PART A: CAPSTONE RESEARCH REPORT

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Abstract

Advances in technology and the proliferation of connected services have pushed us into the fourth industrial revolution, industry 4.0. Industrial robotics have become more connected and more relied upon as we endeavour for peak efficiencies in our factories. The IW.HUB by Idealworks, a subsidiary of the BMW Group, has one such robot employing machine learning and advances in robotics to autonomously navigate complex situations. Classed as an autonomous mobile robot (AMR), the IW.HUB faces challenges similar to that of a human driven forklift, but without the human component. This report investigates advances in interface and interaction design found in literature as well as presents analysis from interviews conducted with industry professionals and researchers. We present design implications, opening discussion about the problems found and opportunities that may inform future design decisions. Solutions found by this report cover the micro-cultures found within a warehouse environment to fulfilling uncertainty found in an AMR.

In collaboration with

idealworks

BMW GROUP + QUT
DESIGN ACADEMY

Acknowledgments

I would like to thank Jordan Domjahn and Dr. Rafael Gomez at the QUT Design Academy for their support in getting this project started and providing valuable research contacts in the industry. I would also like to show great appreciation also for the teaching team of this Capstone project for their guidance throughout this semester to this point.

In the spirit of reconciliation I would like to acknowledge the Traditional Custodians of the country throughout Australia and their connections to land, sea and community. We pay our respect to their Elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples today.

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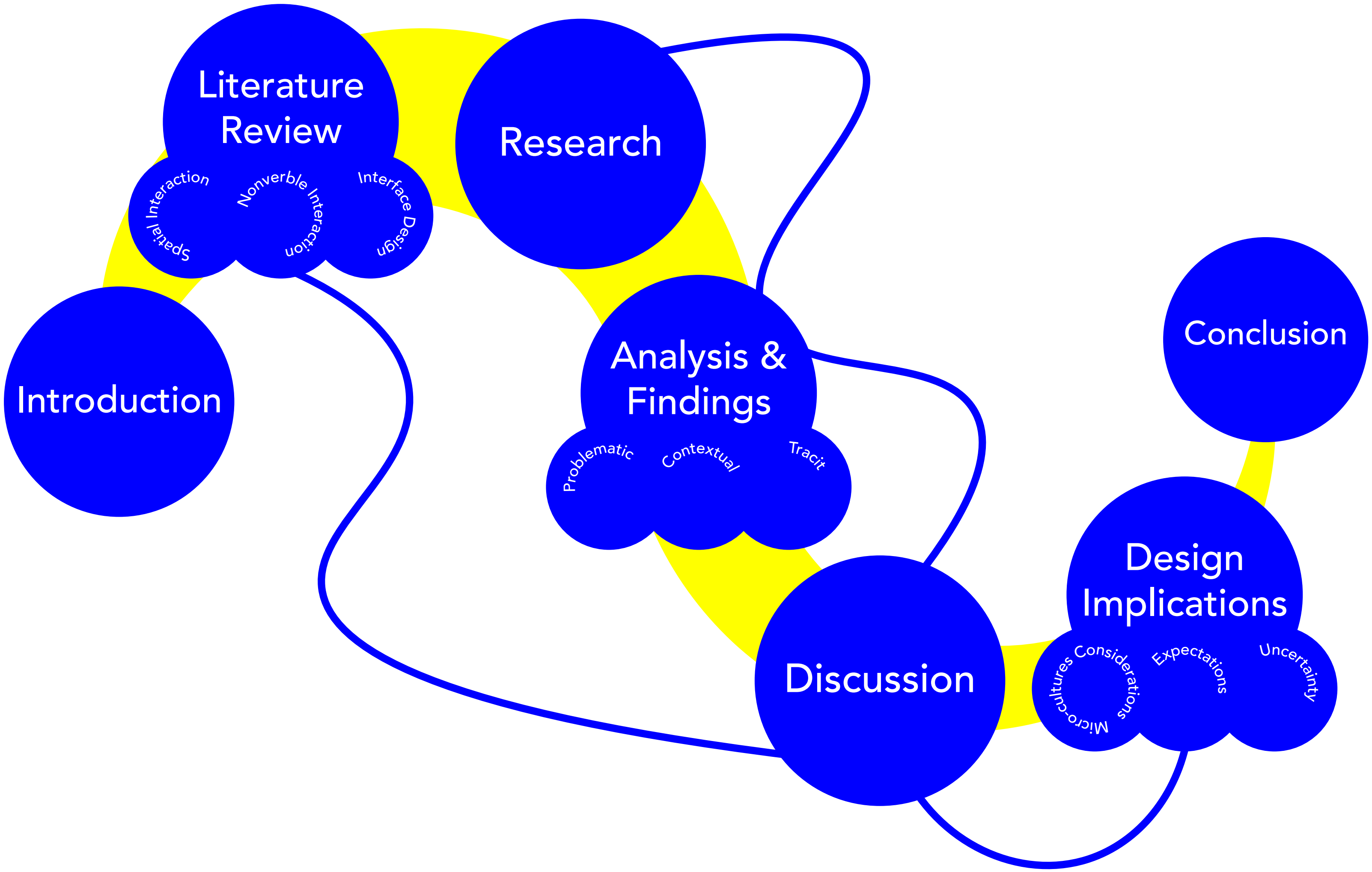

