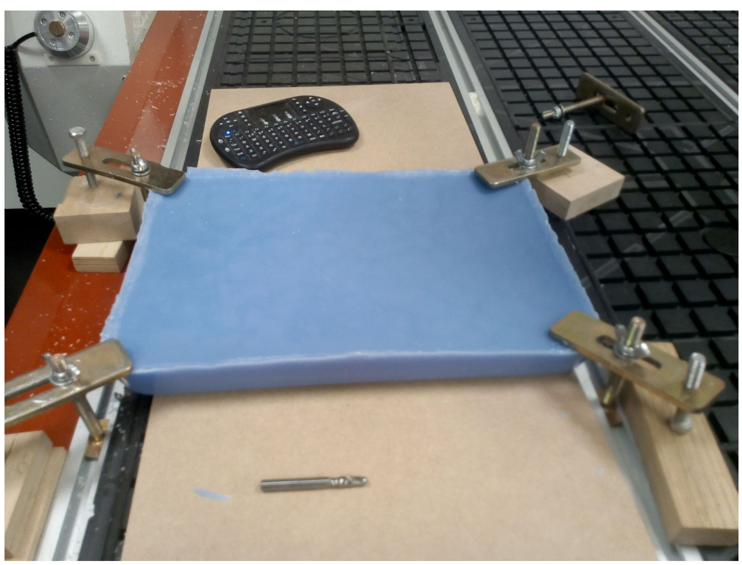

Figure 30: Machineable wax, ready to be milled.

Figure 31: Molds for HITODAMA's arm made from machineable wax.

While the machineable wax didn't exhibit top-grade surface finish levels like those of expensive polyurethane compounds, it was certainly smoother than 3d printed parts and was very easy to mill. Machineable wax is more environmentally friendly than polyurethane since it is not only produced from recycled plastics, it can also be recycled on its own: Once the molds are no longer of use, the wax can be melted back and cast into the pan for re-use. If the CNC machine is equipped with a vacuum that sucks off the scrap while cutting the part, close to zero-waste manufacturing can be achieved.

For making the arm, the first set of molds was milled from machineable wax. After a round of testing and fixes, the final molds were milled from polyurethane to ensure the highest quality product.

Step 1 mold: Artificial muscle actuator

The casting of the muscle actuator is the first step of the casting process. The mold for the muscle (see fig. 32) is composed of the following parts:

1. Main mold for producing the muscle tube (CNC milled).
2. Half-cylindrical metal piece for producing the air compartment (made using lathe).
3. Modular base piece for securing the metal part (CNC milled).
4. Bottom piece space filler (3d printed).
5. Transparent acrylic cover (laser-cut).

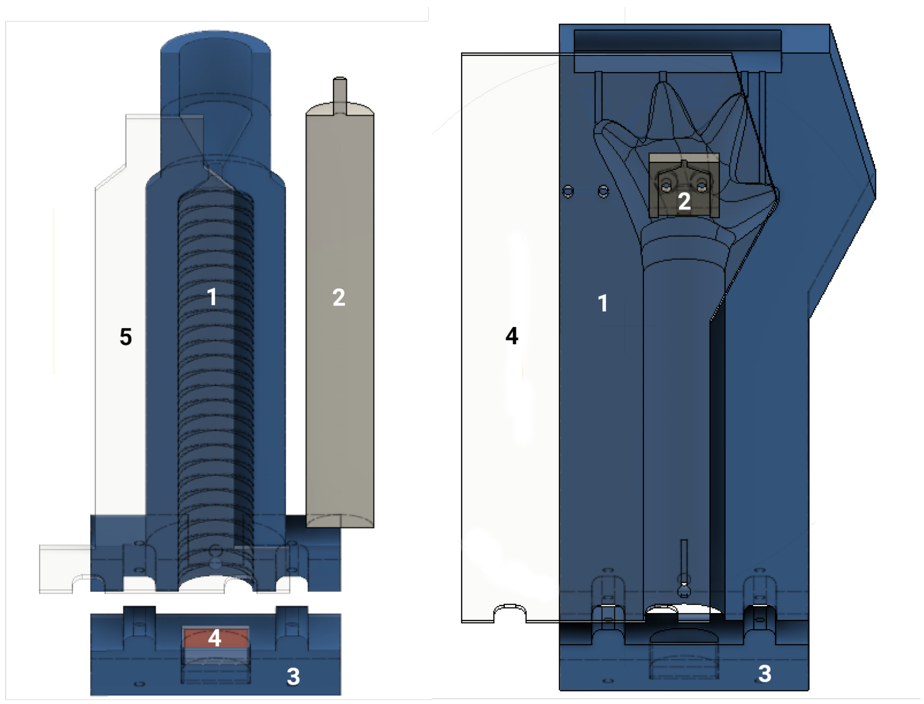

Figure 32: Arm steps 1 & 2: Left: Artificial muscle actuator mold, Right: Arm skin mold.

The CNC parts were milled from machineable wax while prototyping, and from polyurethane after achieving the final form. The mold is put together by inserting the metal piece into the bottom piece along with a small 3d printed filler and attaching the bottom piece to the main piece. A filler is required insofar as the same base pieces are used in both in step 1 and 2 , with the second step requiring extra space on the bottom piece for securing the sensor cable.

Dragon Skin 30 is injected to the molds using a syringe from bottom the top while the mold are clamped in an upright position and fastened with gaffer tape (see [fig:step1-casting]). By virtue of the transparent acrylic cover, it is possible to see any air bubbles forming during the injection process and follow their path as they departure from the top of the mold into the open air. The mold is designed in such way that a small reservoir pool of silicone remains at the top after injection; this pool maintains that if a small amount of silicone leaks out after injection, it is replaced from the reservoir pool and no material is lost in the final form.

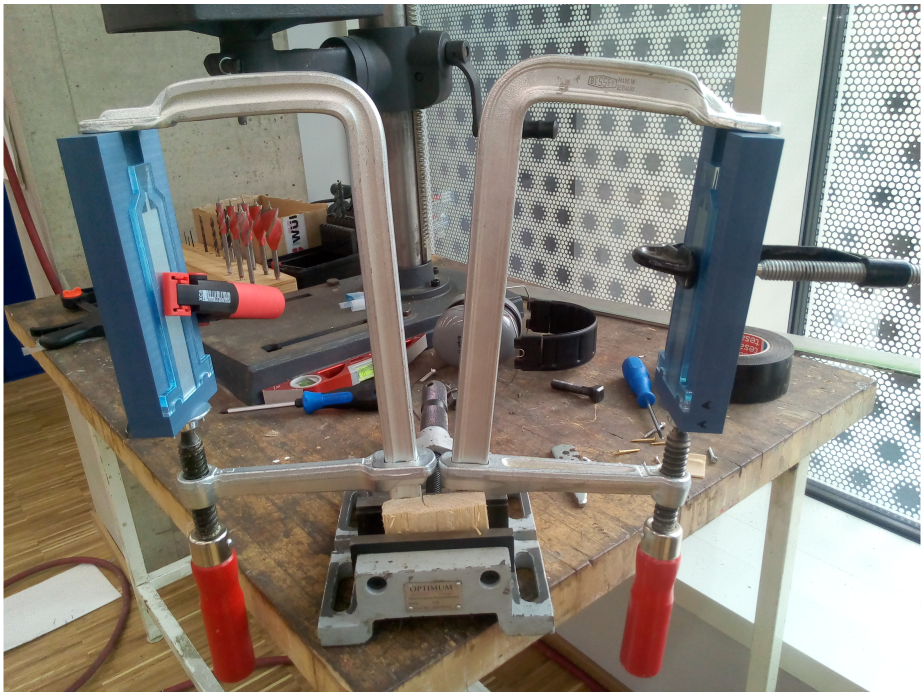

Figure 33: Arm step 1 : Casting apparatus.

Step 2 mold: Artificial arm

Once the first step is cured, the result is released from the mold. Before wrapping the kevlar fiber in a double helical form, a restricting layer should be added on one side to induce a bending motion instead of axial expansion. Usually this is done by gluing non stretchable fabric to the flat side of the half cylinder. Fabric bends very easily but does not stretch axially, causing the actuator to bend instead of elongating when inflated. In our case, however, a six-end flat ribbon cable is used as the restrictive layer. The ribbon cable is glued to flat side of the half-cylinder using Sil-Poxy glue; it conducts the sensing signal from the palm of the hand to the other end, while at the same time restricting the axial expansion of the silicone. The kevlar fiber is then wrapped around the actuator, laying on top of the ribbon cable (see [fig. 34;fig:step2-casting]).Once the mold is ready and situated, Ecoflex 30 silicone is injected, covering the muscle tube and creating the shape of the arm, while the ends of the ribbon cable are protected by the mold so that the sensor and micro controller could be connected later. Overall the second step mold contains the following parts (see fig. 32):

1. Main mold for producing the arm shaped skin (CNC milled).
2. A sensor box, reserving space for the sensor and protecting one end of the ribbon cable.

3. Modular base piece for securing the muscle tube and for protecting the other end of the ribbon cable(CNC milled).
4. Transparent acrylic cover (laser-cut).

As with the first step, the mold is taped and clamped upright and the silicone is injected from bottom to top as the bubbles are monitored through the acrylic glass (see fig. 35). Likewise with the first step mold, the second step also contains a reservoir pool to protect from small leakages.

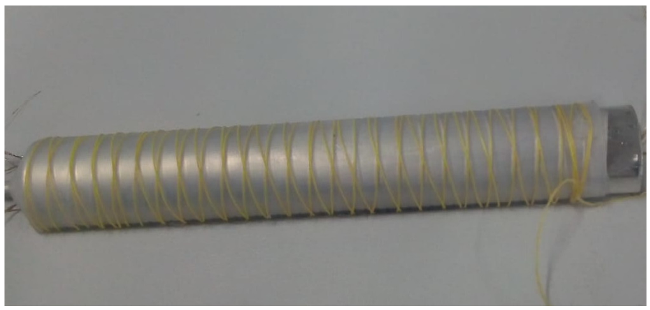

Figure 34: Double helical kevlar fiber wrapping. The fiber is wrapped from one end to the other, and then back.

Figure 35: Arm step 2 : Casting apparatus. The restricting layer formed by the ribbon cable is shown on the flat side of the actuator.

Barometric pressure sensor

The sensing approach in the arm follows the research done by Tenzer, Jentoft & Howe (2014). In their search for tactile sensors that could easily be embedded in robotic arms, and specifically organs made out of soft polymers, they found that low cost MEMS based barometric pressure sensors have the highest value. Those kind of sensors are cheap, easy to install and provide much better readings than other low-cost solutions such as Flexi-Force sensors that “often provide limited accuracy and significant hysteresis” (2014, p. 89). Barometic MEMS sensors also work digitally via SPI or I2C and do not require analog to digital conversions and amplifications. The sensor chosen for the arms was BME280 by Bosch Sensortec (Bosch, 2019).

Once the product of the second step is cured, the sensor is installed into the gap in the palm that was left due to the designated box protecting the area from silicone. The sensor is then soldered into the ribbon cable while the other end of the cable is soldered into an extension cable that would be connected to a microcontroller. It is important to note that the SPI protocol works over limited distances and may introduce noise when more than one device is connected over more than one meter.

The arm is then capped with Dragon Skin 30 on both ends, having one end dipped into a cup with 20g of silicone and the other end resting flat while Dragon Skin 30 is poured on top of the sensor (see fig. 36).

Figure 36: Capping the arm and sensor area.

Actuation and sensing

Once attached to the control board and mounted on HITODAMA's body backbone, the arms could be individually actuated with separate inlets for a wide range of arm expressions. However, for the final HITODAMA prototype the arms shared a single inlet since they were always operating in sync. An inflation to the arms causes them bend upwards in what appears to be a curling bicep motion.

The ribbon cable that comes out of the arm connects to the control board and sends a numeric signal for the amount of pressure being exerted on the palm. These figures are later manually processed by the software and function as pressure sensitive buttons.

Body

Design

The body backbone of HITODAMA was designed rapidly with the help of Joaquin Aldunate in order to make the tight deadlines required by the prototyping and testing process of this Master's thesis. The backbone is entirely rigid and its sole purpose is to provide structural support for other elements, primarily the head, arms and electronic components (see fig. 37). Due to time constraints and a handful of failed attempts, the plan to produce a soft tail as part of HITODAMA's body had to be abandoned, as well as any plan for soft skin that would envelop the rigid body.

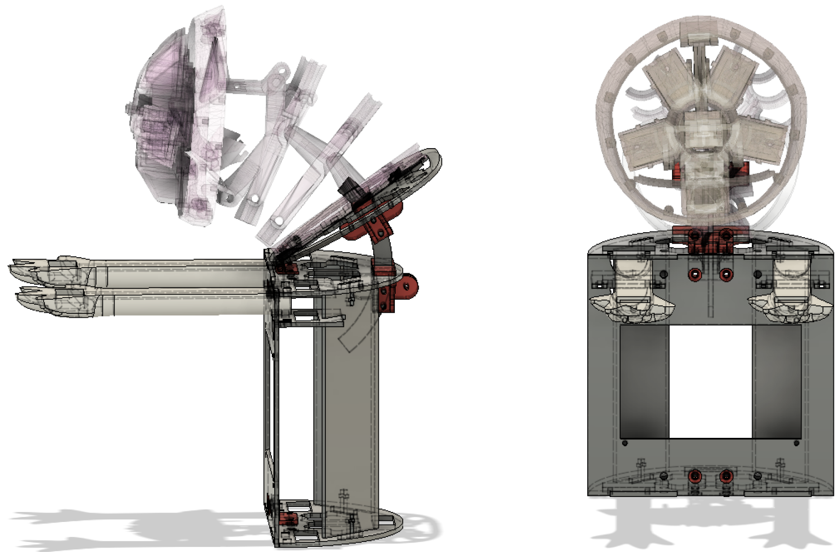

Figure 37: HITODAMA: Body structure design. Visible on the left: a sliding arc that adjusts the angle of the neck connection

The main features of the body include:

1. A slit in which the neck is attached and adjusted into the right angle.
2. Two ports holding the arms in place.
3. A window where a 5 inch display is inserted, allocating enough space at the back for a Raspberry Pi and connection cables.

