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HUMAN ACCEPTANCE AS PART OF THE SOFT ROBOT DESIGN

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ABSTRACT

As machines and robots become a increasingly larger part of society, it is important that they are fully accepted. If the machines are not utilized as intended, it is not only a waste of time and energy, but also of valuable resources. This acceptance by humans of robots is based on how well the interaction with robots is trusted. Trust of robots can be based on three approaches: physical safety, operational understanding, and the social aspect of training. It is important to also consider these aspects when designing machines that will interact with humans, since acceptance by the people is key for the correct utilization of the machines. A possible approach to solve the issues around trust are soft robots. These machines are adaptable to a situation by either a physical flexibility or a digital anticipation due to sensing and control. This adaptiveness to humans in different ways makes Soft Robotics easier to accept then regular rigid machines. With their reduced or prevented effect if collided with humans they are safer. Because of the reduced operational complexity and digital simulations they are therefore easier to understand. Training becomes also easier as operator can experience the flexible nature of soft material themselves as well have augmented reality or virtual reality to assist them in training and operating. All these benefits of Soft Robotics will eventually lead to better acceptance of robots and should therefore be taken into account when designing robots to enable a flourishing automatized society.

INTRODUCTION

As the world develops towards a situation with a continuously increasing level of automation, humans have to interact with robots more and more. This Human Robot Interaction is about social, physical or cognitive cooperation and needs to happen correctly to ensure a smooth integration of robots into society. This works best if the robots are safe and trusted by operators or others they interact with. Soft Robotics may offer some solutions to increase both of these factors. Originally, Soft Robots were designed to copy certain behavior of animals to technical applications with special material or tissue. The goal was to develop robots with innovative, bio-inspired abilities to perform, in order to achieve better flexibility and adaptability during interacting with the unpredictable surroundings or operations. Integrating technology with the softness from the soft body-parts of the animals could enable a lesser need for complexity in mechanical and algorithmic robot development [1].

The aim of this paper is to discover how new or existing soft robotic technologies can improve Human Robot Interactions (HRI) from a design approach. This is done by searching for papers that cover HRI, combining with injury prevention, overall safety and trustworthiness of robotic systems. It was also looked into user experience and maintenance of robots. This information is later combined with the research on Soft Robotic technology, its definitions, characteristics and current applications for solutions in design for a smoother integration of robots into society.

Design with Human-Robot Interaction

In every environment that has both humans and robots acting in it, HRI occurs. This cooperation depends mostly on type of operations and degree of automation at every instance, and whether it is physical, cognitive, or social [2]. In a manufacturing process, existing mostly of human using tools with some tasks being done (partly) by robotics, this interaction is based on safety and trusting of the robot, as it is in every socio-technical system [3]. In other scenario's, for example a fully automated port, the interaction is more about controlling and using the robots, and safety is covered in overall system safety instead of direct interaction. This section covers two important sides of HRI, namely safety and health, and user experience. The first to ensure the interaction is of low risk for humans involved, the latter being an optimization of how robots can be utilized by humans with the most convenience. Figure 1 shows a diagram how the HRI is build on different pillars of trust.