Introduction

The industrial robotic industry has become a $13.8 billion industry, however many of new installations are still a part of a class of robotic arms where they fail to reach a common goal: mobility (International Federation of Robotics, 2020; Siegwart et al., 2011). Autonomous mobile robots (AMRs) are at the forefront of what is the cutting edge in the robotics industry. While still in their infancy, AMRs have proven to be an effective tool in a range of industrial categories such as logistics (Bogue, 2016). This report, in collaboration with BMW Group and the QUT Design academy, takes a lens to Idealworks' IW.HUB (Fig. 1) and attempts to improve on the interaction and interface design. Presently the IW.HUB positions itself unique to its competitors not only in functional ability but also development possibilities. The use of VR and digital twins has enabled the IW.HUB to quickly adapt to its environment through the use of a few sliders in software (Soehmelioglu et al., 2021).

However, the AMR as hardware remains barebones to components available only to fulfil its core function. Existing interactions available to the device are limited to just turning indicators and forward facing lights similar to those found on a forklift, but without the human component. The existing interface solution to the IW.HUB is a proprietary platform, called AnyFleet, that works as the hive mind for all AMRs in a company, and is used for operating daily tasks as well as diagnosing and providing tools to solve issues in the field. Problems found with both interaction and interface design lead to the main difference between an AMR and a traditional forklift: the human driver. While the AMR can pathfind by itself and problem solve just as a human would, the IW.HUB and other AMRs struggle to imitate interactions that a human would easily be able to convey. Simple concepts such as a forklift driver meeting eyes with you as a form of awareness and self-assurance that the vehicle won't collide with you or its environment, is a frustration many have with AMRs.

After a literature review and a discussion about primary research conducted with industry professionals and researchers working closely with the IW.HUB, this report outlines design implications and opportunities. The goal of which is to ultimately fill the human element found missing on the IW.HUB.

Figure 1. IW.HUB hero shot by Idealworks (Friedrich, 2021).

Literature Review

This literature review's focus covers types of interactions and interfaces design either at the cutting-edge of research or being used today within industrial contexts. Limitations were found however when taking a lens to interaction design specifically as many studies have failed to investigate their uses inside of an industrial context, but rather takes a commercial or consumer context. With the manufacturing industry embracing the fourth industrial revolution, the need to integrate manufacturing processes with connected technologies and services has become a sought after solution to achieve higher industrial performance (Dalenogare et al., 2018; Kagerman et al., 2013). To improve efficiency by increasing productivity with integrated automation, industry 4.0 calls for increased flexibility across the manufacturing process (Villani et al., 2018). This is achieved through the intelligent use of autonomous manufacturing machinery, robots and warehousing systems capable of responding to situations in real time with knowledge backed actions (Kagerman et al., 2013). Collaborative robots, also referred to as cobots, are at the forefront of the industry 4.0 revolution, by enabling direct interactions between a human and robot, the opportunity for increased productivity and thus efficiency can be achieved (Colgate et al., 1996; Villani et al., 2018).