Method

The body structure is composed both of laser-cut and 3d printed parts. The parts consisting the primary frame are laser-cut, while the connector pieces are 3d printed. Metal screws are used for fastening the connections. The connection to the neck is supported by a plastic arc that can be moved in order to adjust the angle of the neck (see fig. 37). Once the desired angle is found, the screws are tightened.

The arms are inserted into the ports, allowing the cables to flow through the back and are then secured by the top frame which is also screwed into place. The 5-inch display screws into the designated window. The plastic frame contains enough holes to be able to pass all of the pneumatic and electronic cables through it; therefore it consolidates all of the that go in and out of the robot (see fig. 38).

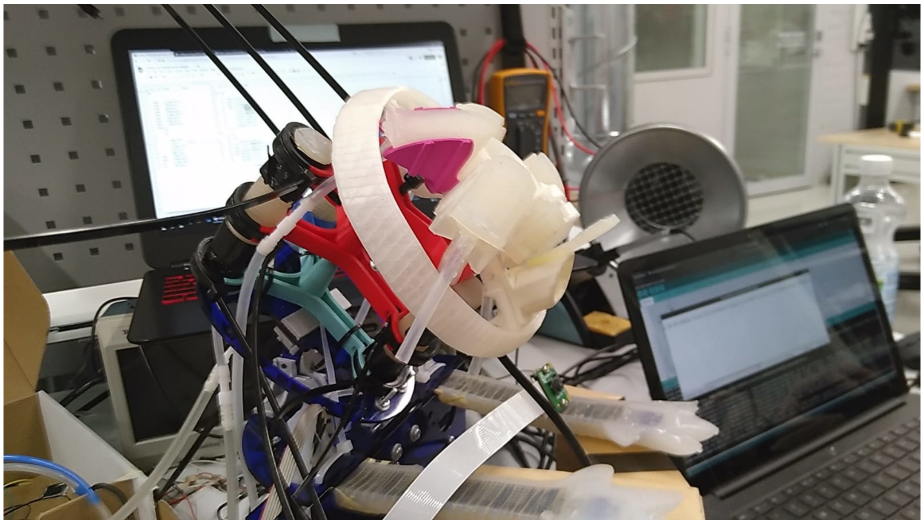

Figure 38: HITODAMA: Assembled body with pneumatic and electronic connections.

Pneumatic control board

Design

The pneumatic control board drives HITODAMA's motor subsystem and was designed with the help of Joaquin Aldunate. As described in tbl. 2, a total of seven air chambers are individually controlled, driving a total of ten silicone actuators (the arms, eyes and cheeks all have two actuators that are fed by one inlet). For the entirety of the pneumatic system, only one pump motor is used. Using the inlet and outlet valves, the air is routed from the single pump into the desired actuators.

The pneumatic system is situated entirely outside of the robot, i.e only air tubes are connected to the robotic parts while full set of valves, the pumps and the connection hub components are externally located (see fig. 39).

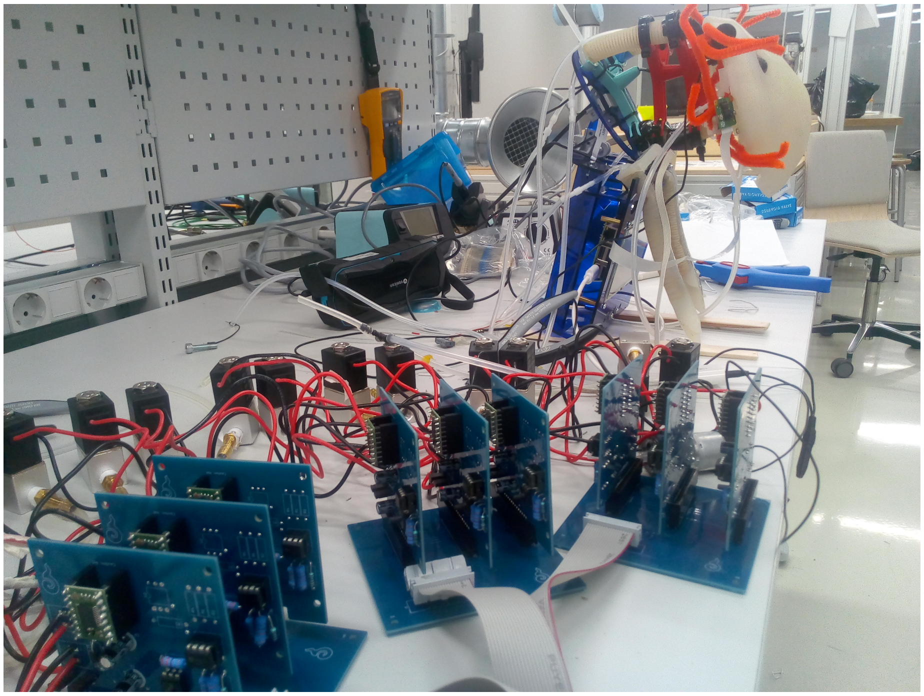

Figure 39: HITODAMA: Pneumatic control board.

A custom modular PCB array was designed for controlling the actuators, consisting of 3 types of boards: 1) Valve / motor board. 2) Intermediate board. 3) Teensy breakout board. The summary of the boards used is described in tbl. 3.

Table 3: PCB boards in the pneumatic control board

PCB type	Function	Quantity
Valve / Motor	Control actuation using two valves (inlet & outlet) and read pressure sensor values from the actuator.	8 (7 inlets + 1 pump)
Intermediate	Bridge between the teensy breakout and 3 valve boards	3
Controller breakout	Connect the teensy to 3 intermediate boards	1

The main unit that controls an actuator is the valve board, which provisions two main functions: 1) PWM control of two 12V motors / solenoids. 2) Reading air pressure values. Essentially it used to control an inlet valve and an outlet valve for every air chamber that needs to be individually inflated or deflated, while providing pressure sensor readings for that air chamber to enable automatic regulation. Additionally, since the board is able to control any 12v motor, it is also used to control to the single pump that drives the pneumatic system.

The operating principle for using the valve board is described in fig. 40 and tbl. 4. As mentioned, two valves are controlled using the board: An inlet valve and an outlet valve. The valves could be open, closed or partially open using low PWM values; this controls the state of the actuator. Tbl. 4 lists the different states of the actuator in relation to the state of the valve.

Table 4: Actuator states in relation to valve states

Inlet valve	Outlet valve	Actuator state
Closed	Closed	Idle. Pressure does not drop or rise.
Open	Closed	Inflating when pump is open, pressure rises.
Closed	Open	Deflating at full speed, pressure drops.
Closed	Partially open	Deflating at a slower speed, depending on PWM value.
Partially open	Closed	Inflating at a slower speed, depnding on PWM value.*

Each valve is a two way linear solenoid, meaning it has an in-port and out-port and it controls the flow of air between them. The in-port of the inlet valve is connected to the pump in a hub like manner, along with all of the other inlet valves of the system. The out-port of the inlet valve is connected to a 4-way splitter leading to: 1) The actuator itself. 2) The outlet valve, 3) the pressure sensor which is housed back at the valve board. The outlet valve is not connected to anything on its out-port, meaning that the air escapes completely when the valve is open.

* Was not used in the final prototype.

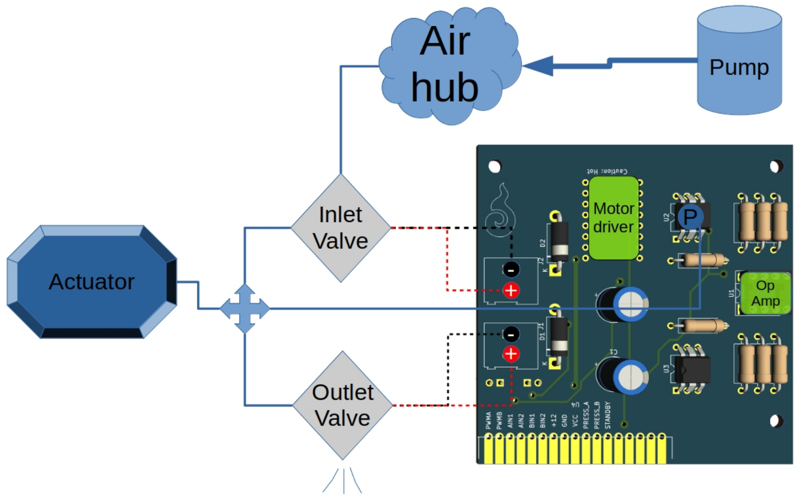

Figure 40: Valve board diagram.

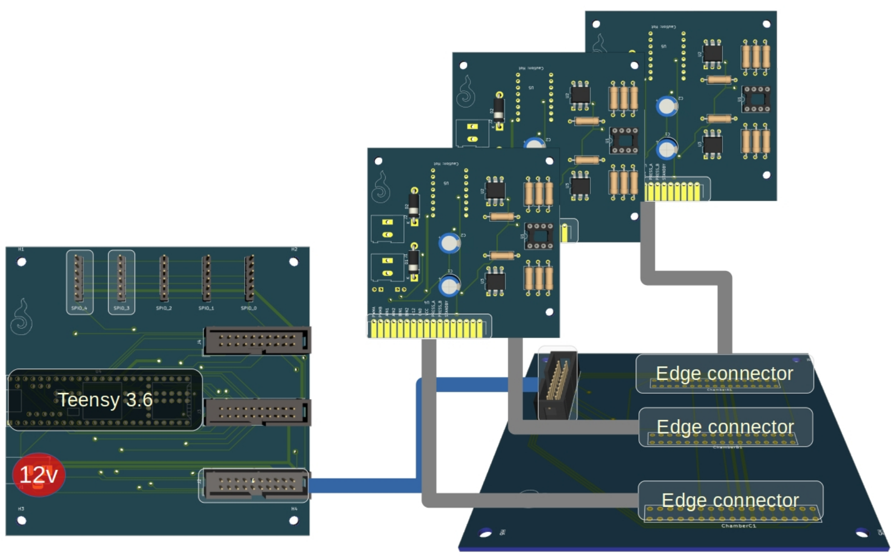

Figure 41: Board connection diagram. Three valve board connect to an intermediate board that connects to the controller breakout board.

The connection between a valve and its control voltage goes through three boards: 1) The valve board. 2) The intermediate board. 3) The controller breakout board. There are several advantages for this separation of concerns: Firstly, having a modular approach allows us to theoretically add as many actuators as needed without changing most of the design. Currently, every intermediate board can host three valve boards and the main controller board hosts three intermediate board, i.e the controller board supports up to nine valve boards. If in the future we would like to support nine more, only the controller board needs to accommodate to the increased amount; the valve boards naturally remain the same and the intermediates have no logic other than forwarding the valve boards to the main controller. Secondly, having intermediate boards allows to easily distribute the physical space between the valve boards without having an overly sized controller board. Insofar as air tubes are going into each valve board, they require some space around them to accommodate the tubes. In this design, the intermediate connects to the controller breakout board by a ribbon cable, while the valve boards ease into the intermediate board using an edge connector mechanism.

Method

Pneumatic components

tbl. 5 describes the pneumatic components used on the system, their connection type, quantity and function. Every table entry is associated with an image on fig. 42.

Table 5: Pneumatic components BOM

No.	Component	Quantity	Connection	Function
1	2-Way aluminum solenoid valve. Normally close, 12v DC.	14 (7 * 2)	1/8" NPT female port	Regulate air flow between the seven air chambers.
2	NPT to barbed tube connector enforced with PTFE tape.	21 (7 * 2 + 7)	1/8" NPT to 1/4" Tube	Connect a valve to a silicone tube. Outlet valves require only one connector while inlet valves require two. PTFE tape is required to prevent leaks.
3	Mitsumi R-14 A221 Micro air pump.	1	4mm outlet	Pump air into the system.
4	Plastic Y connector.	3	4mm outlets	Joins two tubes into one, combining the inlets of two arms, two cheeks and two eyes.

No.	Component	Quantity	Connection	Function
5	Plastic Linear connector.	4	4mm outlets	Acts as an adapater connection to actuators, so they can be easily extended with an additional tube.
6	Plastic X connector.	10 (7 + 3)	4mm outlets	Every of the seven air chambers uses an x connector to split the incoming air between the outlet valve, pressure sensor and actuator. 3 X connectors are also used to split the air from the pump into the 7 inlet valves.
7	Silicone tube.	~40	3mm inner / 5mm outer + 6mm inner / 8mm outer.	3mm tubes are attached to actuators, as it is easier to insert smaller tubes, and to pressure sensors as to maintain a tight connection. 6mm tubes run between the valves and the air hub from the pump (both diameters work well with 4mm connectors)

Figure 42: Pneumatic components asscociated with table entries.

Valve / motor board

The valve / motor board was designed with KiCad software (see fig. 43) after the setup was tested on a breadboard. It includes two main features: 1) Motor driver control over two valves / motors. 2) Amplified pressure sensor circuit.

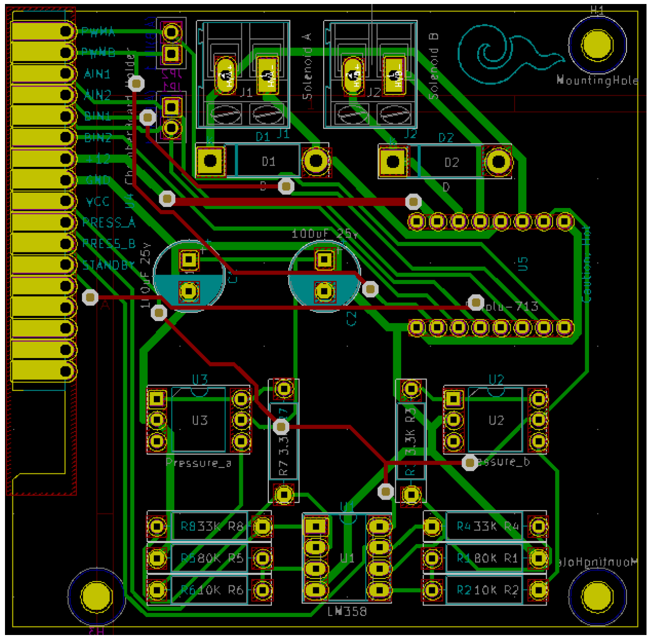

Figure 43: Valve / motor boad: KiCad drawing.