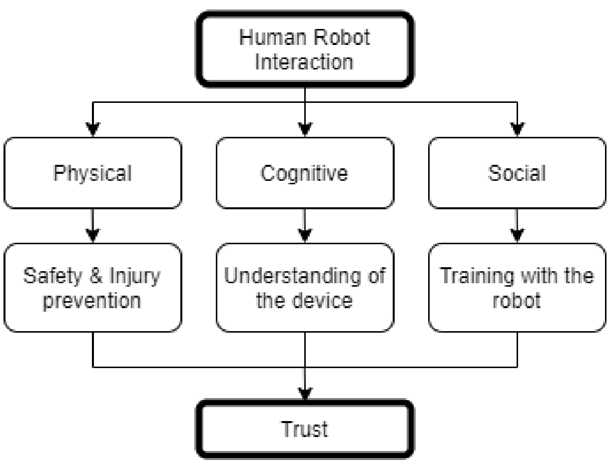

FIGURE 1. How HRI is based on trust, build over multiple approaches

Since humans are the ones that have to accept and work with the robots it is important that this is considered during the design of the robot. In the common design cycle, it is tested only whether it is within legal standards and accepted within the system of operations. The requirements should also consider the human acceptance, and during the testing phase, must be compliant to not only the system but also the human operator. These extra steps should follow a holistic approach, as it is not only the robot itself, but could also cover the system surrounding the machine. Figure 2 shows how this updated design process should look, with the extra requirements made bold.

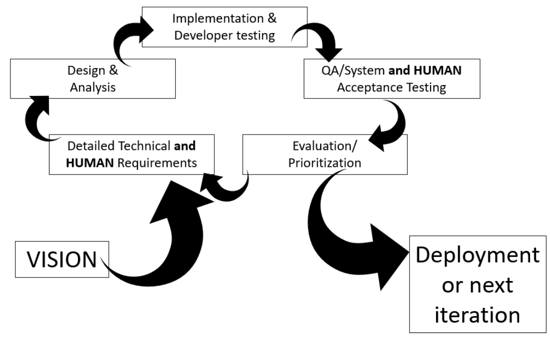

FIGURE 2. Design cycle for a scrum process, with additions to it for better human acceptance.

For every operation that involves both humans and robots, international standards are set to ensure safety in the workplace, the ISO standards. However, still accidents occur, on the largest scale of container terminals, to small scale with direct interaction in manufacturing environment. Starting with the largest scale, ports and sizing down from there, this section will cover hazards for health and safety in operation. To improve safety in a large system is to lower secondary costs of operations, as is occurring in ports worldwide [4]. Fatalities, injuries, and property damage are types secondary costs that are caused by a unsafe HRI [5]. These risks of human lives, property and environment should be reduced as much as economically feasible. Also other larger scale collisions, for example pedestrian with vehicles in non-industrial area's are part of the HRI for bigger robots that lack safety and are a danger to health.

HRI also occurs is an intermediate size situation, in systems with a lower level of automation, direct interaction, and with smaller robots than cranes and automated guided vehicles (AGV's). Safety with robots in these size is mainly to understand them, and work with them more continuously. Currently, in agriculture some robots already make the human job safer by taking over tasks with toxic pesticides. However, there still remains an unsafe part in the maintenance of heavy equipment and the inability to differentiate human and agricultural asset during correct execution of harvesting jobs, and collision in general [6]. Assisting- type of robots usually collaborate with humans when lifting items. Their safety is based on the ability to adapt to movements, as well as lift sufficient to not have to load all pressing upon the human. The priority for health and safety is focused on human injury prevention since the robots do not operate with forces that hurt environment or property significantly.

At last there is the human robot environment on the smallest scale, with an even lower level of automation, meaning the interaction is very direct. Initially it is desired that human and robot work-spaces are separated as much as possible in industrial environments, but if hazardous situations cannot be prevented for the sake of the operation, the risks occur in the shared spaces [7]. In these situations, the most occurring accidents are of a collision nature, so an impact, crushing of cutting injury on body parts. Especially in a Human Robot Assembly cell, where the robot can not adapt to unexpected collisions or malfunctioning, dangers arise. For the operation to be less hazardous it is important that the system functions, the operator is aware to what he may be exposed, and the environment is in line with the professional safety standards [8]. The first and last are mostly due to technical correctness and general safety of the tasks, so in this may be a role for the physical benefits of soft robotics.

