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Analysis of Human-Robot Interactions as a Sustainability Factor

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Robotic systems are traditionally widespread in the efficient automatization of industrial processes. Recent applications include material handling, reconnaissance, and agricultural tasks, besides the more traditional assembly line tasks. On the other hand, the recent advancements of robotic systems aim at enhancing and even replacing the human workforce in traditional social service tasks, like nursery, clerk positions, eldercare, and catering – collectively called social robotics. Developed countries generally suffer from the decreased available workforce in these areas, threatening the long-term availability of such essential services. The robots providing such services are required to appear and behave human-like to some degree to interact with people seamlessly. Human-like behavior requires complex software and hardware systems with learning capabilities to solve social situations appropriately. This paper investigates the relationship between human-robot interactions and sustainability and identifies the foundational similarities between the aims of the two interdisciplinary fields. The paper proposes the effect of complex interaction capabilities on sustainable factors and their possible qualitative verification. The quantitative factors described in this paper are the social perception of different robots and their expected functions defined by the foundational human-robot interaction roles. The paper proposes the possible contribution of future social robot applications to sustainability factors, such as the effect of telepresence. The paper also presents the result of a qualitative survey of participating university students on the acceptance of different types of robots based on their visual appearance. The assumption of possible integration of robots into social roles and what appearance is perceived as acceptable. In summary, this paper highlights the sustainable factors in human-robot interactions by identifying the effects of social robot roles and mapping between corresponsive sustainability factors, most importantly resolving workforce deficit.

1. Introduction

Robotic systems are widespread in handling monotonic and typically dangerous industrial and manufacturing processes. Prominent examples are welding and painting by industrial manipulators. More recently, material handling has been done by autonomous mobile robots (AMRs) and automated ground vehicles (AGVs). These devices were successful at a large scale in substituting the human workforce in repetitive tasks, thus contributing to the automatization and effectiveness of industrial processes and supply chains. On the other hand, industrial robots are considered dangerous as they work with lethal force and material with agility, thus potentially leading to fatal accidents and damage to corporate property. Consequently, industrial robots are isolated from the rest of the workers between safety zones.

While heavy and repetitive tasks have been successfully replaced by industrial robots, soft and inconstant jobs are yet to be supported by some degree of automatization. Developed countries generally face labor scarcity in conventional jobs providing derived service factors, such as cleaning, catering, social care, and nurseries. In some countries, the deficit of workers leads to availability and quality issues of otherwise mandatory social services in healthcare, tourism, and service sectors. In summary, these services are on the brink of unsustainability and require intervention.

On the other hand, widespread automatization technologies face problems handling non-deterministic social situations in terms of responsiveness or immersivity. One possible solution to this problem is boosting

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immigration, with its social tensions as a side-effect. Another solution is the introduction of automatization on different levels of such service tasks through robots and automatic processes of different degrees. The role of robots and their interaction with human actors have been discussed by Rinaldi et al. (2023) from a sustainability perspective and by Ghobakhloo (2020) from an Industry 4.0 perspective.

This paper focuses on the possible contribution of mobile robots to sustainability through human-robot interactions (HRI). As a main objective, this paper introduces the modeling of robotic systems using HRI paradigms and fundamentals of cognitive info-communication (Coginfocom) embedded into sustainable processes. This model is used to provide a context for human-robot interactions. Based on the model and human-robot interaction fundamentals (Bartneck et al., 2020), it can be concluded that the visual appearance of robots contributes to their efficiency in human-robot interaction and their role in a sustainable society. This research is concluded similarly to another research conducted in South Korea (Song and Kim, 2022). The paper also provides preliminary results on the acceptance of robots potentially used in social situations on a sample of university students from Hungary to analyze the acceptance of the current visual appearance of robots and, therefore, as a preliminary evaluation of the proposed model. The results are presumed to provide useful information on the design of service robots that will participate in a sustainable socio-economic lifecycle.

This section summarizes the factors contributing to the sustainability of tasks associated with human-robot interaction (HRI). The section also overviews the social context of robots, providing the reason for robots contributing to sustainability with social robotic applications. The sustainability factors are mostly related to a socio-economical extent, with some mixed with industrial applications, widely accepted as the efficiency factors to substitute human workforce.