The motor driver circuit uses the **Pololu 713 TB6612FNG dual motor driver carrier**. It provides standard back EMF protection using **1N4001 diodes** and **bypass capacitors of 100u** in parallel to the voltage supply lines. The valves chosen for the pneumatic system are

For pressure sensing, the **MPS20N0040D Pressure Sensor** was selected for its low cost and high availability. The pressure sensor requires amplification and normalization to the produced analog values. A standard **LM358N Op-Amp** was used; different resistor configurations were tested using an oscilloscope until the desired output was reached. Fig. 44 describes the configuration used in the final prototype.

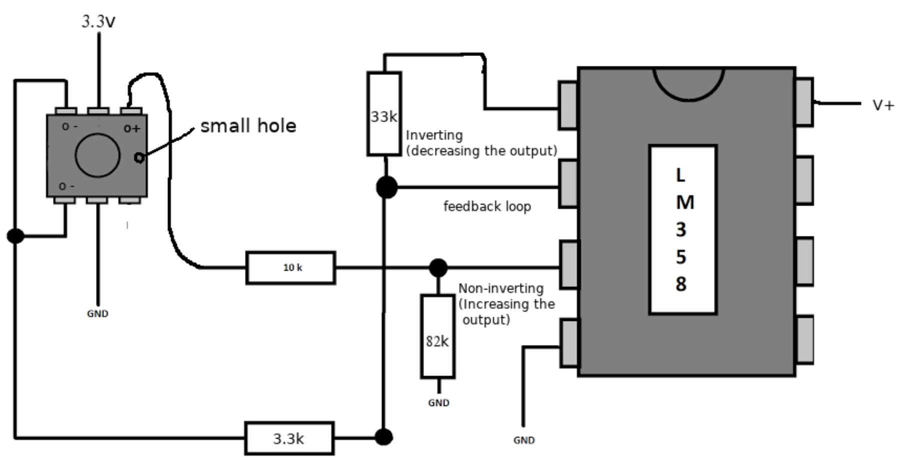

Figure 44: MPS20N0040D: Op-Amp circuit. The sensor orientation is determined by the small hole at one side.

Valve board to intermediate board

A modular slot-like arrangement was chosen for the connection between the valve boards and the intermediate boards. Three **TE Connectivity 5-5530843-3** edge connectors are soldered on the intermediate board, allowing the valve boards to be slotted in and out easily (see fig. **??**).

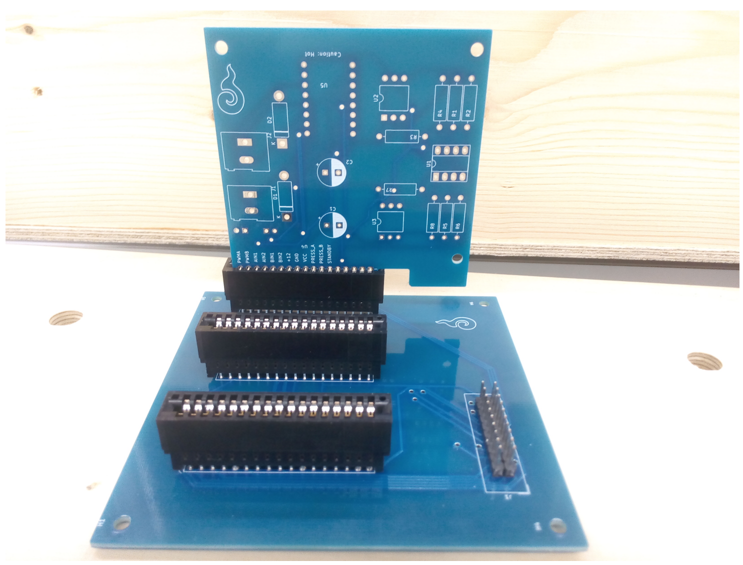

Figure 45: Valve board to intermediate board slot mechanism

Intemediate board to controller breakout

A 20-pin ribbon cable connects the intermediate board to the controller breakout board (see fig. 46). The intermediate board forwards all of the necessary pins to the micro-controller, allowing PWM control over three air chambers (six valves) and reading three pressure values.

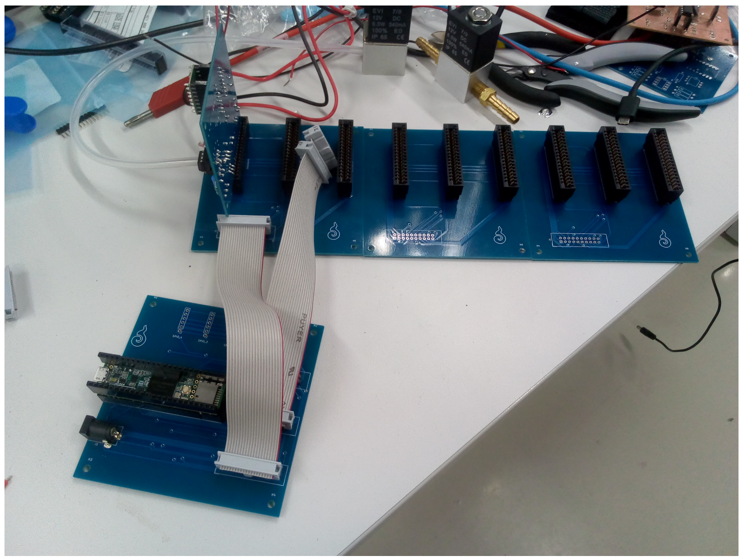

Figure 46: Intemediate board to controller breakout ribbon cable

Microcontroller breakout

Teensy 3.6 was selected as the microcontroller for the pneumatic circuit. It provides an Arduino compatible interface with an exceptionally high performance and a large number of analog, digital and PWM enabled pins. Nevertheless, due to the high number of pneumatic components, several concessions had to be made to save pins:

1. All motor drivers share one “standby” pin which is indefinitely set to HIGH, i.e keeping the motors always connected to power. Instead, the IN1 and IN2 pins are used to turn off the pump or valves (when both IN1 and IN2 are set to HIGH, the motor does not power).
2. Within each air chamber, the IN2 pin is shared between the inlet valve and outlet valve, reason being that for every chamber either the inlet valve or outlet valve is open, never both at the same time.
3. For the same reason, the PWM pin within each air chamber is also shared between the inlet valve and outlet valve.

Software to hardware interface

Design

HITODAMA provides a simple web based programmable interface for controlling and interacting with the robot's hardware. The input and output signals travel through several stops before finally being accessible via javascript through the API. Fig. 47 outlines the high-level flow of input and output signals in the system.

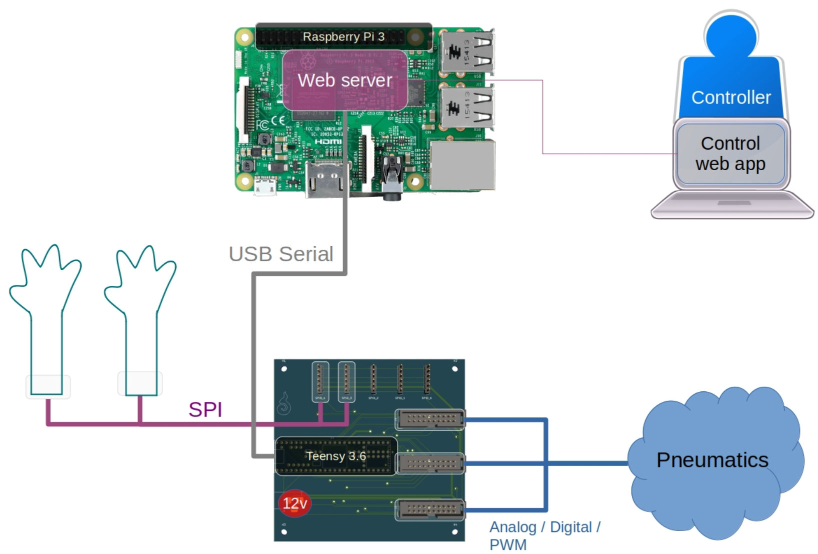

Figure 47: Programmable interface: singal flow

Method

As described in the previous section, the pneumatic system sends and receives signals from the main Teensy controller breakout board. In addition to pneumatic control, the microcontroller can receive SPI input from up to 5 different sensors. In the final HITODAMA prototype, only two SPI connections are used to detect tactile pressure on the palms.

The web API for HITODAMA is powered by a Raspberry Pi 3, connected to the Teensy via a USB serial cable. At the core of the Raspberry PI, a Rust based web socket server mediates between a javascript programmable interface and the microcontroller. Detailed software architecture is described in the dedicated section.

Digital I/O

Design

HITODAMA's digital I/O subsystem (see fig. 11) provides audio-visual interaction functionalities that are all accessible through a web-based interface (see fig. 48).

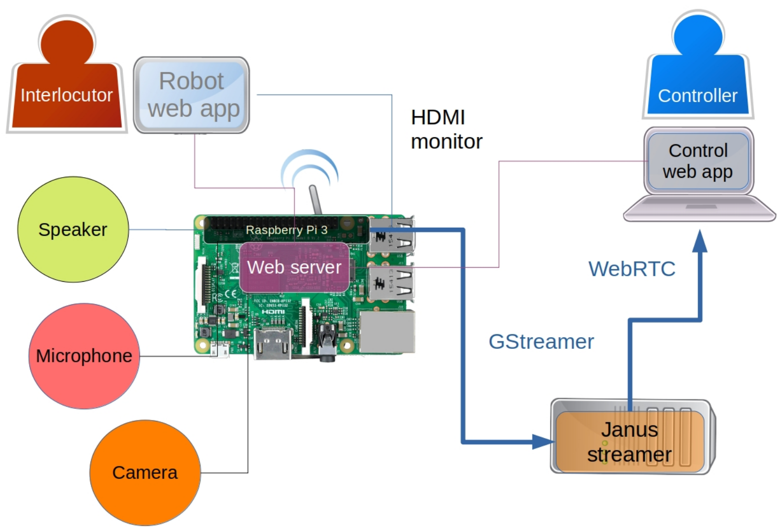

Figure 48: Digital I/O: connection diagram

An open web based design enables developers to easily build interaction apps for HITODAMA and ensures that anyone with a web browser on a phone or desktop could connect and control the robot. In its most minimal and inclusive form, no other special hardware is required by a controller to interact through the robot; a web capable device with typing ability and a speaker is sufficient, allowing the controller to type utterances while viewing and hearing the robot's surrounding environment. Nonetheless, an application may request additional input from the controller, such as webcam and microphone, location and so forth.

Method

Audio/Video streaming

The subsystem makes use of a WebRTC gateway to stream audio and video from the robot to the controller. There are numerous advantages to using a gateway rather than streaming directly from the robot: 1) This makes is possible to offload the network processing to a stronger server in case multiple clients are consuming the stream. 2) It enables easy recording and storing of videos on a separate server without consuming resources on the robot's Raspberry Pi. The free and open-source Janus gateway was used for this purpose (Janus, 2019), along with the open-source GStreamer client library. A standard **Raspberry Pi camera** was used for video streaming, while a **Rusee Lapel Omnidirectional Microphone** connected to a **UGREEN External USB Sound Card** was used for audio. The following GStreamer command streams VP8 video with Opus audio at 640x480 resolution to a designated server denounced by the bash argument (All modern browsers are supported):

```
gst-launch-1.0 alsasrc ! queue ! opusenc ! rtpopuspay ! udpsink
host=$1 port=8003 rpicamsrc preview=false ! videoconvert !
video/x-raw, framerate=30/1, width=640, height=480 !
vp8enc cpu-used=0 threads=1 end-usage=vbr min-quantizer=1
deadline=1 ! rtpvp8pay ! udpsink host=$1 port=8004 sync=false
```

The controller's web client then uses the Janus client library to obtain a reference to a standard WebRTC video resource containing the stream.

Display

A 5-inch LCD display by Waveshare is connected to the Raspberry Pi via the HDMI port and supports a resolution of up to 800x480. The display runs a full screen web browser (to be detailed in the next section).

Systems and software architecture

Overview

Fig. 49 describes the overall systems architecture offered by HITODAMA, separated across three different physical locations: 1) The controller's whereabouts. 2) The robot's location. 3) An external gateway server operating online. At the front, two web applications are operating the experience: One control application running on the controller's device (phone or desktop) and one web application running on the robot and displayed on the HDMI screen. At the backend, several different components are integrated. The following sections describe each of them in detail.

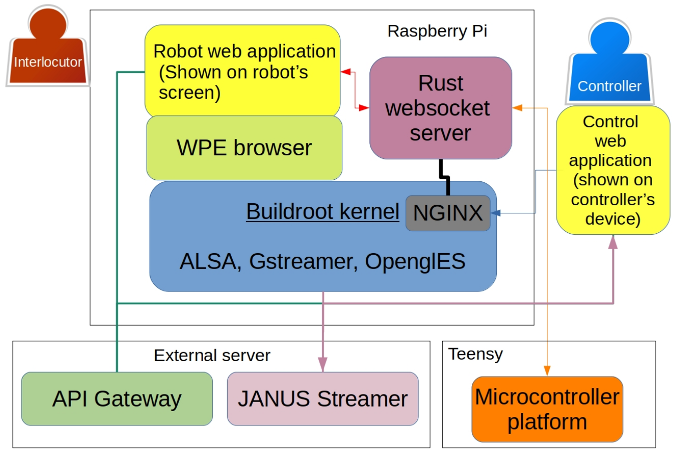

Figure 49: Architecture overview, divided by physical hardware and main software components

Buildroot & WPE

A web infrastructure is suited for interaction app development due to its openness and accessibility. However, there are still many challenges in running web applications on small and cheap embedded hardware such as the Raspberry Pi. Several projects are tackling those challenges with web platforms that are designed with embedded devices in mind, such as the Chromium project[1] and Mozilla Servo.[2] One project that stands out above the rest is WPE: Webkit for embedded.[3] WPE is built on the foundation of WebKit: an open source web framework started by Apple that serves as the basis for a variety of web browsers and frameworks, including Google's Blink engine; particularly, WPE is based on WebKitGTK, a web framework for the Linux-Gnome ecosystem. According to its stated mission, the WPE project is "designed from the ground-up with performance, small footprint, accelerated content rendering, and simplicity of deployment in mind" (WPE, 2019).