Autonomous mobile robots (AMRs), a subset of autonomous guided vehicles (AGVs) are unique to the industrial format as they are able to freely adapt to their environment, navigating in real-time, responding to changing conditions (Dwyer et al., 202; Karabegović et al., 2015). This is an evolution over traditional AGVs where they would typically follow embedded guidewires dictating possible paths (Siegwart et al., 2011).

Nonverble Interaction

Studies surrounding nonverble types of communication build on from spatial interaction, finding promising results. Mutlu et al (2009) discovered types of nonverbal leakage cues that can convey information about a subject's emotional state as well as their implied intentions. Their study involved comparing two types of robots, one that was human-like in appearance and one that was abstract in character. Mutlu et al (2009) found that leaking human social cues through eye gazing was able to convey a wealth of information. They went on to find that the human-like robot was more successful in conveying information than it's abstract counterpart. However, it should be mentioned that there is a 10% difference between each type of interface (Mutlu et al., 2009). Bartneck et al (2020) also confirms these findings and goes on to discuss the use of mimicry and imitation as a form of nonverbal interaction. Finding that mimicry indirectly signals positive affection in a human to machine relationship. This is further affirmed by Wills et al (2016) where they had found a 32% increase in positive human interaction through donations collected with a robot that manipulated behavioural cues over ones that did not.

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Spatial Interaction

Cheng et al (2018) discusses the need to consider the uncertainty of human behavior and the interaction found between humans and machines when robots navigate human environments.
They find that to accommodate a single person interaction the improvement of human robot interactions must be considered (Cheng et al., 2018). Existing research in this space however is limited to domestic and commercial applications (Bartneck et al., 2020). Studies looking at spatial interaction have shown promising results, one study looks at how a drone's movement and position in space can convey a myriad of social information (Cauchard et al., 2016). By adjusting the speed of movement and direction of the drone in space, Cauchard et al (2016) finds that they are able to accurately identify behaviours displayed by the drone and associated certain emotional states.
Hall et al. (1968), discusses the concept of proxemics, describing the relationship found between people in shared spaces. Presented by 4 levels of space around an individual, Hall et al. (1968) tells us how the position between individuals can influence behaviors and attitudes. Hall et al (1968) finds that intrusion of one's space occurs at different points across cultures. With some cultures finding a closer contact is more normal over others. Suggesting that cultural differences afford different requirements when investigating the best solutions for interface and interaction design. This is further expanded by Bartneck et al. (2020), suggesting that micro-cultures inside of an office environment require people to maintain social distances whereas a home environment can allow for socially accepted private space contact.

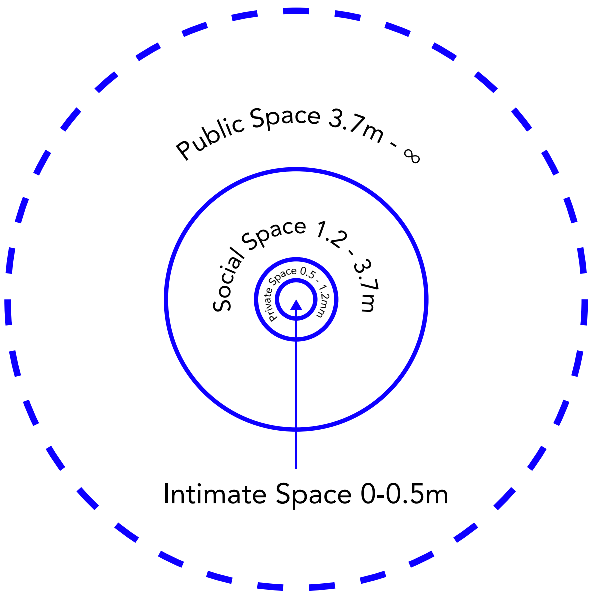

Figure 2. Public, Social, Private and initimate spaces defined by Hall et al. (1968)