1.1 Social context

The population in most developed countries has reached the transitional (e.g., USA) or mature (e.g., Germany, Japan) demographic phase, meaning the population is close to or under the replacement rate. The active workforce stagnates or decreases in these countries, as visible in current demographic statistics (United Nations, 2022). Additionally, the active workforce increasingly pursues high-education jobs such as medical, engineering, and research positions.

Currently, the population of developing countries (e.g., African countries, South-East Asian states) is growing. However, in the 2060s, these countries will also face mature age distribution (according to the UN forecast, the population will stop growing at around 10 billion people). Some developing countries, such as China and Russia, already face decreasing populations, limiting the workforce replacement of some service sectors (United Nations, 2022).

Low-income service jobs, such as office clerks, retail service, catering, and nursery, require substantial human work and presence. Besides providing variable yet repeatable tasks – e.g., medication health monitoring – the workers are usually required to interact with people around in varying space and time. The automatization would require devices with high mobility, communication capabilities, and soft actuation. The devices should have an appealing, if not comfortable, appearance to allow their blended acceptance in society.

The subject nation of this paper, Hungary, is considered a developed OECD country with a mature demographic trend, with a decreasing population, average labor force participation (around 60 %), and increasing problems in social sectors such as healthcare, cleaning, and social care due to the deficit of workforce in these sectors.

1.2 Human-Robot Interaction (HRI)

The field of human-robot interaction (HRI) investigates the models and modalities of possible interaction between humans and different types of robots. The research area is relatively new, as complex interactions appeared just recently (Bartneck et al., 2020). This field combines design, engineering studies, and social studies to approach interactions and communication. The subject can be any type of robot, from a very simple vacuum-cleaner robot to a humanoid robot with complex problem-solving skills and extensive sensory interfaces. The prominence of robots in human cooperative situations to sustainability has been revealed by other scholars (Rinaldi et al. 2023), as it has already contributed to Industry 4.0 applications (Ghobakhloo, 2020). In some developed countries (e.g., South Korea and Finland), retail stores tend to be equipped with robots, and researchers conducted a questionnaire on their acceptance (Song and Kim, 2022).

From this vast field, this paper investigates the design, social robotics, and (verbal and nonverbal) interaction of robots through its modeling paradigms and results. The questionnaire presented in this paper focuses on the potential interaction capabilities and their visual appearance.

1.3 Cognitive Info-communications

Cognitive Infocommunications (Coginfocom) is a research area that investigates the communication of cognitive agents (e.g., humans, robots, smart devices) in a connected setup (Baranyi and Csapó, 2012). The field also defines a fundamental framework on the mode and blending of the communication, alongside with the cognitive (i.e., computational) capabilities of the participants in the communication. The framework is useful to define the interaction and computation capabilities of different agents participating in a quasi-social setup. Indeed, Coginfocom has been used to define robotic communication capabilities, which is a further contribution to the field by the authors (Hajdu and Csapó, 2022).

2. Methodology

The article provides a literature review to investigate the newest contributions of human-robot interactions and sustainability. Based on previous research in robotics and cognitive communications, a model has been developed with sustainability factors as further elements. To evaluate the model, we concluded an analysis of the visual appeal of robots.

3. Modelling robotic interactions from a sustainable viewpoint

The previous research of the authors (Hajdu and Csapó, 2022) defined the Coginfocom perspective of human-robot interactions. The aim of the model was to describe fundamental robotic properties from a CogInfocom perspective. Briefly highlighting the main points of the referenced model:

- Robots can be easily defined as cognitive agents, as nowadays, they possess the necessary computational and learning capabilities to perform and improve tasks and participate in communication with other cognitive agents.
- Robots and human actors communicate with each other in an inter-cognitive bridging fashion: the data and knowledge obtained by the robots must be mapped to a representation understandable by humans (typically audio-visual interfaces). Similarly, robots can access external computational clouds through adapters specific to the external source framework.
- Robots and other cyber-physical systems may communicate with each other through an intra-cognitive bridge if they share the same communicational framework, e.g., Robot Operating System 2 (Macenski et al., 2022) or another DDS-related middleware. With intra-cognitive bridging, information can be used instantly without explicit mapping.