The Raspberry Pi is indeed one of WPE's target reference boards and in order to run it natively one must cross-compile the release to the Pi's architecture. This is most easily achieved by using a custom modular linux OS platform that is cross-complied from any desktop machine. The two most common platforms for embedded hardware are the Yocto project[4] and Buildroot.[5] While Yocto shines in its ability to install and remove packages after image generation, Buil-

[1] https://www.chromium.org/Home
[2] https://servo.org/
[3] https://webkit.org/wpe/
[4] https://www.yoctoproject.org/
[5] https://buildroot.org/

droot is more lightweight and simple to use and was recommended by one of the WPE developers on the #webkit IRC channel; therefore the chosen solution for running web applications on the Raspberry Pi is WPE on Buildroot. The configuration used for generating the Buildroot image is published on Github.[6] In addition to WPE, Buildroot was compiled with support for the Rust language, GStreamer multimedia and Nginx server. Several scripts were added for quick activation of the robot's facilities; the main WPE browser is started with the following code, enabling media extensions, mouse support and a remote debugging facility. The chosen web page is then loaded and displayed in full screen on the robot's display:

```
#!/bin/sh
export WEBKIT_INSPECTOR_SERVER=0.0.0.0:1234
export WPE_BCMRPI_CURSOR=1
cog --set-permissions=all --enable-webaudio=true --enable-mediasource=true
--enable-media-stream=true --media-playback-allows-inline=true
--enable-media-capabilities=true $1
```

Rust web socket server

Rust is a relatively new yet highly mature programming language with a rapidly growing community. It was started at Mozilla research[7] as part of an effort to build faster and safer internet browser foundations and has since then been adopted by the community with at least 9 dedicated conferences in 2019.[8] Rust focuses on memory safety and concurrency without a performance overhead as well as on interoperability and portability, making it a prefect candidate for embedded hardware applications.[9]

Thread overview

In HITODAMA, the Rust web server is at the center, mediating between the hardware, software and the network. Fig. 50 displays an overview of the simultaneous threads running on the server core. In rust, the threads communicate safely and asynchronously through *channels*, passing data messages from one thread to another rather than sharing a piece of memory which could pose issues such as race conditions and dereferenced variables. However, data of the web socket client state is still shared between threads, using Rust's builtin mutex locks that force the developer to work safely with shared data. In the future, the shared state could be removed and replaced by an immutable state that passes between threads.

[6] https://github.com/Avnerus/softbot-buildroot/blob/softbot/configs/raspberrypi3_softbot_defconfig
[7] https://www.rust-lang.org/
[8] https://blog.rust-lang.org/2019/05/20/The-2019-Rust-Event-Lineup.html
[9] https://www.rust-lang.org/what/embedded

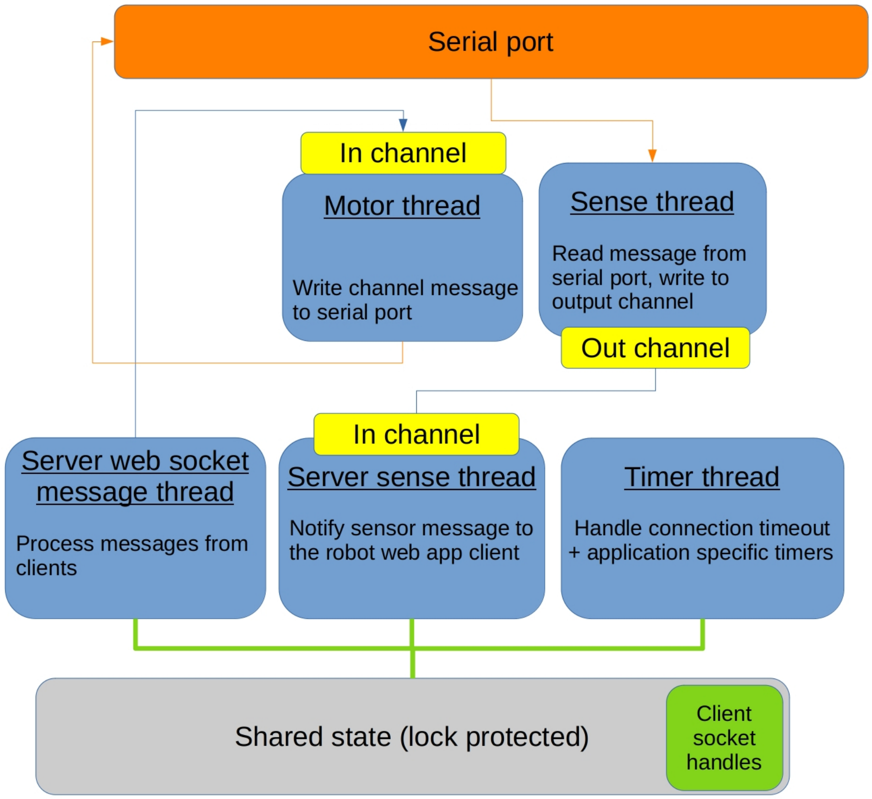

Figure 50: Rust server: thread overview. The rust server simultaneously listens to connections through web socket and to data coming from the serial port that is the bridge to the hardware interface.

Binary protocol

A simple binary protocol was implemented for passing messages between the controller, robot and hardware. Tbl. 6 describes the message types, formats and functionality. When communicating through the serial port, the special characters '>' and '<' are used to signal the start and end of transmissions, this is due to the serial protocol's lacking reliability in comparison to web socket messages. It is worth noting that authentication and authorization security has not yet been implemented on the protocol, and would be required feature for further development. Nevertheless the web socket server supports end to end encryption by making sure all messages are channeled through NGINX[10] proxy's SSL module. In addition to message passing, the server also sends a

[10]https://www.nginx.com/

JSON formatted state object to all clients when changes in the server state occur, such as client registration and disconnection.

Table 6: Rust server: binary protocol messages

Source	Format	Function
Any client	R{Role ID}	Register as one of three client roles: controller, avatar (robot) or admin console.
Avatar or controller	C{JSON string}	Pass a communication JSON message between the controller to the avatar or vise-versa.
Controller	>{Binary data}<	Motor control command, fowarded to microcontoller via serial port.
Serial port	>SA{ID}{P/R}<	Arm sensor message including arm ID and *pushed* or *released* state. Forward message to controller and avatar clients.
Serial port	>SP{Name}{Pressure read}	Pressure sensor monitor message including the name of the chamber and the reading. Forward the message to the admin console.
Serial port	>D{Message string}	Debug message from the microcontroller. Forwarded to the admin client.
Server	I{Message string}	Server system message, can be sent to any client.
Server	E{Message string}	Server error message, can be sent to any client.

Microcontroller platform

Class diagram

The microcontroller platform controls the pneumatic components and sensors; it runs on the Teensy microcontroller and connected through the custom made PCB boards. The code is available on Github[11] and free for use under the MIT license. An object oriented approach was chosen for the development

[11] https://github.com/Avnerus/softbot/tree/master/softcontrol/circuit

of platform. Fig. 51 describes the classes developed, their functionalities and connections.

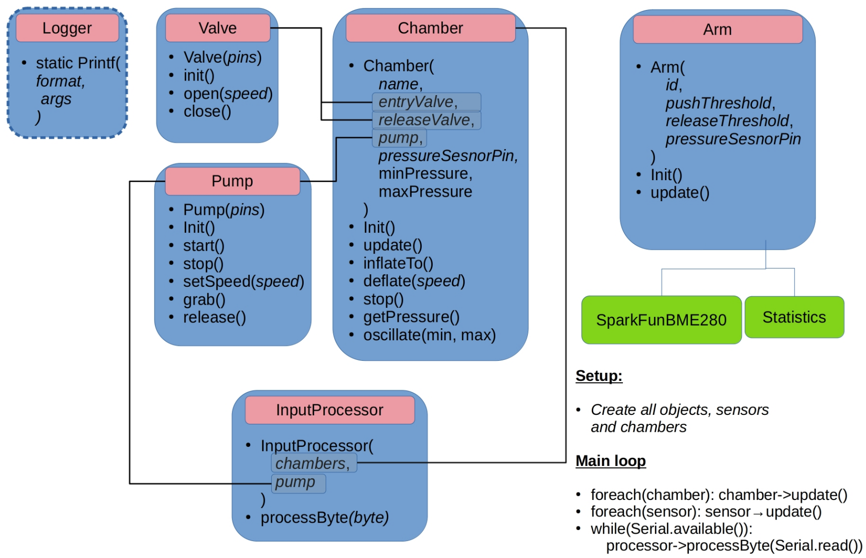

Figure 51: Microcontroller platform: class diagram

API

The *Chamber* class represents one of the seven air chambers that are connected to the pneumatic system. Each chamber object contains the following components:

- Entry (inlet) valve.
- Release (outlet) valve.
- Associated pump.
- Dedicated pressure sensor.
- Minimum and maximum pressure value.

A Chamber is calibrated using minimum and maximum absolute pressure values. Once calibrated, a chamber would always maintain the minimum pressure by inflating itself and avoid surpassing the maximum pressure. It is then possible to direct the chamber to reach a certain pressure by providing a figure between 0.0 and 1.0, having 0.0 represent the minimum pressure and 1.0 represent the maximum pressure. One could control the deflation speed of the chamber by passing a speed argument between 0.0 and 1.0, which would then be translated to PWM values. Additionally, it is possible to have the chamber oscillate between a certain minimum and maximum pressure level to create a variety of expressive movements.

Although a typical pneumatic circuit contains only one pump, it is still advised to inform a chamber about the pump it is using; the chambers would then use the pump's *grab()* method when they're being inflated and *release()* when they're done. This, in fact, allows the pump to turn itself off when it is not being used by any chamber and start again only when it is needed.

An *Arm* is calibrated using threshold values for pressure readings to determine when the arm is being pushed and when it is being released. These values, however, are relative to a running average that is continuously updated by the Arm during the main loop. This is due to the fact that barometric pressure measurements are liable to change with external fluctuations of the surrounding environment. Typically the push threshold would be around 20, while the release threshold around -10, assuming that the mean average is updated again when the arm is being pushed.

Binary protocol

Tbl. 7 describes the other side of the communication between the microcontroller and the rust server. Messages that were passed from the web clients to the rust server and then forwarded to the motor thread to be sent on the serial port are received on the microcontroller side and activate the appropriate module function. Accordingly, information messages that originate from the hardware modules are sent on the serial port to be picked up by the rust server and then sent to the web clients.

Table 7: Microcontroller platform: binary protocol messages

Source	Format	Function
Arm module	>SA{ID}{P/R}<	Arm sensor message including arm ID | s and *pushed* or *released* state. Sent to serial port.
Chamber module	>SP{Name}{Pressure read}	Pressure sensor monitor message including the name of the chamber and the reading. Sent to serial port.
Logger module	>D{Message string}<	Debug message, sent to the serial port.
Serial port	>P{Speed}<	Set pump speed, activates pump->setSpeed()
Serial port	>H{Index}{State}<	Sets chamber state by index in a pre-defined list. Either inflates to max pressure, deflates to min pressure or stops.

Source	Format	Function
Serial port	>C{Index}{Pressure}<	Sets chamber pressure by index in a pre-defined list. 255 translates to max pressure, 0 to min pressure.

Web client platform

To ease the development of apps for HITODAMA, utility libraries and components were developed and can be used both on the controller side and the robot side. The web platform is available on Github[12] and the usage of the most pertinent components is listed below.

Socket controller

The socket controller manages the connection and interaction with the rust server. It is initialized by providing the address of the robot with the following code :

```
const socketController = new SocketController('wss://incarnation.hitodama.online',
    () => console.log("Connection callback")
);
socketController.init();
```

Table 8: Socket controler Javascript API

Function	Arguments	Usage
subscribeToPrefix	Message prefix (such as ‘E’ or ‘S’)	Add a callback function to when a message with the specified prefix arrives. Refer to tbl. 6 for possible prefixes.
on	Command name as it appears in the communications JSON’s {command: } property.	Add a callback function to when a JSON message with the spcified command arrives.
sendSerialCommand	Prefix, list of 1 byte values.	Sends a command to the motor subsystem via the serial port connection to the microcontroller.

[12] https://github.com/Avnerus/softbot/tree/master/client

Function	Arguments	Usage
sendJSONCommand	Object, should have a {command: } property specifying the command name.	Sends a communoication command JSON to the other side (controller to avatar or vise-versa).

The JSON commands are used by various application components for specific functionalities to be described in the web components section. One base JSON message is sent by the server with the command *softbot-state* every time the state of the interaction has changed. For example the following JSON states that both the controller and avatar are now connected, and the controller whose name is Avner is currently typing:

```
{
    "command": "softbot-state",
    "CONTROL": 1,
    "AVATAR": 1,
    "softControllerName": "Avner",
    "softControllerTyping": true
}
```

Redux state

Redux[13] is a functional, immutable state container for javascript, with great debugging tools and flexibility. While not all of HITODAMA's functionality relies on it, the majority of components were migrated to make use of Redux. HITODAMA's state container also contains definitions for commonly used objects such as air chambers and role definitions. In order to use the state for application development, one only has to initialize it with the socket controller and identity once connected to the robot:

```
import store, {setSocketController, setIdentity, ROLES} from '../common/state'

const socketController = new SocketController(
    'wss://incarnation.hitodama.online',() => {
        store.dispatch(setSocketController(socketController, true))
        store.dispatch(setIdentity(ROLES.CONTROLLER));
    }
);
socketController.init();
```

In Redux, manipulation of the state works through pre-defined *actions*. Different web components make use of different actions and are described in detail in the web components section.