The social aspect of trusting, the digital understanding and empowerment, and the actual physical work environment are important factors for the user experience. For the physical parts, it is mostly relevant for situations that the technology specifically holds the human, like a dancing robot [9] or in a more interactive way, how the robots adapts to physical actions by the human. However, this is more related to health than comfort, so the emphasize of user experience is digital. The social factor of trusting is of significant importance in HRI as it assists determining the effectiveness, systematic safety as well as reliability of robotics.The increase in trust can originate from different aspects: influence of design, understanding of the device, and training with the device [10]. The assisting in design helps them visualize what is on operational level expected from both them and the robot. The understanding of the device will help them predict how a device can act and what to initially expect during cooperating and what the possibilities are for further utilization. The training is about learning to work with the robot in real life, to have physical interaction and to experience how the robot (re)acts in certain situations. This improvement in expectations also reduces injuries, making it safer henceforth more trustworthy.

Soft Robotics: definitions and characteristics

Soft Robotics can be described with different definitions, the most common one from the Soft Robotics community is the following: ”soft robots are devices which, due inherent or structural compliance, can actively interact with the environment and can undergo ’large’ deformations ”([11] p3). So the robots should be ”soft” for most of the parts, with a focus on material that acts flexible, can handle large strain and adapts to the object it is handling.

Rigid components in regular robotics have a negative impact on the ease of grabbing something. Fragile object can be broken or damaged due to the stiff nature that give these robots their reliability. As with Soft Robotics, the fingers are capable of curling around objects without damaging either operation equipment or object, as shown in figure 3. The compliant parts improve adjust-ability and, in case of less predictable human behaviour, also safety. Next to that, soft robots are better in mimicking human like, fluid and natural, movements. This results not only in acceptance of robotic counterparts in work or private environments but also enables a more precise and better controlled operation because of the higher accuracy achieved [12]. Soft robotics are also able to operate with less operational complexity if looked at the rigid alternatives. One soft flexible part can cover movements in three dimensions, whereas the rigid robots need 3 linear actuators. Finally, the bending soft robots also have the potential to have a higher energy efficiency, as it is possible to store and release the elastic energy during operations.

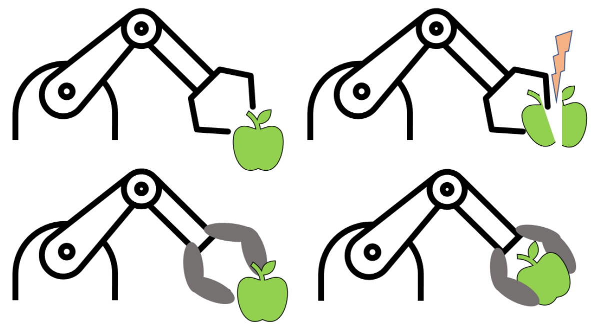

FIGURE 3. Example of the benefits of soft materials in robotics. The apple can now be without being damaged due to the adaptive nature of the soft materials.

The field where these benefits are most useful is medical. Soft robots, for example in endoscopic applications, are a key solution for not damaging intestinal tissue while operating. But next to this field of health, which is in general about very tender environments and sensitive tools, there are also fields with harsher environment which still require the delicacy of soft robots. Agriculture requires a soft touch for handling fruit, or to shake trees. The materials that are being handled, the peel of fruit or bark required a correct handling to not get damage for the correct quality or to maintain. A final example is aerospace, in the confined outer space operational work space, being able to adapt and not too rigid to cause harm are of great influence for this the transition to more softness in robots to happen. Robotic arms that are flexible and bend along when they colide with something, are a prime example for this field. [12].

Although Soft Robotics seem like a suited way to tackle a large part of current and future challenges in the industry, there are three reasons why these not widely applied yet: actuators, materials and the downsides of small scale and controlling of deformations.