The summary of this framework is shown in Figure 1, depicting the high-level communication channels between robots and other cognitive entities.

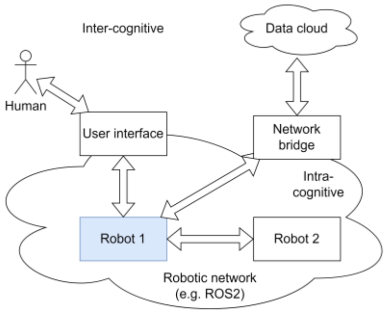

Figure 1: Overview of the communication channels between robots and other cognitive entities

3.1 Extension of the model

This contribution investigates the role of robots from a socio-economical perspective. The sustainability factors are analyzed from this point of view. In these situations, robots appear as surrogates for humans or are obliged to outperform in specific tasks analogously to manufacturing lifecycles.

Most socio-economic tasks require intensive communication and interaction, explicitly derived from the requirements defined by HRI goals. The following design goals must be addressed from an HRI sense:

- Visual appearance of robots: how appealing and comfortable they look.
- Expected purpose based on appearance: what function is expected from the robot given its visual appearance and visible actuators?
- Responsiveness: how naturally robots respond to audio-visual, tactile, and other nonverbal stimuli.
- Adaptivity: how robots can adapt to different (social) situations to improve service efficiency.

From a sustainability perspective, the following must be addressed in the socio-economic context:

1. How can robots be used for service labor, such as nursery and retail jobs?
2. How can robots improve the quality of socio-economic services, such as retail clerks and nurseries?

3. How can robots sustain services despite the decreasing workforce in service jobs?

The availability of robots is a considerable advantage compared to human workers, as robots can operate on a particular task indefinitely without loss of attention or need for amenities. It should be noted that robots consume energy, so the energy efficiency of control processes has an essential role in their operation time. On the other hand, spatiotemporal localization, detection, planning, and real-time control, in general, require complex computational systems that can be redundant given the situation. The power requirement of high-end computational devices entails a trade-off between energy efficiency and computational power – latency, capacity - therefore, characteristics such as responsiveness adaptivity are limited by power capacity.

The associated tasks typically require lots of verbal and meta-level interaction fixed to a place and time (fixed spatial and temporal location). Such illustrative tasks include:

- Medication: the nurse communicates with patients, administers the pharmaceuticals and nutrition, assists other medical personnel, and monitors the health state of the patient.
- Retail: the retail clerk assists customers and makes recommendations, places ware and handles the payments, and reports malicious activity.

It is clear from these examples that proper visual appearance serves a crucial role in the effectiveness of robot surrogates. On the side of the robot, spatial and temporal perception is emphasized to detect human communication and surrounding activities. The sense-think-act model popular in cognitive robotics (Siegel, 2003) and the derived model introduced in (Hajdu and Csapó, 2022) can be extended with these factors (depicted in Figure 2.), considering sustainability elements in a human-robot scenario. The physical (communication) interface plays a crucial role in reaching humans with tactile (touching), audio (voice), and visual feedback (e.g., gestures, emotions). Consequently, the model collects the required factors to perform efficiently in a human-robot interaction scenario as a part of any socio-economical process.