[13]https://redux.js.org/

Pneumatic utility library

A small utility library makes use of the socket controller and the state definitions to invoke the motor subsystem. The library is based on javascript Promises, making it easy to chain together different actions with a timed delay. For example, the following code inflates HITODAMA's cheeks to 90% of the maximum pressure and then deflates them after 4.5 seconds:

```
import {CHAMBERS} from '../common/state'
import * as Hitodama from '../common/hitodama'

Hitodama.inflateTo(
    socketController,
    CHAMBERS.CHEEKS,
    0.9,
    4500
)
.then(() => {
    Hitodama.deflate(
        host.socketController,
        CHAMBERS.CHEEKS
    )
});
```

Web components

Web components[14] are an emerging standard for creating reusable, encapsulated components that anyone could embed in their web application without worrying about conflicting code and styling. Granted, creating reusable web components has been an emblem of modern web development in the last couple of years, but components tend to be framework specific, such as Vue.js[15] components or React[16] components. Web components, on the contrary, are framework agnostic and rely on open standards of the W3C[17] and WHATWG[18] organisations. Specifically, web components build upon the following specifications:

1. **Custom Elements** : enabling the use of custom HTML tags such as rather than just using the standard ones such as
   and
   .
2. **Shadow DOM** : allowing he styling and naming of elements independently of the enclosing document, as if they were on their on page.
3. **HTML Templates**: allowing a developer to define a fragment of HTML than can be moved from place to place.

[14]https://www.webcomponents.org/introduction
[15]https://vuejs.org/
[16]https://reactjs.org/
[17]https://www.w3.org/
[18]https://whatwg.org/

Web components are now supported by all modern browsers, including mobile browsers for iOS and Android, with only some bugs remaining in Apple's Safari as of summer 2019[19]. In most cases, the lack of support could also be compensated by the use polyfills: external libraries that patch the browser in places where functionalities are missing.

As much as web components simplify the world of reusable components, their direct use is not entirely simple and introduces some development overhead for rather mundane tasks. For this reason, several helper libraries have emerged, simplifying the use of web components. The library Hybrids JS[20] stands out as an extraordinarily simple, functional and elegant companion for creating web components, therefore it as chosen for the development of HITODAMA components. Most of the web components were used in the controller client rather than the avatar, but in the future the avatar (the robot's display), but in the future the avatar would be migrated to only use web components as well. Tbl. 9 lists available components and their function:

Table 9: List of web components supported by HITODAMA

Component	Target client	Function
<hitodama-video>	Controller	Displays a video stream from HITODAMA's camera and microphone through the Janus gateway.
<hitodama-control>	Controller	Adds buttons that control HITODAMA's facial expressions and gaze direction (right, left, center).
<hitodama-transcript>	Controller	Displays a transcript of messages in the HITODAMA control session.
<hitodama-vision-control>	Controller	Adds arrow buttons that manually control HITODAMA's neck.
<hitodama-sense>	Controller	Shows visual feedback when HITODAMA's arms are being pressed by flashing the corrosponding half of the container.

[19]https://caniuse.com/#search=web%20components
[20]https://hybrids.js.org/

Component	Target client	Function
<langauge-select>	Any	A language select control allowing to choose a langauge by selecting the matching flag icon.
<hitodama-speech>	Controller	Displays a text box to have HITODAMA speak. Uses the <langauge-select> element and supports typing indicator.
<hitodama-arm-control>	Controller	Adds buttons that raise or lower HITODAMA's arms.
<hitodama-avatar>	Avatar	General avatar layout for HITODAMA's display including <language-select> to select the interlocutor's language.

All of the components make use of the Redux state and socket controller. They are sized normally using CSS properties. Some of the components require special parameters to be used, below are example for usage:

<hitodama-video> : Displays the video stream coming from the robot through the Janus gateway. Used on the page as following:

```
<hitodama-video
    streamURL="${'https://stream.hitodama.online/janus'}"
>
</hitodama-video>
```

<hitodama-transcript>: Displays transcript information of the control session. It is embedded as such:

```
<hitodama-transcript></hitodama-transcript>
```

To add new lines to the transcript, the *addTranscript* method is used from the Redux state:

```
import store, {addTranscript} from '../common/state'

store.dispatch(addTranscript({
    from: "Source",
    text: "some text"
}));
```

The state automatically adds system and error messages to the transcript.

<language-select>: Displays a language select button that uses flags as selectors. The component takes a list of supported languages and their flags as follows:

```
<language-select languages=${[
    {value: 'en', title: 'English', flag: 'us'},
    {value: 'fi', title: 'Finnish', flag: 'fi'},
    {value: 'ja', title: 'Japanese', flag: 'jp'},
    {value: 'he', title: 'Hebrew', flag: 'il'},
    {value: 'ca', title: 'Catalan', flag: 'catalonia'},
]}>
</language-select>
```

If a flag icon does not exist in the standard database, it can be added as an svg files in the *images* folder of the project.

API gateway server

Some functions for HITODAMA, primarily those involving language and speech, are best implemented using cloud services. While it is possible to have HITODAMA's rust server directly access those cloud services, it was more convenient to manage the access through and external Node JS gateway server that can be accessed easily from the web clients. Tbl. 10 describes the language services provided by the current server implementation[21]. Application specific functionalities could be added to the same gateway.

Table 10: API Gateway server: language functions

Route path	Arguments	Function
/api/ms-speak	**Target**: target langauge to be spoken. **Text**: text to be uttered.	Returns an audio stream of the text generated by Microsoft's Cognitive speech services. If the source text is not in the target langauge, it is **translated** using Google's cloud translate services.

[21]https://github.com/Avnerus/softbot/tree/master/server

Route path	Arguments	Function
/api/transcribe	**Model**: Source langauge of the audio. **Translate**: Language to translate to.	Transcribes an audio buffer that came from a WebRTC stream, using Google's speech to text services according to the specified model. If the translate argument is specified, the text is also **translated** using Google's cloud translate services.

Admin web client

An admin web client was developed for testing and management of HITODAMA's functions. At the time of development, web components were not at the front of the research and therefore it was created only with simple Javascript objects and JQuery UI manipulation. Tbl. 11 describers the admin client's features, numbered and shown on fig. 52.

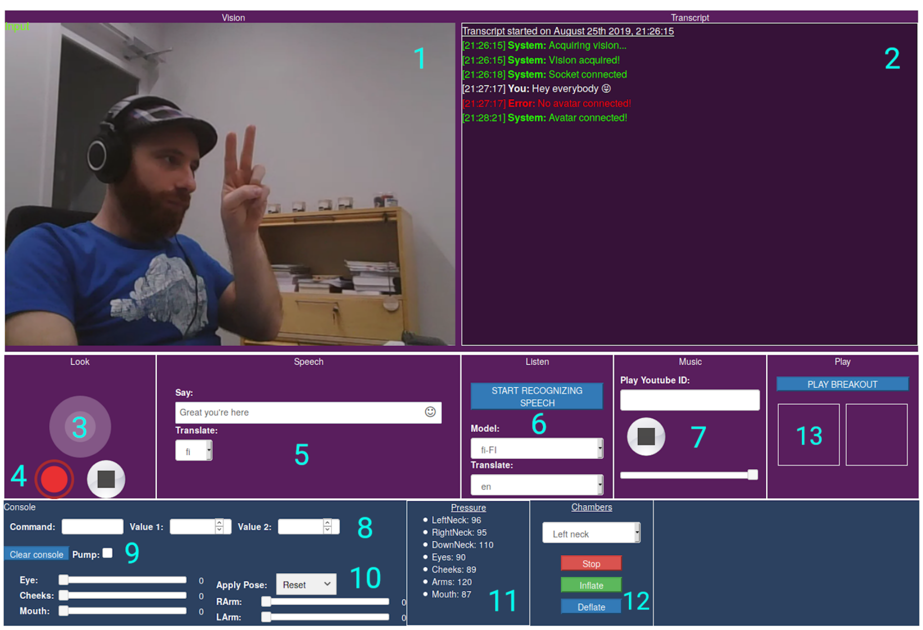

Figure 52: Admin web client panels.

Table 11: Admin web client panels and their functions

No.	Panel	Function
1	Video stream output.	Outputs video and audio from the robot through the Janus gateway.
2	Transcript log.	Transcript including conversation, server system messages and debug messages from the microcontroller.
3	Neck joystick control.	Manual movement of the neck using a virtual joystick.
4	Stream recording controls.	Buttons to start and stop the stream recording on the Janus server.
5	Speech control.	Activate HITODAMA's speech with a text and option for translation.
6	Speech recognition control.	Activate speech transcription with an option for translation.
7	Youtube control.	Play a youtube video on the robot's screen, with pausing and volume control.
8	Arbitrary serial command.	Send a serial command with a prefix specified in the "Command" fields and up to two numeric values.
9	Pump control.	A dedicated checkbox to start or stop the pump; speed could be adjusted using the "P" command.
10	Face and arm control with pose presets.	Manually control the pressure of the face and arm actuators; a slider between 0 and 1 maneuvers between minimum and maximum pressure.
11	Pressure readings.	Pressure readings sent periodically from the microcontroller for all air chambers.
12	Individual chamber control.	Buttons to start inflation, deflation or stop (close the valves) for every air chamber individually.

Experiment

Design

Goals

The HITODAMA experiment was designed to evaluate the first prototype of HITODAMA under the framework of intercorporeality and incarnation. The following primary goals were defined:

1. Evaluate mediated telerobotic intercorporeality: As mentioned in the the-

oretical review, mediated intercorporeality opens several gaps and shortcomings in communication and understanding and at the same time offers new bridges and paths of communication. One of the main purposes of the experiment was to test different features of HITODAMA and how they mold the experience of the controller and interlocutor.
2. Evaluate the contribution of soft materials to intercorporeality: As mentioned in the theoretical review, the hypothesis asserts that the organic and non-linear properties of soft materials would ease and deepen the interaction and understanding in mediated communication.
3. Examine the possibilities of knowing a stranger through mediated communication, especially in light of existing prejudices and biases.

Picture game

Pictures have a decisive role in determining and facilitating our perception and cognition. According to Cutting and Massironi (1998), while the act of perceiving and interacting with a picture is differentiated from our perception of the world, it is clear that "the ability to understand pictures is deeply embedded in the human mind" (1998, p. 138). Merleau-Ponty discusses pictures mostly in relation to paintings, our perception of them and the corporeality that is mediated by them. In *Phenomenology of Perception* discusses Van Gogh: "Van Gogh's paintings have their place in me for all time, a step is taken from which I cannot retreat, and, even though I retain no clear recollection of the pictures which I have seen, my whole subsequent aesthetic experience will be that of someone who has become acquainted with the painting of Van Gogh" (2013, p. 457).

Perhaps as much as pictures shape our perception, they can also be a gateway to our cognition and for self-expression. Therefore, We have chosen to use pictures as facilitators of intercorporeal interaction in the HITODAMA experiment. The flow is a very simple:

1. Each round, the controller and interlocutor are presented with a similar pair of pictures.
2. Both parties must choose their favorite picture out of the two, or the one that catches their eye the most.
3. When both parties chose their picture, it is revealed whether they both chose the same picture.
4. They must then explain to each other why the chose their picture.
5. Once both have finished explaining, the round ends and a new one can begin.

Through pictures, we hope to generate meaningful exchanges between the participants, allowing them to briefly get to know each other, express their opinions and perhaps juxtapose their image of the stranger against the present conversation partner.

Controller interface

A dedicated controller UI was developed for the purpose of the experiment, opting to simplify the experience, making it as language independent as possible and encouraging actions that we wished to evaluate. Due to time constraints and insofar as it was possible to sit privately with the participants and explain the interface, the development and design process was rapid and a number of UX gaps definitely remained at the time of the launch. The controller interface is based on a newer web components architecture and several web components were developed especially for this experiment. Fig. 53 outlines the basic view of the interface and tbl. 12 describes the numbered sections by web component and their functionalities.

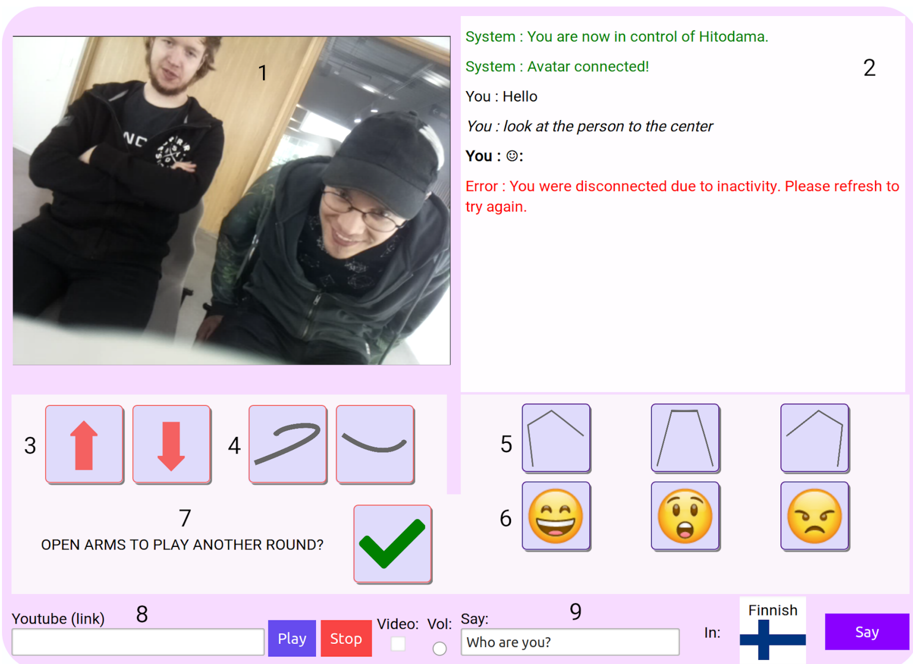

Figure 53: HITODAMA experiment: contorl client

Table 12: Experiment control client: web components and their functions

No.	Web component	Function
1	<hitodama-video>	Outputs video and audio from the robot through the Janus gateway.
2	<hitodama-transcript>	Transcript including conversation, server system messages and debug messages from the microcontroller.