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Interface Design

Typically interfaces created around industrial application are built with engineers in mind, with complicated diagrams and instructions to perform basic tasks (Nikolakis et al., 2021). While possible okay in situations where the robot is static in its position and interacts with a subset of people. The advent of AMRs comes with more opportunities to have a wider range of interactions with people of different levels of responsibility with the AMR (Dwyer et al., 202; Karabegović et al., 2015). Examples of existing interfaces continue to provide sub-par experiences without prior learnt knowledge. Kuka, a robotics company, continues to develop in this field, with a recently released interface, which has won an design award, yet continues to fail to appeal to a non-technically minded person (Follett, 2014; Red Dot Design Award: KUKA SmartPAD-2, 2018).

Development outside of the industrial context has included interfaces that incorporate cutting edge technologies from gesture recognition to wearable devices (Liu & Wang, 2021; Xiong et al., 2021). Follett (2014, p. 140) reaffirms the concept that robots should be used in collaboration with humans, citing popular examples of cobots such as the da Vinci Surgical System as triumphs of interface design. Discussing the importance of clear and effective interface design as a component of success in human machine interactions (Follett, 2014).

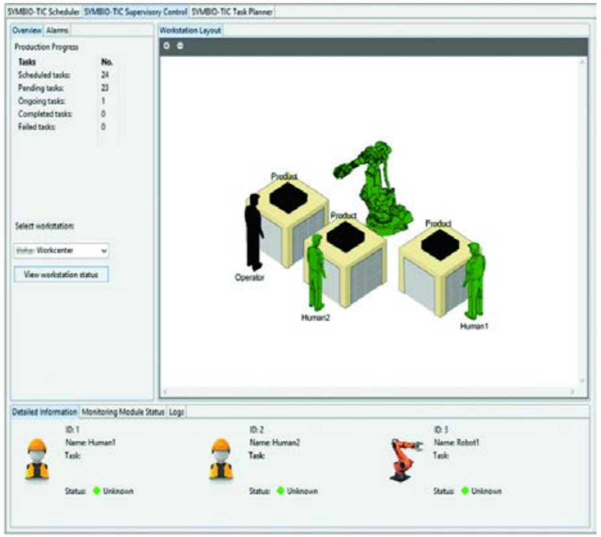

Figure 3. Symbio-TIC Schedular GUI
(Nikolakis et al., 2021)

Figure 4. Kuka Robotics Interface.
(Red Dot Design Award: KUKA SmartPAD-2, 2018)

Research

Across two rounds, Interviews were conducted with thematic analysis methodology to discover friction areas within the context of this project.Aa range of experts that currently work or have worked with the IW.HUB, as well as researchers at the cutting-edge of human robot interactions (HRIs) thanks to the cooperation with the QUT Design Academy and the BMW Group this project afford. The interview format was favoured over survey or observational techniques as the robotics platform being discussed, the IW.HUB, is currently only being deployed in europe. Strict privacy policies and strong unions in European factories, where these devices are being deployed, also prevent surveys from being an effective option due to the short period of time available to conduct this project. Only two rounds were completed due to the constrained time from when industry contacts were made available.

Each interview was conducted in a semi-structured format to ensure larger points were discussed but enabled the opportunity to discover new topics and ideas that were missed during the initial outlining period. After a transcription process using the Otter.ai platform, thematic analysis methodology was then used to yield meaningful and useful results from each interview. This qualitative research tool, thematic analysis, is an effective method to conduct data analysis in a precise, consistent manner (Nowell et al., 2017). Topics discussed with industry professionals included personal and second hand experiences with stories from warehouse workers and their interactions with the IW.HUB. Participant 1, a research associate close to the IW.HUB, was a part of the interviewee cohort thanks to his deep knowledge in the cutting-edge human-machine interactions that's being discussed in literature. Conversations with this participant afforded a unique insight into what the long-term development of advanced manufacturing robots could look like.

Participant 1

Researcher associated with Idealworks, investigating the opportunities and challenges facing autonomous mobile robots.