To ensure sufficient force available for the operation of the fully soft robot, the actuators need to do deliver. However, to create an actuator that is both soft and has sufficient driving force is the real challenge. There are currently three popular techniques to create this flexibility in actuation systems [1]. Dielectric elastomeric actuators (DEAs) are driven by electric forces. Most of soft robots with this actuation are limited by the need for high quality electrodes, a rigid frame and having the material pre-strained before they are considered reliable. Shape-memory alloy (SMA) is a second way of actuating the soft robots in which worm-like behaviour is copied. They can act like flexible threadlike springs and can give rigidity to another soft material. Nonetheless, SMAs depend on temperature for force generation, so to have control of temperature in thermal varying environments is challenging. Next to that, the efficiency of this technique is low (+-1%) and permanent damage can easily occur due to overheating or - straining. The third technique is compressed air or pressured fluids usage. This one works by filling compartments with different levels of pressure, making the shape change and adding local stiffness for correct configuration of the robot. This can be done using gasses or fluids. Gasses working faster but need more control and offer less stiffness. On the other liquids are easier to control, remain stiffer during operations due to not being compressible, but work slower because of higher viscosity [13].

Another reason why it is hard to integrate soft robotics is the need for very specific materials. The skin- or muscle- like behaviour of contraction, stretching and controlled bending is hard to mimic, especially if those parts also have to sense in the case of "smart skins". These should also be able to sense and actuate, to correctly get signals through and act upon it. On one hand this seems the solution for fully integrated human like robots as it makes robots more intelligent or sensitive while remaining compact and soft. However, it becomes even more complex to have suited materials for soft robotics. Also the multiple layers of material, all in different shapes are harder to manufacture. The operational reduction of complexity in parts with larger amount of DoF is a trade-off with how hard it is to manufacturing the robots. Next to this complexity in material demands, the elastic materials have a maximum stress of around 2 MPa, and a strain of maximum 325% . Materials with these specific characteristics are rare and the ideal shapes are harder to manufacture as every applications demands different specifics. Unlike their regular counterparts, the rigid robots that all usually demand very high tensile strength and stiffness and not often irregular shapes. As can be reasoned from the yield strength, there is a maximum of when elastic materials are realistic to apply in processes with very high forces. In large scale environments such as ports, gravity and heavy machinery forces occur that are hard to elastically contain. To withstand those the amount of soft material needed is not realistic to work with.

Furthermore it is harder to control movements with soft parts, since individual compartment needs to be actuated in a much more fluid way. Controlling the physical flexible behaviour as intended requires high performance with distributed control. Hence the benefit of multiple DoF is also a downside as every possible configuration needs to remain stiff or become lose in the exact correct order. Therefore one can say that the complexity moved from the execution to the control [14]. The challenge in soft robotics is to address and solve the issues in physical architecture modules and interfaces, and the design of the controllers, to enable better soft robotics for integration in society [15]. Generally speaking, Soft Technology is more about anticipation and adaptability. Although there is relatively little research done into these pseudo-soft technologies, the ability to handle situations smoother, to copy more fluid behaviour, hence the Soft in Soft Robotics can also be redefined. The softness that is based on the bio-inspired robots can also be only used in the end of grippers, so still with more rigid actuators. This way, flexibility is preserved without all the control complexity or stiffness shortcomings, also actuating problems are removed since general actuators can be applied in this perspective of Soft Robotics. This also leads to a third definition of soft, with the Soft is more related to software. These soft as in smart systems are also flexible, in these occasions in their reactive nature. By being able to adapt not physically but digitally to situations it still can anticipate to humans involved in the larger systems, by sensing them and acting on it. Therefore can these other definitions also be considered as different perspective on how robotics or robotic systems are able to act flexible, adapt to humans or other machinery and anticipate fluidly.

Integrated Design

In the current evolution towards a technology based society, and humans can be considered completely soft, it is important that the robot which is interacted with has an adaptable automated counterpart [16]. This chapter elaborates first on how a design with soft robotics can increase safety, going deeper in the differences in scale, covering different type of equipment from both maintenance and safety applications point of view. The chapter will end with pointing out how a design with any type of "soft" robotics improves the general user experience as well.