No.	Web component	Function
3	<hitodama-vision-control>	Manual movement of the neck up and down.
4	<hitodama-arm-control>	Buttons to raise or lower HITODAMA's arms.
5	<hitodama-control>	Buttons to direct HITODAMA's gaze (left, center, right).
6	<hitodama-control>	Buttons that activate HITODAMA's facial expressions.
7	<hitodama-pics-control>	An interface that controls the different stages of the picture game.
8	<hitodama-youtube>	Interface for playing a YouTube video on HITODAMA's display, including volume control and a checkbox for showing video or just audio.
9	<hitodama-speech>	Interface for activating HITODAMA's speech with supported language translation (type in any langauge and it would get translated).

The control interface also supports mobile devices, resizing and re-organizing the layout to a mobile-friendly formation (see fig. 54).

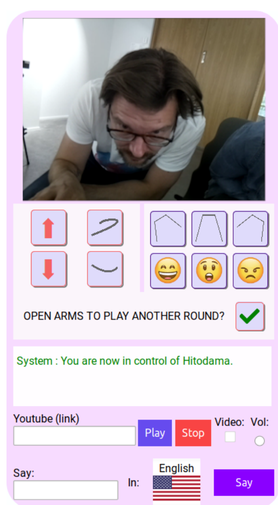

Figure 54: HITODAMA experiment: contorl client on mobile devices

Avatar interface

The avatar interface is shown on HITODAMA's built in 800x480 5-inch display; it is kept simple due to the low resolution and screen size. Fig. 55 outlines the basic view of the interface and tbl. 13 describes the numbered sections by web component and their functionalities.

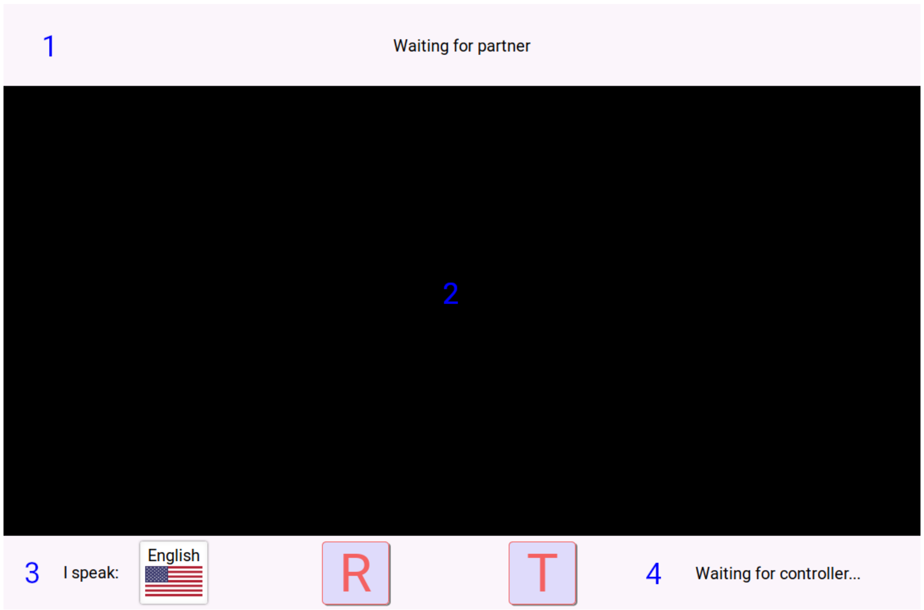

Figure 55: HITODAMA experiment: built-in avatar client

Table 13: Experiment avatar client: web components and their functions

No.	Web component	Function
1	<hitodama-pics-control>	An interface that controls the different stages of the picture game.
2	<hitodama-pics>	In this component the pictures are shown, asking the users to select their favorite ones.
3	<language-select>	A language select component that determines the language in which the interlocutors speaks, so they could be correctly transcribed and translated back to the controller.
4	<hitodama-avatar>	This compoment displays the current status of the controller, including information about their name, native tounge and whether they are typing. Two debug buttons allow a refresh of the page or activation of the transcribe listener.

Experiment flow

Note: The following screens are for not part of an actual experiment and are for illustrative purposes only. The participants in the screens have signed a consent form for publication of the images.

Ideally, at least two people would be interacting with the controller through HITODAMA. This allows the controller to make use of the robot's gaze, switching their perceptive focus between one interlocutor and another. At the first step (see fig. 56) the controller has to sign in with their chosen name and native tongue while the interlocutors wait for a connection. HITODAMA's display shows that it is waiting and it is already possible for the interlocutors to select their language of speech.

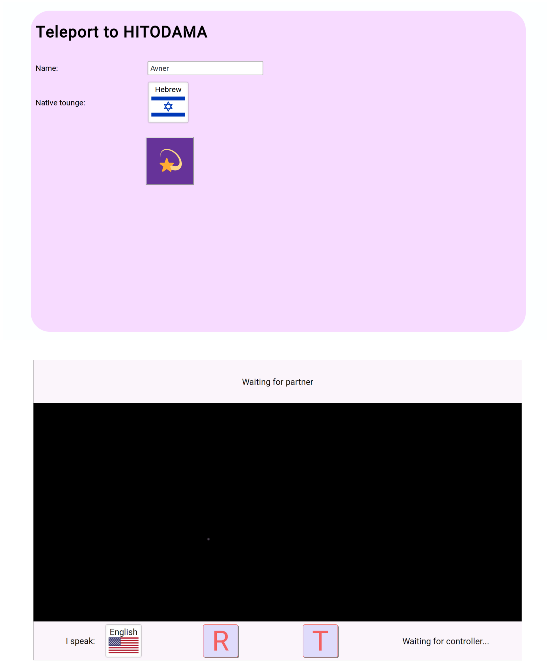

Figure 56: HITODAMA experiment: Initial screens (controller sign-in on top, robot display at the bottom).

Once the controller is logged in, the interface opens and HITODAMA's display shows that a controller has connected, specifying their name and native tongue. At this point, HITODAMA's arms, which serve as the interface for interaction, are closed and it is not possible to interact by pressing on the palms (see fig. 57).

Figure 57: HITODAMA experiment: HITODAMA's arms are closed and interfacing is not possible.

The controller already has full control over HITODAMA's functions, including speech, expressions and body movement; to start playing the picture game, the controller must press the check mark button which will open HITODAMA's arms. When that happens, the interlocutors must also signal that they are ready to play by squeezing HITODAMA's right arm (see figs. 58, 59)

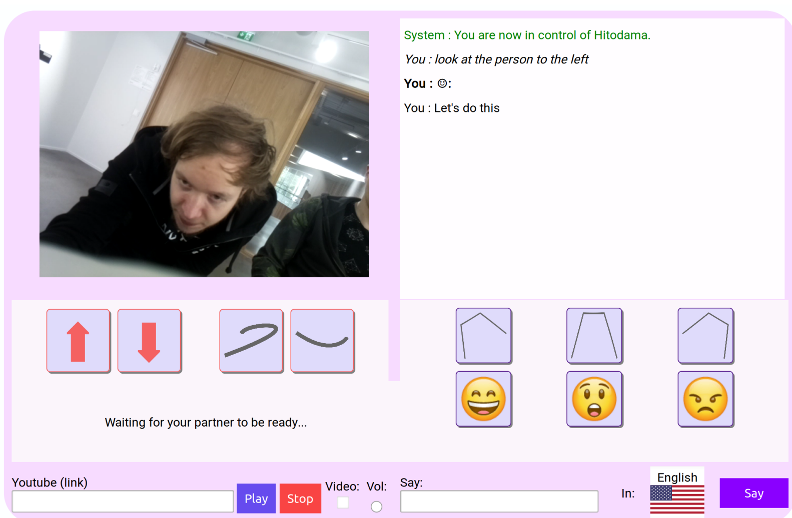

Figure 58: HITODAMA experiment: The controller has pressed the check mark button and is waiting for the interlocutors to start.

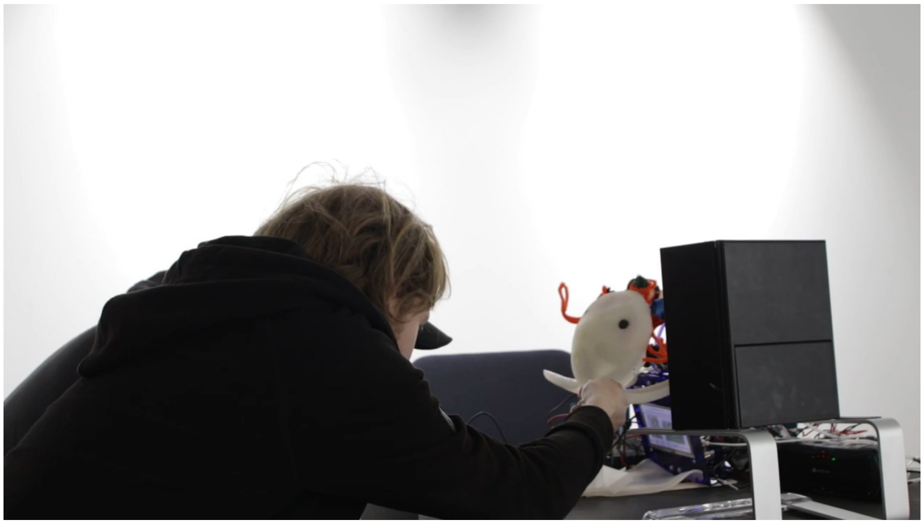

Figure 59: HITODAMA experiment: The interlocutors squeeze HITODAMA's right palm to start the picture game.

When both sides are ready, the pictures are randomly chosen and appear both on the controller's screen and on HITODAMA's display (see figs. 60, 61). The picture view, implemented by the **<hitodama-pics>** component, replaces the camera view for the controller until they choose a picture. The same component is used on the robot's display.

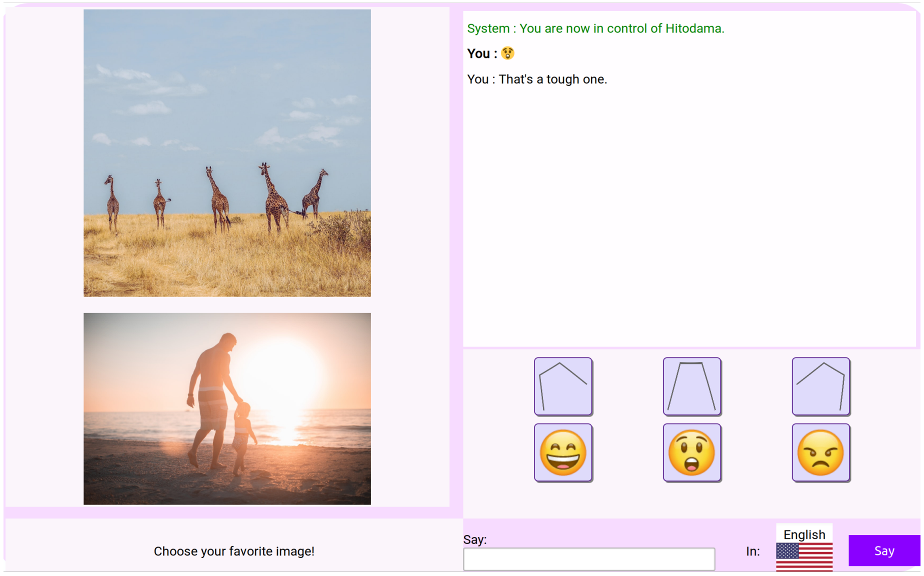

Figure 60: HITODAMA experiment: Chosing a picture, controller interface.

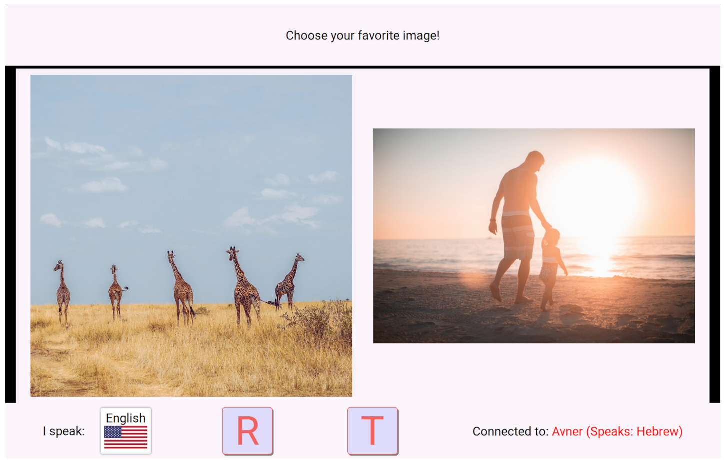

Figure 61: HITODAMA experiment: Chosing a picture, HITODAMA's display.

Initially it was intended that the controller would look at one of the interlocutors and that person would choose the image. Howbeit, it proved simpler to just let the participants decide the on order by themselves. The interlocutors decide on their favorite picture by squeezing either the left or right palm (see fig. 62) while the controller simply clicks on the desired image. The interface then displays to all of the participants whether they chose the same picture or a different one (see figs. 63, 64). They must then explain why they chose that specific picture.