Participant 2

Previous employee of the BMW Group, investigating the interfaces sounding industrial machinery including the IW.HUB.

Participant 3

Employee of Idealworks, apart of the digital design team based in Germany. Working daily with the IW.HUB.

User Groups Defined

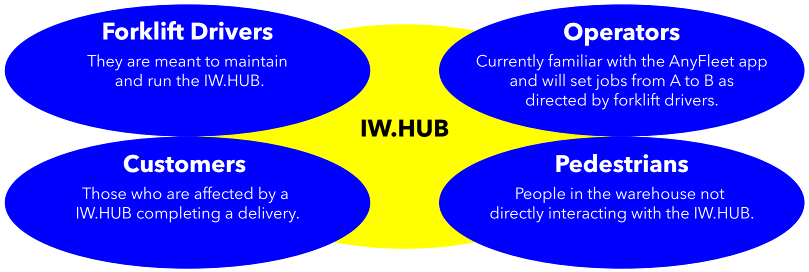

Figure 5. User groups identified by converstions with Participant 3.

Research Timeline

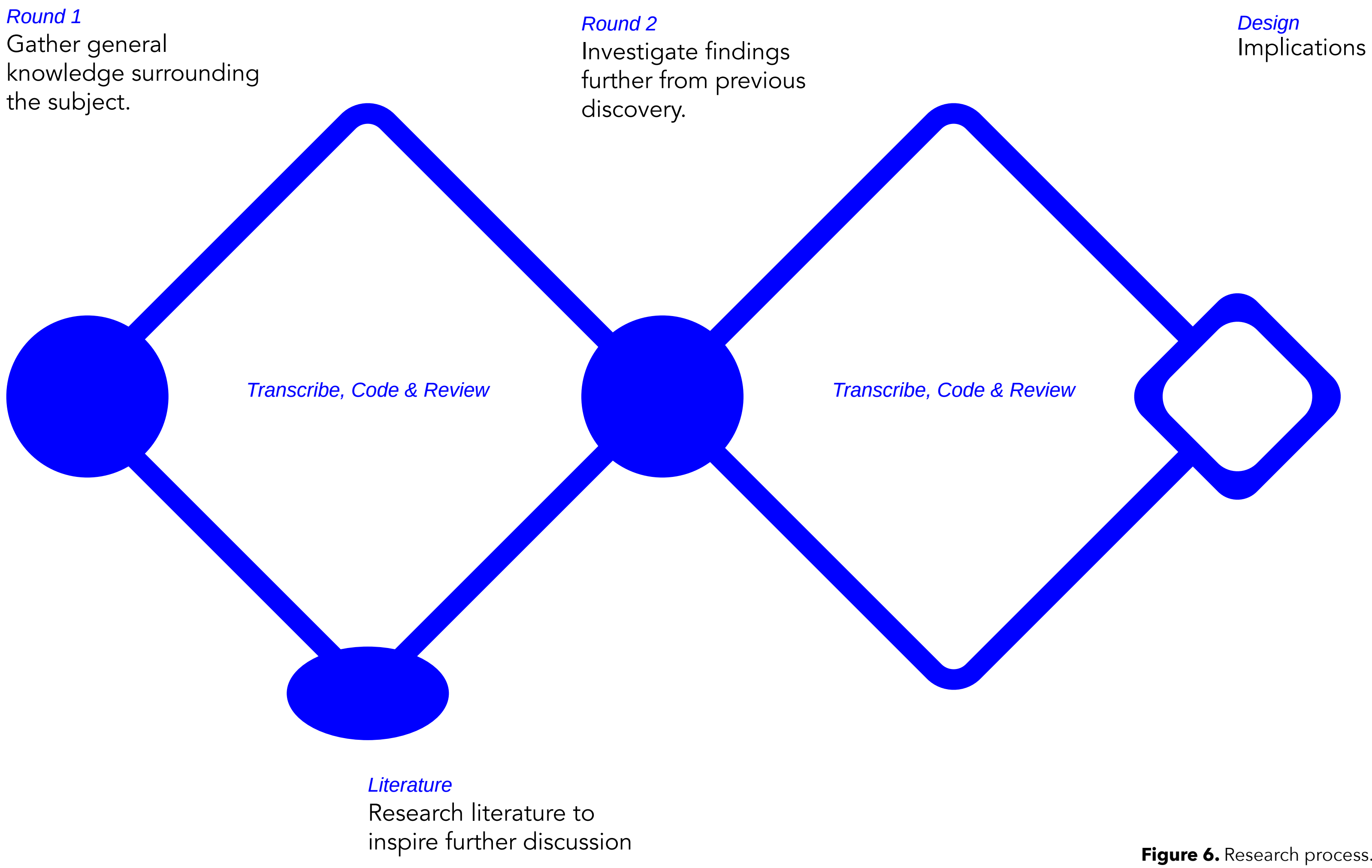

Figure 6. Research process.