One of the most important points in design for large scale machine systems, for example the transport sector, is the demand for strength and stiffness. The operations (container lifting, conveyor belt transportation, the pumping of liquid bulk etc.) require such forces and power because of the mass flow that is necessary to meet market demands. Therefore is it near impossible for soft robotics to offer any direct physical improvement or reduced complexity. However, benefits of soft materials can still have some kind of function to increase safety in either protection or reduction of damage. Furthermore, the software side of soft robotics can still generate an adaptable system with higher safety and an increased user experience. This is perceived as one of the major challenges in bio inspired robotics in which soft robotics are a substantial part, to keep having the desired flexible behaviour. Especially when materials can no longer adapt physically, the robots should be able to anticipate digitally [17].

Since the deformations of soft robotics can not be controlled working with the forces acting in large scale operations, rigid robots remain a necessity. Although regular soft robotics are therefore not an option for replacement, lessons can be taken from the advantages of this technology. The elasticity that prevents damage on impact is already used in a situation where the soft buffers prevent sharp impact and reduce damage simultaneously. However, this emphases on passive safety, with protecting everything that could be acted an impact upon. The same way as employees needing to wear protective parts like helmets and steel-toed shoes. However, for some devices it is obvious that adding soft material to it will only complicate operations or will not solve any impact issues due to the forces being to large, like grabs for bulk or complete containers. For AGV's in the port area it might be possible, as they usually travel at low velocities (8-16 km/h). The impact is than still in range that a layer soft materials can reduce injuries [18].

Nevertheless, that only covers the material side of adaptable behaviour. The correct control to have a flexible interaction with the human is still a necessity to develop. It is important for the machine to anticipate for the human-in-the-loop. The sensing and control could be the first line of protection, with the soft materials functioning as a back-up safety system in case of a false negative in sensing for humans or impact in general.

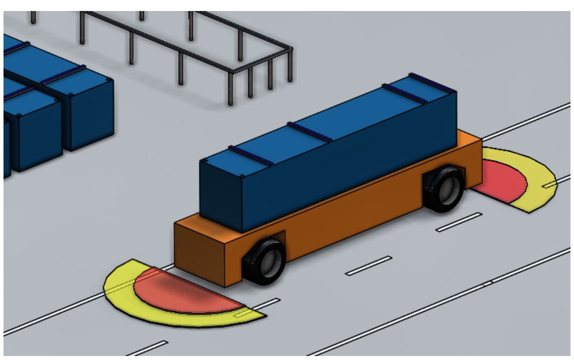

FIGURE 4. Danger zones around the AGV, within reach of next steps, need impact reduction or prevention.

Something similar can also be designed for smaller interactions, for environments with a lower level of automation. Smaller AGV systems, for example in manufacturing environment, where they work with both machines and humans, and industry 4.0 offers solutions in safety as well [19]. The awareness within a system of the presence and planning of all actors involved can initially prevent any collision from happening in the first place if executed flawless, as shown in figure 5.

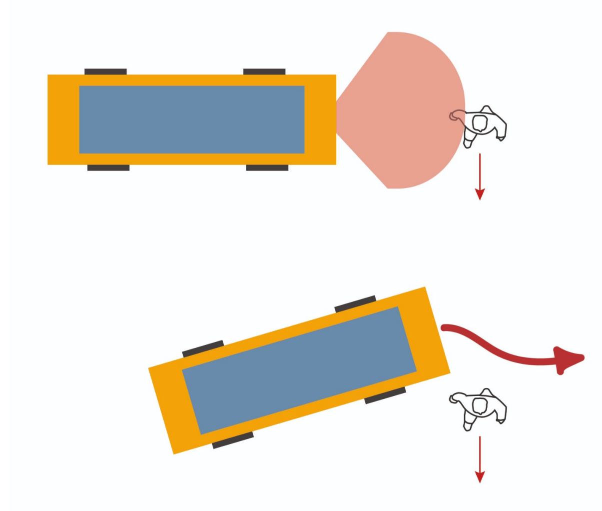

FIGURE 5. The AGV senses the human, and anticipates to its route to avoid collision, as if it was his co-worker.