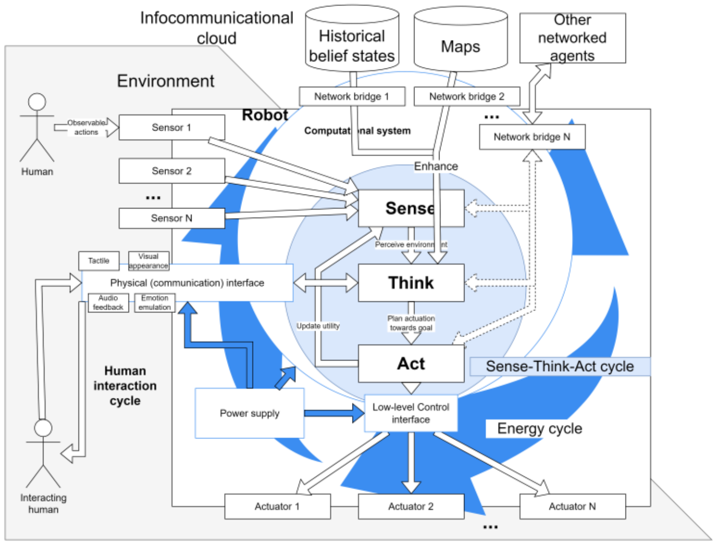

Figure 2: Sense-think-act cycle extended with sustainability factors and indicating the physical interface

4. Questionnaire on Human-Robot Interaction

The visual appearance of robots has a crucial role in the acceptance. Therefore, their effectiveness in a sustainable society of a high life quality. To investigate the current acceptance of different robots, a questionnaire was conducted on a group of university students representing the current youth generation of the Hungarian society as of 2023. The total number of respondents was a total of 77 people, which is high in student questionnaires. Unfortunately, the robots could not be tried out in a physical environment. Only assumptions were made by the students based on pictures derived from the IEEE Robots website (ROBOTS, 2023) maintained by the IEEE organization. This website collects all robots available in academia and on the market. The questionnaire focused on the visual appeal and the predicted functions of such robots. Most of the robots were humanoid robots, with certain special additions. The main hypotheses to be concluded from the questionnaire were the following:

1. Robots that have a more coarse appearance (i.e., more robot-like, e.g., Boston Dynamics ATLAS, NASA Valkyrie, ASIMO) are more accepted than robots of realistic appearance, e.g., Geminoid ERICA (Shuichi et al. 2007), Softbank NAO or Pepper.

2. Modern humanoid robots could be generally accepted in certain roles – such as clerking, reception, and catering - by the youth, thus by the emerging workforce.
3. The robots have reached a development level as of 2023 to support the human workforce in specific tasks, such as retail jobs, reception, and healthcare.
4. The appearance of currently available assistance robots implies the possible interaction capabilities.

The questions focused on what functionality the recipient expects from the robot or how they generally feel about the robot based on its appearance. The robots that appeared were largely humanoid robots (e.g., Care-o-bot 4, ERICA, Atlas), but some other examples appeared (e.g., Sony AIBO, SPOT). The following questions were listed with implications to certain hypotheses noted:

1. What functions would you expect from the following robot? (hyp. 2, 3, 4).
2. How would you interact with the following robot? (hyp. 3, 4)
3. Which of the following humanoid robots' appearance do you find comfortable? (hyp. 1)
4. Which of the following robot's appearance do you find uncanny? (hyp. 1)
5. Which of the following robots would you find talking comfortable? (hyp 2, 4)
6. Which of the following robots could you imagine to help you during a service? (hyp 2, 3)
7. Which of the following robots would you touch, at least for a moment of handshake? (hyp 1, 4)
8. Which of the following robots could you imagine in your home? (hyp 2, 3)

Some answers could be arbitrary text-based responses, but we expected the respondents to give answers in the target domain of catering, social care, healthcare, and retail jobs to support the current workforce.

4.1 Analysis of data

The significance factor α was set to a value of 0.05 for each hypothesis, providing the rejection criterion for the hypotheses. Unfortunately, the male recipients were overrepresented in the sample.

In Question 1, a short textual description was expected from the respondents regarding ERICA and Care-o-bot. Most responses proposed usage as expected in social care (eldercare), hotel receptionist, and retail jobs. On the other hand, there were creative responses, such as giving the role of surrogate children, newsreaders, and housewife surrogates. The same question was asked about Care-o-bot, with similar results. Similarly, the responses to Question 2 indicate that most recent robots have an appropriate interface to interact with, and users can recognize these. The responses confirm that robots could be used in specific tasks with the acceptance of the emerging society.