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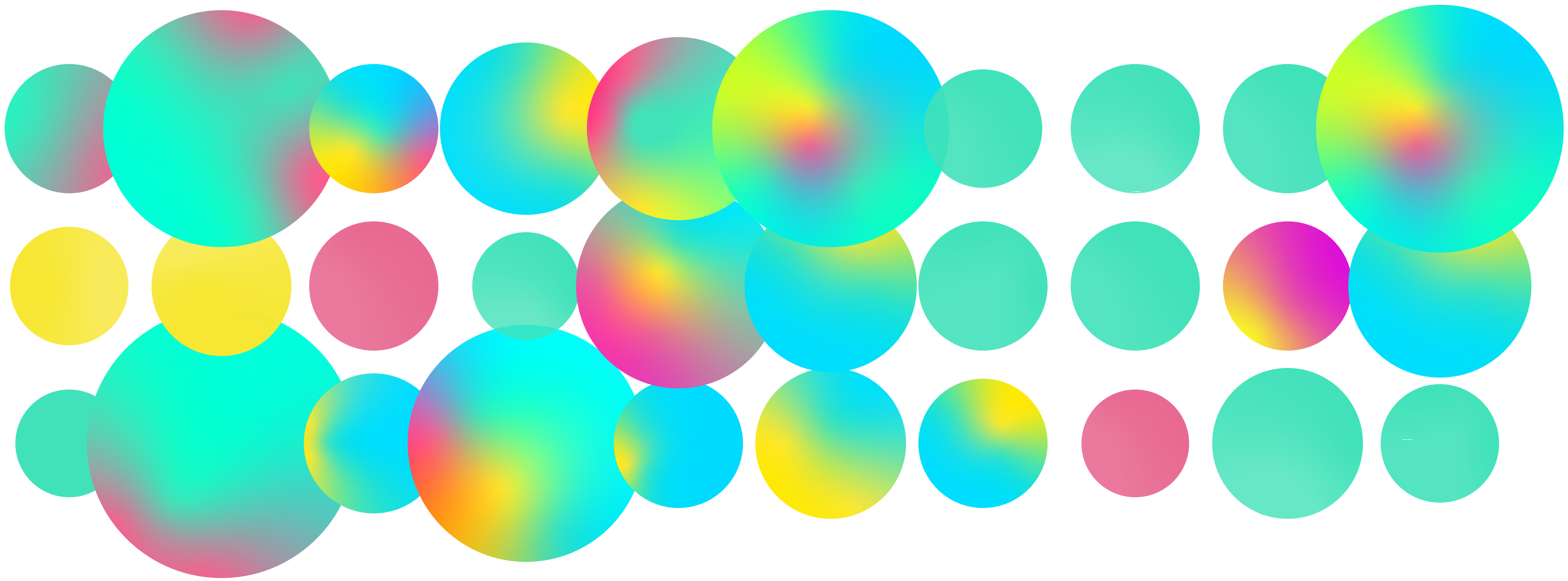

Figure 7. Spread of participant mentions across 30 sub-codes.

Analysis & Findings

After an exhaustive coding process using specialist coding software (Appendix 1.2) to achieve accurate and valuable results, data was then analysed through the use of spreadsheet software. A total of 30 sub-codes, 7 codes, and 3 categories were found in the coding process. The 3 core categories and their codes encompass the nuances found in a human to machine interaction.