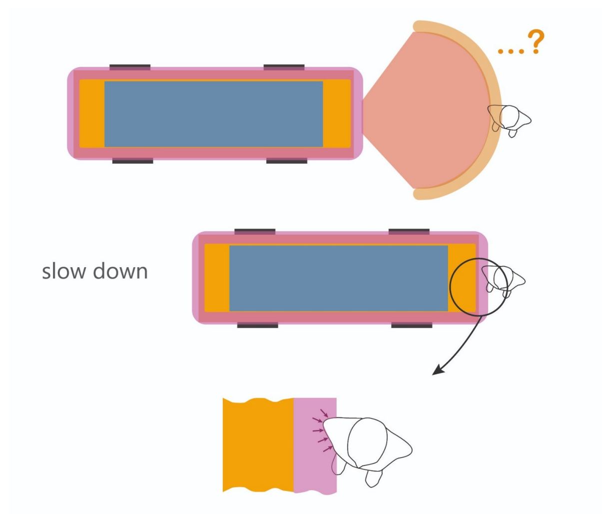

FIGURE 6. As the person or obstacle is not recognised directly, and put into an uncertainty category. The vehicle can just slow down a bit and in case of an actual collision the soft layer will reduce the impact. This way unnecessary stops or reroutings are avoided at the expense of slightly more collisions, which will be less harmful.

Furthermore, here the forces are not necessarily not of such impact that the control needs be overly careful with sensing and preventing potential impact. This not only relevant for AGV, but also for other type of robots that interact with humans. As long as the grasping or other operational task is effected with soft handling a more risky approach or threshold may be implemented, for a more faster and smoother working process, without risking injuries. With the machine only slowing down in case of high risk collision and having a full stop in case of sensing impact, the operation can continue more, because of less false negatives.

In the cases of smaller size, but more direct interaction with the robots, soft robotics have proven to increase safety [13]. As long as the end grippers are softer, the impact of collision nature, cutting, crushing or breaking will be reduced and therefore injuries as well. Not only just soft grippers create a safer situation, a totally soft device, with a design focused on HRI delivers even better result in acceptance by employees [20]. Especially on these smaller scales, where the forces are already of a non-fatal risk, the robots can be accepted even easier.

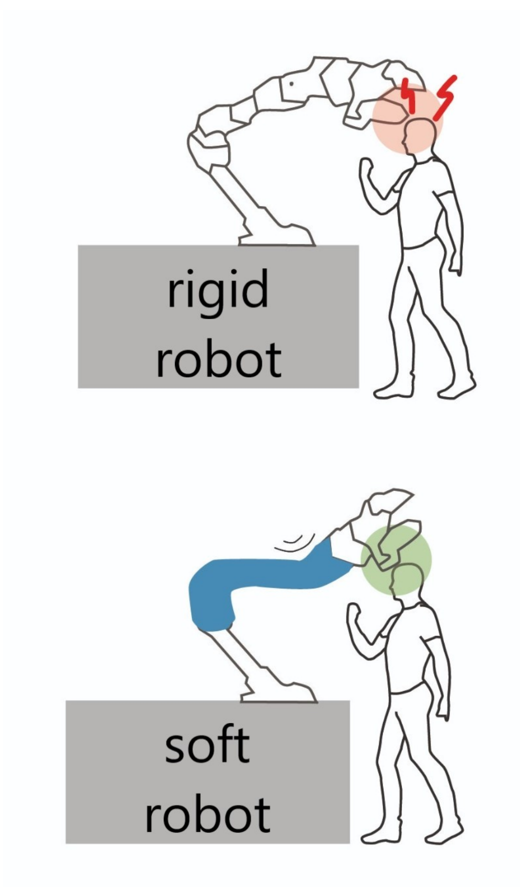

FIGURE 7. In the initial situation, there is a hard impact due to the rigidity of the robot. As the soft arm can transfer the impact to elastic energy, the effect of the collision is reduced and there is less risk of injury in the new situation.