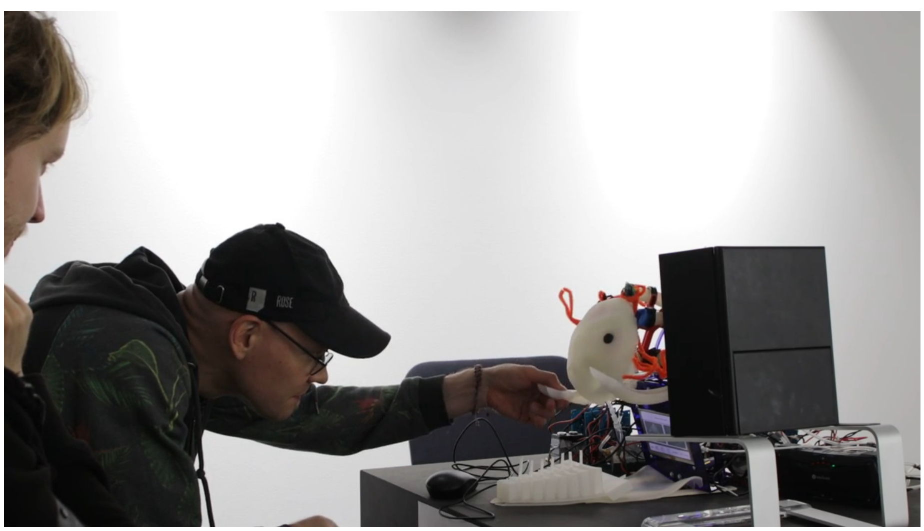

Figure 62: HITODAMA experiment: step 5. The interlocutors choose their favorite picture.

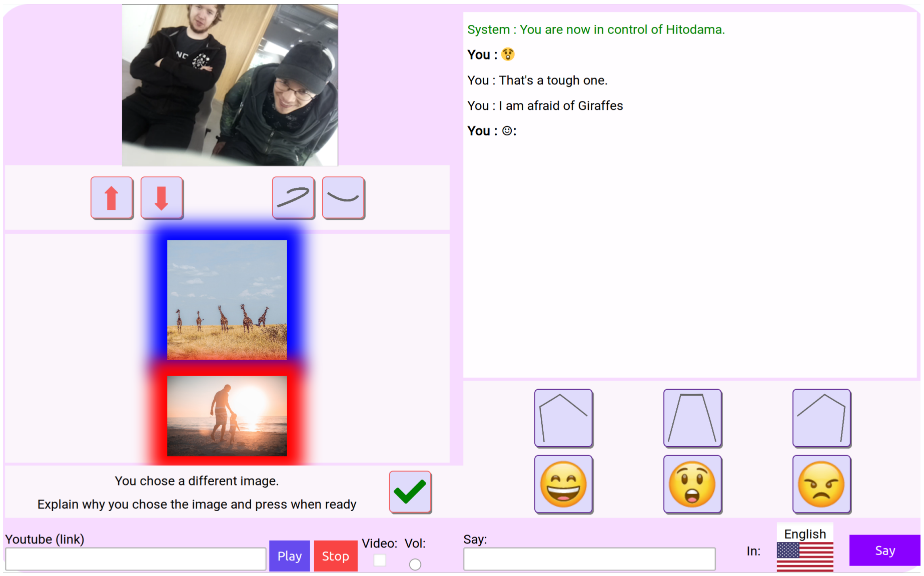

Figure 63: HITODAMA experiment: result of the picture selection, controller view.

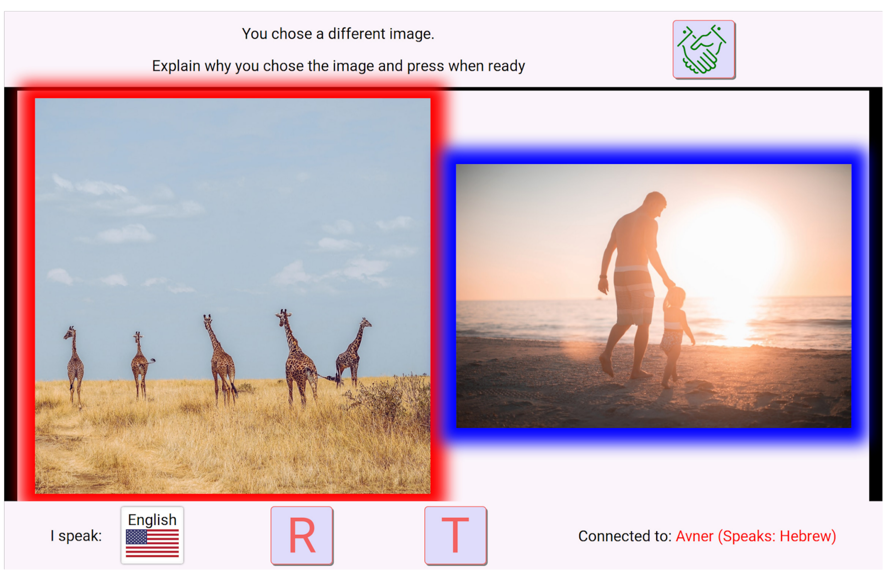

Figure 64: HITODAMA experiment: result of the picture selection, robot display view.

From both sides of the interaction, it is possible to explain the selection in the user's native tongue and have it translated to the partner's native tongue. In the case of the controller, one simply has to type the desired sentence and choose the target language for the utterance; HITODAMA would translate and speak the result using the aforementioned cloud services. From the interlocutor side, the participants use the arms as an interface to initiate a recording that would then be translated for the controller. By squeezing both hands simultaneously for two seconds (see fig. 65), a recording pop-up appears (see fig. 66).

Figure 65: HITODAMA experiment: The interlocutor is squeezing both of HITODAMA's hands in order to initiate a transcription/translation procedure.

Figure 66: HITODAMA experiment: The recording pop-up appears on HITODAMA's display, showing the time left for the recording. A special sound effect accompanies the pop-up.

The interlocutor has about 5 seconds to utter a sentence that would be translated to the controller. The sentence appears translated in the controller's transcript view (see fig. 67). Once both parties are done explaining, they signal each other that they are ready and the process can repeat.

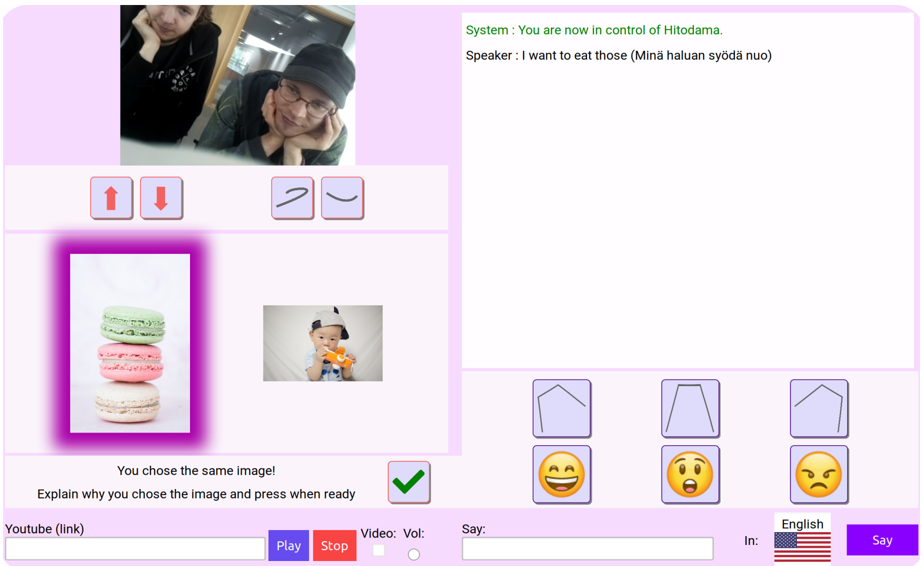

Figure 67: HITODAMA experiment: The interlocutor's sentence appears translated on the controller's interface.

Despite of the structured flow, the participants were encouraged to make us of available functions freely, such as speech translation, YouTube plays, expressions and movements. Additionally, they were encouraged to develop loose conversation and small-talk that stem from the picture game, without feeling compelled to go over as many pictures as possible.

Method

Implementation

Most of the features required for the experiment are available through HITODAMA's standard web components. On the client side, two dedicated web components were developed:

1. **<hitodama-pics>** : A component for showing the random pictures and the selections made by the participants.
2. **<hitodama-pics-control>** : A component for displaying and controlling the current status of picture game (ready, waiting and so forth).

For obtaining the actual picture, the public API from Unsplash was used[22]. For every picture, a random category was selected out of a pre-defined set of categories. The following set was used:

- For the first picture, one category of the following:

```
"animal", "game", "food", "music", "fun", "pain", "spiritual", "technology"
```

- For the second picture, one category of the following:

```
"toy","culture","robot","family","money","politics","business","nature"
```

Procedure

Five experiment sessions were organized: One at the iso-omena library in Espoo and five at the Aalto school of arts building. The interlocutors interacting with the robot were always Finnish locals and the robot controllers were foreign nationals. Different age group and genders were selected. The experiment was divided into two parts: First, a picture game session approximately 30 minutes long. Second, an interview session lasting as well about 30 minutes. The sessions were recorded and analyzed from the lens oh phenomenological interpretation.

Results

Session 1 - iso omena

- Samer from Iraq - 4 years in Finland. Young adult.
- Juha - 60 years old
- Even less afraid of robots after the experiment
- Eja: wife
- Juha Feels the solution is needed. Not all pictures appeared properly light was disturing.
- Samer: exciting, new thing, fun. Speaking in Arabic and getting Arabic responses.
- Ejas: has been talking to Pepper robot, but it couldn't understand Finnish. After figuring out the interface, it was easy to have contact with the robot.
- Samer: super easy to control the robot.
- They could see the face gestures and assumed that they mean something, but weren't sure what.
- Juha: Felt that the pictures reflected culture, but there wasn't enough time to go sense the differences.
- Samer: People are anyway different, but only two picture choices were different "This is nice!".
- Juha: Cultural background affects interpretation of the outside world.

[22] https://unsplash.com/

- Juha: Didn't have any expectations because he didn't know anything about the person.
- Eja: All machines have a mind of their own.
- Juha: Could see just the human behind. Couldn't believe that a machine this simple has a mind.
- Samer: In the future it will be more and more. Can't judge people but can have an idea about their thoughts. In the future could be more than pictures, maybe music. More ways of expression.
- Juha: It would tell more if there was more than pictures, such as music. Can skip the pressing with the hands there was too much.
- Eja: Touching was OK. Soft. But human touch is different.
- Antti (organizer): First experience with soft robots, felt much warmer but not sure why. It wasn't only the touch, the whole thing.
- Eja & Juha: Would like face gestures to be more human like.
- Samer: Looks like Mosquito. Funny that you can change your shape and language.
- Samer: Felt freedom to say what you want. Maybe felt more free than in real life.
- Eja & Juha: Wasn't scary!
- Juha: Would prefer face to face conversation, but it's good as a translation machine. would like humans to treat him in the elderly home and not robots.

Themes: session 1

First impression is of something new and unfamiliar.

Agent	Scenario	Theme
Controller	Session	
Controller	Session	
Controller	Session	
Controller	Session	
Controller	Session	
Interlocutor	Session	
Interlocutor	Session	
Interlocutor	Session	
Interlocutor	Session	
Interlocutor	Session	
Creator	Session	
Creator	Session	
Creator	Session	
Creator	Session	
Creator	Session	
Controller	Interview	
Controller	Interview	
Controller	Interview	

Agent	Scenario	Theme
Controller	Interview	
Controller	Interview	
Interlocutor	Interview	
Interlocutor	Interview	
Interlocutor	Interview	
Interlocutor	Interview	
Interlocutor	Interview	
Creator	Interview	
Creator	Interview	
Creator	Interview	
Creator	Interview	
Creator	Interview	

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References

Ahmed, S. (2000). *Strange encounters : Embodied others in post-coloniality*. London: Routledge. Retrieved from https://aalto.finna.fi/Record/alli.752377

Ahmed, S. (2014). *The Cultural Politics of Emotion* (NED - New edition, 2.). Edinburgh University Press. Retrieved from http://www.jstor.org/stable/10.3366/j.ctt1g09x4q

Allport, G. W. (1954). *The nature of prejudice*. Oxford, England: Addison-Wesley.

Auguste Rodin, P. G. (2012). *Rodin on Art and Artists: Conversations with Paul Gsell*. Dover Publications. Retrieved from http://gen.lib.rus.ec/book/index.php?md5=dbb102e88f0cc7b8016293b77d0d639f

Barad, K. (2007). *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning*. duke university Press.

Beane, S. R., Davoudi, Z., & J. Savage, M. (2014). Constraints on the universe as a numerical simulation. *The European Physical Journal A*, *50*(9). doi:10.1140/epja/i2014-14148-0

Bigelow, S. J. (2009). Technologies of Perception: Miyazaki in Theory and Practice. *Animation*, *4*(1), 55–75. doi:10.1177/1746847708099740

Blazquez Cano, M., Perry, P., Ashman, R., & Waite, K. (2017). The influence of image interactivity upon user engagement when using mobile touch screens. *Computers in Human Behavior*, *77*, 406–412. doi:10.1016/j.chb.2017.03.042

Bosch. (2019). BME280. Retrieved from https://www.bosch-sensortec.com/bst/products/all_products/bme280

Bostrom, N. (2003). Are we living in a computer simulation? *The Philosophical Quarterly*, *53*(211), 243–255.

Braidotti, R. (2017). *The posthuman*. Polity.

Caddeau, P. (2004). Tree Spirits(kodama)and Apparitions(henge):HagiWara Hiromichi's Analysis of Supernatural Events in Yngao and the Uji Chapters, 17.

Campanella, T. (2000). Eden by wire: Webcameras and the telepresent landscape. In (pp. 22–46).