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Problematic

Each category tells us a story, problematic codes show us that there may be a division found between workers and the IW.HUB. Both participant 1 and Participant 3 have a strong affinity with this finding, whereas Participant 2 displays a small relationship with the result. Participant 3 quotes this divide as being "... very much a cultural aspect.", this is also backed by Participant 1's research who further refines the cultural divide as possibly being the "... micro-cultures determining the behaviours you see towards (robots)".

The example Participant 1 gives for micro-cultures refers to two separate departments within the same organisation and building, where the primary difference is the speed of which people in their environment have to perform in; thus stresses on each department. Furthermore the lack of considerate interactions in stressful environments, leads to perceived rude behaviour Participant 1 discusses. Another micro-culture that has been described by participants close to the IW.HUB is the difference between computer literate and illiterate warehouse workers. With Participant 3 citing that many warehouse workers are computer illiterate leading to frustrations and misunderstandings.

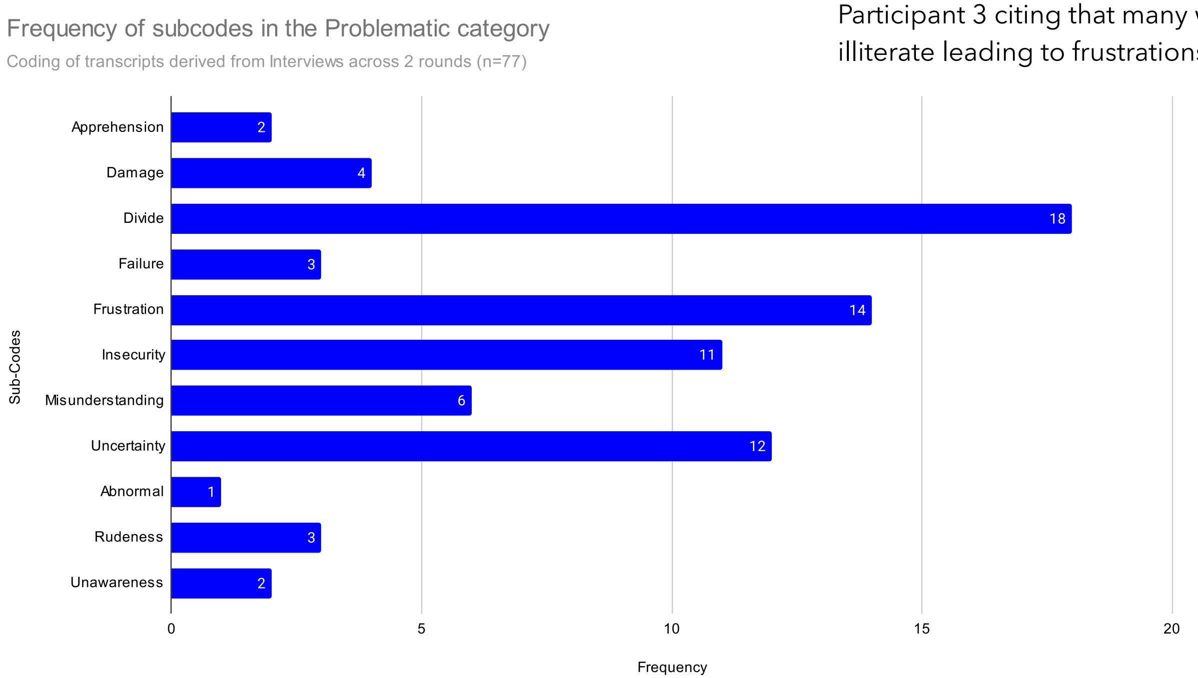


Figure 8. Frequency of sub-codes in the Problematic category.

Contextual

Participant 2 helps us understand the complexities within the warehouse environment thanks to their first hand experience. This affords valuable insights into the barriers found at the contact points between machine and human.