Whereas the rigid robots do severe damage when having an impact on the user, soft robots turn the impact into elastic energy. Next to that there is another benefit for the operation if the machine has a impact avoiding protocol that senses for the human in the loop or if the human robot environment is on the minimum requirements of international standards. With this, working closer together, less safety precaution needed, the jobs done with robots can be done more efficient. This way injury risks are reduced, as the opportunity is maybe larger since robots are easier approached, but the collision is less harmful. Figure 7 shows how a soft robot offers a safer work space.

Figure 8 shows an schematic overview of which sizes of machine are better anticipating with which approach. The reason that digital anticipation is less likely to help anticipating with small machinery is the need for electronics that enable any digital awareness. As soon as the machine become sufficiently large these will not be an issue to integrate anymore.

The social and cognitive expect of trusting the robot is key for the correct implementation. Only when the user experience is truly based on trust the integration of robots happen correctly and the benefits optimally be acquired. How can soft robotics improve the influence of design, training with the device, and understanding of the device for a better trust relation.
The reduced complexity may lead to an easier understanding of the design. This, next to a explanation of the soft materials and therefore the better safety can lead to a faster understanding and appreciation. Especially after training with the soft elements, and experiencing its benefits first hand. However, this is only in the case of lower forces and actual soft materials. Soft as in software is another big opportunity for improving the trusting of the robots. However, safety on large scale operations is mostly related to safety culture, which exist by having and protecting a safe environment, but also emphasizing the correct usage of machines. This is best achieved by correct training before being having to operate in real life.

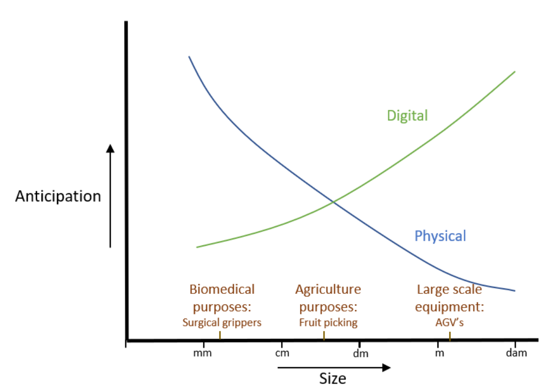

FIGURE 8. The qualitative relation between size of the machines, and which type of anticipation is the most useful.

Conclusion

When considering the future of automation it is important to take into account the human-robot interaction. As the technology is more and more available to take over human tasks, it is simultaneously more important that this coexistence between human and machine is correctly approached. The HRI is based mainly on trust. Therefore it is important that not only physical safety but also social and cognitive acceptance of the robots are considered for a correct implementation of automation. Soft Robotics offer a solution towards a better acceptance of robots, as they provide a soft counterpart for humans, that is both safer for impact and more adaptable to human handling. Furthermore, as this "soft" criterion can also be based of software, to be adaptable because of sensing and control. This offers more ways to gain trust of human as well. With the entire system connected, it is better capable of reacting to the human-in-the-loop and can anticipate digitally to prevent risky situations.

So either digitally or physically, "Soft" Robotics can adapt better to humans, gain their trust faster, and are therefore a solution in the acceptance of robots compared with their rigid alternatives. This improved interaction forms a link between the present industry and every day life, and to a future society with higher levels of automation.

REFERENCES

[1] Kim, S., Laschi, C., and Trimmer, B., 2013. "Soft robotics: a bioinspired evolution in robotics". *Trends in biotechnology,* ***31***(5), pp. 287–294.

[2] Murphy, R. R., Nomura, T., Billard, A., and Burke, J. L., 2010. "Human–robot interaction". *IEEE robotics & automation magazine,* ***17***(2), pp. 85–89.

[3] Bednar, P. M., and Welch, C., 2019. "Socio-technical perspectives on smart working: Creating meaningful and sustainable systems". *Information Systems Frontiers,* ***22(7)***(22).