Cole, J., Sacks, O., & Waterman, I. (2000). On the immunity principle: A view from a robot. *Trends in Cognitive Sciences*, *4*(5), 167. doi:10.1016/S1364-6613(00)01459-5

Craighero, L. (2014). The role of the motor system in cognitive functions. In *The Routledge Handbook of Embodied Cognition* (pp. 69–76). Routledge.

Cutting, J. E., & Massironi, M. (1998). Pictures and their special status in perceptual and cognitive inquiry. *Perception and Cognition at Century's End: History, Philosophy, and Theory. Academic Press, San Diego, CA*, 137–168.

Danese, E. (2015). Fashion tech and robotics. In *Social Robots from a Human Perspective* (pp. 129–138). Springer.

Dewey, J. (1923). *Democracy and education: An introduction to the philosophy of education*. Macmillan.

Dinan, T. G., Stilling, R. M., Stanton, C., & Cryan, J. F. (2015). Collective unconscious: How gut microbes shape human behavior. *Journal of Psychiatric Research*, *63*, 1–9. doi:10.1016/j.jpsychires.2015.02.021

Dolezal, L. (2009). The Remote Body: The Phenomenology of Telepresence and Re-Embodiment. *Human Technology*, *5*(November), 208–226. Retrieved from http://www.humantechnology.jyu.fi/current/abstracts/dolezal09.html%5Cnpapers2://publication/uuid/2F26DFF0-21CC-45AE-AAF2-1B170EDB8781

Dreyfus, H. L. (2000). Telepistemology: Descartes's last stand. In *The robot in the garden* (pp. 48–63). MIT Press.

Feldman, R., Rosenthal, Z., & Eidelman, A. I. (2014). Maternal-preterm skin-to-skin contact enhances child physiologic organization and cognitive control across the first 10 years of life. *Biological Psychiatry*, *75*(1), 56–64. doi:10.1016/j.biopsych.2013.08.012

Fortunati, L. (2003). Real people, artificial bodies. In *Mediating the Human Body* (pp. 81–92). Routledge.

Freeman, W. J. (2000). *How brains make up their minds*. Columbia University Press.

Freud, S. (1953). *The standard edition of the complete psychological works of Sigmund Freud.* (Vols. VII (1901-1905)). London: The Hogarth Press : The

Institute of Psycho-Analysis.

Freud, S. (1955). *The standard edition of the complete psychological works of Sigmund Freud.* (Vols. XVII (1917-1919)). London: The Hogarth Press : The Institute of Psycho-Analysis.

Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Sciences*, *4*(1), 14–21.

Gallagher, S., & Cole, J. (1995). Body Image and Body Schema in a Deafferented Subject. *The Journal of Mind and Behavior*, *16*(4), 369–389. Retrieved from https://www.jstor.org/stable/43853796

Galloway, K. C., Polygerinos, P., Walsh, C. J., & Wood, R. J. (2013). Mechanically programmable bend radius for fiber-reinforced soft actuators. In *2013 16th International Conference on Advanced Robotics (ICAR)* (pp. 1–6). doi:10.1109/ICAR.2013.6766586

Goodman, R., & Refsing, K. (Eds.). (1992). *Ideology and practice in modern Japan.* London ; New York: Routledge.

Goodwin, M. H. (2017). Haptic sociality. *Intercorporeality: Emerging Socialities in Interaction*, 73–102.

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of Psychosomatic Research*, *57*(1), 35–43. doi:10.1016/S0022-3999(03)00573-7

Hackerspace, L. (n.d.). Making machinable wax Leeds Hackspace. Retrieved from https://leedshackspace.org.uk/2016/05/09/making-machinable-wax/

Haraway, D. (2006). A cyborg manifesto: Science, technology, and socialist-feminism in the late 20th century. *The International Handbook of Virtual Learning Environments*, 117–158.

Hoel, A. S., & Carusi, A. (2018). Merleau-Ponty and the Measuring Body. *Theory, Culture & Society*, *35*(1), 45–70. doi:10.1177/0263276416688542

Hoffman, G., & Ju, W. (2014). Designing Robots With Movement in Mind. *Journal of Human-Robot Interaction*, *3*(1), 89–122. doi:10.5898/JHRI.3.1.Hoffman

Husserl, E. (1982). *General introduction to a pure phenomenology.* The Hague; Boston; Hingham, MA, USA: M. Nijhoff ; Distributors for the U.S.; Canada, Kluwer Boston.

Ihde, D. (1990). *Technology and the lifeworld: From garden to earth.* Indiana University Press.

Ihde, D., & Malafouris, L. (2018). Homo faber Revisited: Postphenomenology and Material Engagement Theory. *Philosophy & Technology.* doi:10.1007/s13347-018-0321-7

Janus. (2019). Janus WebRTC Server: About Janus. Retrieved from https://janus.conf.meetecho.com/

Jentsch, E. (1997). On the psychology of the uncanny (1906). *Angelaki: Journal of the Theoretical Humanities*, *2*(1), 7–16.

Jørgensen, J. (2017). Prolegomena for a Transdisciplinary Investigation Into the Materialities of Soft Systems. *Prolegomena.*

Katsumi, T. (1990). *幻想世界の住人たち〈4〉日本編 (Truth in fantasy (9)).* Retrieved from https://en.wikipedia.org/wiki/Kodama_(spirit)

Katz, J. E. (2017). Do machines become us? In *Machines that become us* (pp. 15–25). Routledge.

Kaye, L. K., Malone, S. A., & Wall, H. J. (2017). Emojis: Insights, Affordances, and Possibilities for Psychological Science. *Trends in Cognitive Sciences*, *21*(2), 66–68. doi:10.1016/j.tics.2016.10.007

Keating, E. (2017). Challenges of Conducting Interaction with Technologically Mediated Bodies. In *Intercorporeality: Emerging Socialities in Interaction* (p. 303). Oxford University Press.

Kress, G. (2009). *Multimodality: A social semiotic approach to contemporary communication*. Routledge.

Leland, M. (2015). Mindfulness and Student Success. *Journal of Adult Education*, *44*(1), 19–24.

Litman, S. (2018). Haaretz inteview with Dr Yael Berda. . Retrieved from https://www.haaretz.co.il/magazine/.premium-MAGAZINE-1.5975041

Lockett, D. (2017, September). Last Night's South Park Commanded People's Amazon Echos to Say NSFW Lines. *Vulture*. Retrieved from https://www.vulture.com/2017/09/south-park-commanded-peoples-amazon-echos-to-say-nsfw-lines.html

Malafouris, L. (2013). *How things shape the mind*. MIT Press.

Martin, M. G. F. (1995). Bodily awareness: A sense of ownership. In *The body and the self* (pp. 267–289). Cambridge, MA, US: The MIT Press.

Marx, K. H. (2015). *Capital: A Critique of Political Economy* (Vol. 1). Moscow, USSR: Progress Publishers. Retrieved from https://www.marxists.org/archive/marx/works/download/pdf/Capital-Volume-I.pdf

Merleau-Ponty, M. (1964). *The primacy of perception: And other essays on phenomenological psychology, the philosophy of art, history, and politics*. Northwestern University Press.

Merleau-Ponty, M. (2013). *Phenomenology of perception*. Routledge.

Merleau-Ponty, M., Lefort, C., & Lingis, A. (1968). *The visible and the invisible : Followed by working notes*. Evanston: Northwestern University Press. Retrieved from https://aalto.finna.fi/Record/alli.761571

Mills, T., Bunnell, H. T., & Patel, R. (2014). Towards personalized speech synthesis for augmentative and alternative communication. *Augmentative and Alternative Communication*, *30*(3), 226–236.

Miyazaki, H. (1997). Princess Mononoke.

Nietzsche, F. W., Williams, B. A. O., Nauckhoff, J., & Del Caro, A. (2001). *The gay science : With a prelude in German rhymes and an appendix of songs*. New York: Vintage.

NinjaTek. (2019). NinjaTek NinjaFlex. Retrieved from https://ninjatek.com/ninjaflex/

Novak, P. K., Smailović, J., Sluban, B., & Mozetič, I. (2015). Sentiment of emojis. *PloS One*, *10*(12), e0144296.

O'Connell, M. E. (2009). Unlawful killing with combat drones: A case study of Pakistan, 2004-2009. *SHOOTING TO KILL: THE LAW GOVERNING LETHAL FORCE IN CONTEXT, Simon Bronitt, Ed., Forthcoming*, 09–43.

O'Reilly-Shah, V. N., Lynde, G. C., & Jabaley, C. S. (2018). Is it time to start using the emoji in biomedical literature? *Bmj*, *363*, k5033.

Papp, Z. (2010). *Anime and its roots in early Japanese monster art*. Global Oriental.

Parker-Pope, T. (2008, April). The Truth About the Spinning Dancer. *Well*. Retrieved from https://well.blogs.nytimes.com/2008/04/28/the-truth-about-the-spinning-dancer/

Patel, S. (n.d.). The Benefits of Being a "Cyborg". *Beam*. Retrieved from https://suitabletech.com/news/blog/full/1368-the-benefits-of-being-a-cyborg

Paulos, E. (1996). Legal Tender. Retrieved from http://www.eiu.org/orig/experiments/legal_tender/

Peleg, I., & Waxman, D. (2011). *Israel's Palestinians: The Conflict Within*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511852022

Reynolds, J. (2014). *Understanding existentialism*. Routledge.

Rosenberger, R., & Verbeek, P.-P. (2015). *Postphenomenological Investigations Essays. Essays on Human–Technology Relations* (Vol. 1). doi:10.1017/CBO9781107415324.004

Sartre, J.-P. (2012). *Being and nothingness*. Open Road Media.

Sevdalis, V., & Keller, P. E. (2011). Captured by motion: Dance, action understanding, and social cognition. *Brain and Cognition*, *77*(2), 231–236. doi:10.1016/j.bandc.2011.08.005

Smith, D. W. (2018). Phenomenology. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2018.). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/sum2018/entries/phenomenology/

Smooth-On. (2019a). Dragon Skin™ 30 Product Information. *Smooth-On, Inc.* Retrieved from https://www.smooth-on.com/products/dragon-skin-30/

Smooth-On. (2019b). Ecoflex™ 00-30 Product Information. *Smooth-On, Inc.* Retrieved from https://www.smooth-on.com/products/ecoflex-00-30/

Smooth-On. (2019c). Sil-Poxy™ Product Information Smooth-On, Inc. Retrieved from https://www.smooth-on.com/products/sil-poxy/

Stone, A. R. (1991). Will the real body please stand up. *Cyberspace: First Steps*, 81–118.

Stupacher, J., Wood, G., & Witte, M. (2017). Synchrony and sympathy: Social entrainment with music compared to a metronome. *Psychomusicology: Music, Mind, and Brain*, *27*(3), 158–166. doi:10.1037/pmu0000181

Suzumori, K., Iikura, S., & Tanaka, H. (1991). Development of flexible microactuator and its applications to robotic mechanisms. In *1991 IEEE International Conference on Robotics and Automation Proceedings* (pp. 1622–1627 vol.2). doi:10.1109/ROBOT.1991.131850

Syväoja, H., Kantomaa, M., Laine, K., Jaakkola, T., Pyhältö, K., & Tammelin, T. (2012). Liikunta ja oppiminen. *Tilannekatsaus Lokakuu. Helsinki: Opetushallitus.* Retrieved from https://www.oph.fi/download/145366_Physical_activity_and_learning.pdf

Tate, C. E. (2008). Knowledge Systems of the Olmec. *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*, 1203–1212.

Tate, C. E. (2010). The axolotl as food and symbol in the basin of Mexico, from 1200 BC to today. In *Pre-Columbian Foodways* (pp. 511–533). Springer.

Tenzer, Y., Jentoft, L. P., & Howe, R. D. (2014). The Feel of MEMS Barometers: Inexpensive and Easily Customized Tactile Array Sensors. *IEEE Robotics & Automation Magazine*, *21*(3), 89–95. doi:10.1109/MRA.2014.2310152

Toolkit, S. R. (2018). (35) Remove Inner Rod From Actuator Body - YouTube. Retrieved from https://www.youtube.com/watch?v=YgKgAP8eEKU

Toolkit, S. R. (2019). *Fiber-Reinforced Actuators*. Retrieved from https://softroboticstoolkit.com/book/fiber-reinforced-bending-actuators

TopeconHeroes, ア.-m. . (2019). Fire icon アイコン素材ダウンロ🄵ドサイト「icooon-mono」商用利用可能なアイコン素材が無料 (フリ🄵) ダウンロ🄵ドできるサイト. Retrieved from http://icooon-mono.com/11150-fire-icon/?lang=en

Unicode Emoji. (2019). Retrieved from https://unicode.org/emoji/index.html

Verbeek, P.-P. (2016, December). Techno-flesh: Toward a phenomenology of human-robot relations. *Peter-Paul Verbeek*. Retrieved from https://ppverbeek.wordpress.com/2016/12/17/techno-flesh-the-phenomenology-of-human-robot-relations/

Vitiello, G. (2007). Quantum dissipation and information: A route to consciousness modeling. *NeuroQuantology*, *1*(2).

Von Uexküll, J. (1982). The theory of meaning. *Semiotica*, *42*(1), 25–79.

Walker, M., & Mann, R. A. (2016). Exploration of mindfulness in relation to compassion, empathy and reflection within nursing education. *Nurse Education Today*, *40*, 188–190. doi:10.1016/j.nedt.2016.03.005

Weil, S. (2002). *Gravity and Grace*. London: Routledge. Retrieved from http://www.amazon.com/dp/0803298005

WPE. (2019). WPE. *WebKit*. Retrieved from https://webkit.org/wpe/

Xue, L., Zhu, X., An, X., & Xie, L. (2018). A Comparison of Expressive Speech Synthesis Approaches based on Neural Network. In *Proceedings of the Joint Workshop of the 4th Workshop on Affective Social Multimedia Computing and first Multi-Modal Affective Computing of Large-Scale Multimedia Data* (pp. 15–20). ACM.

Zeki, S., & Romaya, J. P. (2008). Neural correlates of hate. *PloS One*, *3*(10), e3556.