Most respondents found robots like NAO, Pepper, and ASIMO appealing in Question 3. On the other hand, ERICA and Valkyrie (realistic humanoid robots) were also viewed as comfortable-looking robots, while ATLAS and Sophia could be considered uncanny. 48 % of the respondents found coarse-looking (e.g., Valkyrie, industrial robots, SPOT) robots, and 51 % responded that the realistic-looking robots were comfortable. On the other hand, only 32 % of the participants responded that they found realistic robots comfortable and found very realistic robots (e.g., ERICA, SOPHIA) appealing. This conclusion can be further deduced when the response regarding uncanny robots is analyzed (Question 4). About half of the respondents found realistic robots, such as iCub, Sophia, and ERICA, uncanny (~45 %). On the contrary, Geminoid DK (constructed around the same time as Sophia) was only found uncanny by 25 % of the respondents. This robot looks more comfortable despite the very realistic look, or maybe gender-specific attributes play a role in this result (Geminoid DK looks like a male). On the other hand, coarse-looking robots (e.g., AILA, Rollin' Justin) were found to be unsettling (~30 %). Pepper and Aibo were found to be the least uncomfortable appearing robots based on the responses.

Respondents found Care-o-bot 4 would be the most comfortable to talk with (~60 %) in Question 5. Pepper and NAO also looked comfortable to talk with (~40 %), with ERICA only a little less comfortable than these robots (~33 %). On the other hand, these scores are relatively low, indicating that robots still need development to appeal to communication. On the other hand, only 55 % of the responses indicated being comfortable to touch Pepper, ERICA is around 35 %. Interestingly, 82 % of respondents found that AIBO is comfortable to touch.

In Question 6, Care-o-bot and Pepper were found to be relatively comfortable with helping during service (70 %). All other robots received scored under 50 %. Contrary to this, 60 % of respondents could imagine a Care-o-bot at home (Question 8) but not a Pepper (36 %). In this question, AIBO scored the highest, 64 %.

4.2 Discussion of results

Based on the results, hypothesis 1 should be extended, as there is no ground evidence to support either the null hypothesis or the antithesis. More data is required on a more diverse sample.

The responses show that most people would find it comfortable to interact with robots in the target areas. The responses were primarily according to our expectations. However, all robots reached a low score on visual appeal in communication, but Pepper and Care-o-bot received a good score on interaction via touching. It can be observed that the visual appeal must be improved to initiate communication with humans. Hypothesis 2 in

the current sample could be rejected in summary. Hypothesis 2 somewhat implies Hypothesis 3, meaning that robots would be seen at least uncanny in a public place (e.g., retail stores, hospitals) or at home.
Hypothesis 4 could be accepted, as most respondents could identify all the interaction capabilities available in commercially available robots (tactile, visual, voice feedback).
Based on the results, it can be observed that visual appearance plays a vital role in initiating interaction with humans and handling a comfortable interaction with humans. However, the visual appearance of most of the robots must also be improved, indicating further research on the design of the robots with particular attention to ergonomics and visual appearance. In summary, it is advisable to extend the questionnaire to a broader population of more diverse backgrounds.

5. Conclusion

This paper revisited the theme of human-robot interactions, with a sustainability emphasis, highlighting how appearance can aid in accepting robots in social contexts and service jobs. Based on these results, the operating efficiency of the robots can be improved, contributing to sustainability by supporting the workforce or addressing the decreasing workforce in service jobs.
The sustainability analysis could be further continued. From a socio-economic perspective, the questionnaire could be extended to a broader and more diverse population sample. The newest version of the questionnaire is currently online, allowing continuous extension to the research available online (Google Form, 2023). The results presented in this article indicate that current robots could surrogate for specific tasks, and interaction capabilities are appropriate most of the time. However, humans would find interaction to be more convenient than the current state.
The resilience of interaction components could be further investigated via different methods (e.g., Petri nets, P-graphs, redundancy analysis). The robot and its compartments could be analyzed for how reliable they can perform and what redundancy is required. A more ambitious aim would be to approach the resilience analysis of the whole interaction processes consequently, the sustainability of socio-economic processes with robots involved. The current article presented the importance of visual look in these scenarios as a central element in the interaction loop.

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