[4] Kadir, Z. A., Mohammad, R., Othman, N., Chelliapan, S., and Amrin, A., 2017. "Risk assessment of human risk factors in port accidents". *International Journal of Mechanical Engineering and Technology,* ***8***(11), pp. 535–551.

[5] Darbra, R.-M., and Casal, J., 2004. "Historical analysis of accidents in seaports". *Safety science,* ***42***(2), pp. 85–98.

[6] Vasconez, J. P., Kantor, G. A., and Cheein, F. A. A., 2019. "Human–robot interaction in agriculture: A survey and current challenges". *Biosystems engineering,* ***179***, pp. 35–48.

[7] Robla-Gómez, S., Becerra, V. M., Llata, J. R., Gonzalez-Sarabia, E., Torre-Ferrero, C., and Perez-Oria, J., 2017. "Working together: A review on safe human-robot collaboration in industrial environments". *IEEE Access,* ***5***, pp. 26754–26773.

[8] Gopinath, V., and Johansen, K., 2016. "Risk assessment process for collaborative assembly–a job safety analysis approach". *Procedia CIRP,* ***44***, pp. 199–203.

[9] Kosuge, K., and Hirata, Y., 2004. "Human-robot interaction". In 2004 IEEE International Conference on Robotics and Biomimetics, IEEE, pp. 8–11.

[10] Shani, A. B., Grant, R. M., Krishnan, R., and Thompson, E., 1992. "Advanced manufacturing systems and organizational choice: Sociotechnical system approach". *California Management Review,* ***34(4)***, pp. 91–111.

[11] Cianchetti, M., Calisti, M., Margheri, L., Kuba, M., and Laschi, C., 2015. "Bioinspired locomotion and grasping in water: the soft eight-arm octopus robot". *Bioinspiration & biomimetics,* ***10***(3), p. 035003.

[12] Rossiter, J., and Hauser, H., 2016. "Soft robotics—the next industrial revolution". *IEEE Robot. Autom. Mag,* ***23***(3), pp. 17–20.

[13] Polygerinos, P., Correll, N., Morin, S. A., Mosadegh, B., Onal, C. D., Petersen, K., Cianchetti, M., Tolley, M. T., and Shepherd, R. F., 2017. "Soft robotics: Review of fluid-driven intrinsically soft devices; manufacturing, sensing, control, and applications in human-robot interaction". *Advanced Engineering Materials,* ***19***(12), p. 1700016.

[14] Angelini, F., Santina, C. D., Garabini, M., Bianchi, M., Gasparri, G. M., Grioli, G., Catalano, M. G., and Bicchi, A., 2018. "Decentralized trajectory tracking control for soft robots interacting with the environment". *IEEE Transactions on Robotics,* ***34***(4), pp. 924–935.

[15] Zhang, T., Zhang, W., and Gupta, M. M., 2017. "Resilient robots: concept, review, and future directions". *Robotics,* ***6***(4), p. 22.

[16] Whitesides, G. M., 2018. "Soft robotics". *Angewandte Chemie International Edition,* ***57***(16), pp. 4258–4273.

[17] Pfeifer, R., Lungarella, M., and Iida, F., 2012. "The challenges ahead for bio-inspired 'soft' robotics". *Commun. ACM,* ***55***(11), Nov., p. 76–87.

[18] Alhaddad, A. Y., Cabibihan, J.-J., Hayek, A., and Bonarini, A., 2019. "Safety experiments for small robots investigating the potential of soft materials in mitigating the harm to the head due to impacts". *SN Applied Sciences,* ***1***(5), p. 476.

[19] Yao, F., Keller, A., Ahmad, M., Ahmad, B., Harrison, R., and Colombo, A. W., 2018. "Optimizing the scheduling of autonomous guided vehicle in a manufacturing process". In 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), pp. 264–269.

[20] Rahman, S. M., 2012. "A novel variable impedance compact compliant series elastic actuator for human-friendly soft robotics applications". In 2012 IEEE RO-MAN: The 21st IEEE international symposium on robot and human interactive communication, IEEE, pp. 19–24.