Complexity

I watch it every day, I know where it's going, which is fine, when there's a handful of robots in this hall. But at that time, they wanted 100 robots in that environment in three months. *So I was like, you're not gonna know where that robot needs to go. When there's way more.*

Uncertainty

Figure 9. Quote from participant 2, coded with proximity.

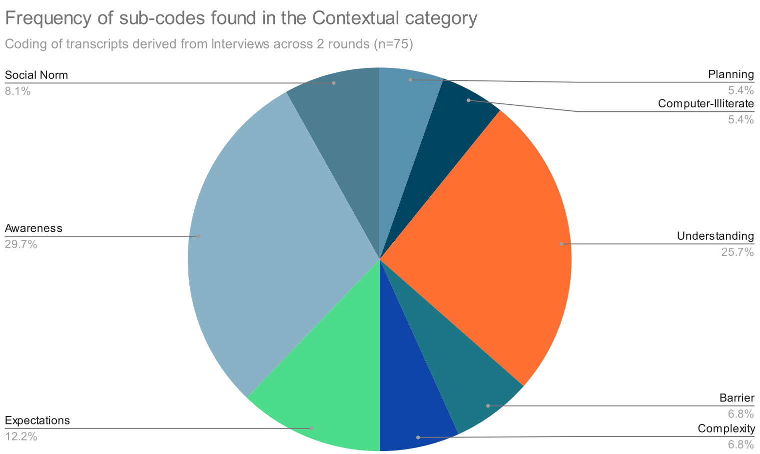
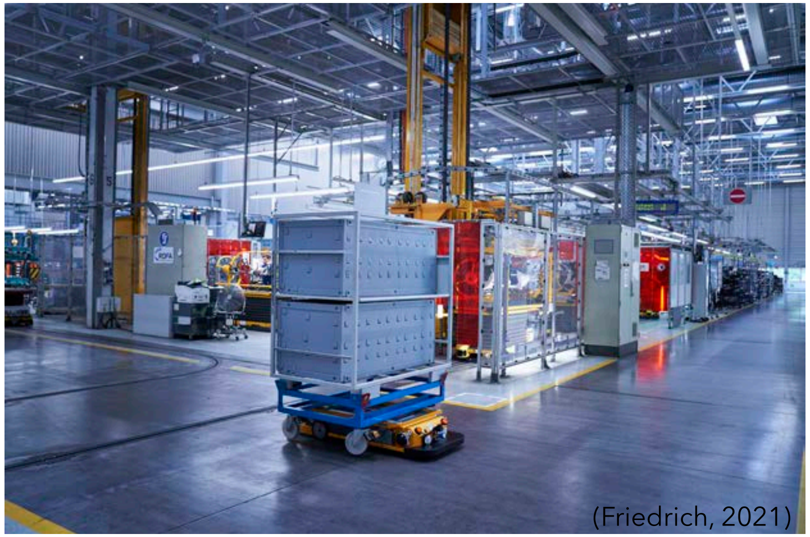


Figure 10. Frequency of sub-codes found in the Contextual category.

Under the contextual umbrella, this quote highlights the daily issue that workers may have. Based on departments and their environment, a worker may display positive outcomes to just a few robots. But, as mentioned previously, the impact of a high-speed and potentially stressful environment filled with "100 robots" could promote problematic outcomes. This crossover between categories is further enforced thanks to the proximity of the sub-code uncertainty with complexity. Looking closer at the codes extracted from the interview transcriptions, this finding is qualitatively affirmed thanks to a large amount of references to asking for awareness and understanding of a human machine interaction.



(Friedrich, 2021)

Tacit

Tacit, describes what is built knowledge around the human to machine interactions. Curiosity of warehouse workers was described by participants 2 and 3, referencing cases of personification of those robots; characterizing each IW.HUB with stickers and nicknames. Proximity however to problematic codes such as frustration, uncertainty and periods of division were described as close to moments of curiosity. Interviewees suggested that curiosity took place out of uncertainty in a human machine interaction (HRI). This negative form of curiosity was attributed to technology illiteracy, insecurities around labour replacements, and poor forms of communication conveyed by the IW.HUB itself at points of HRI.

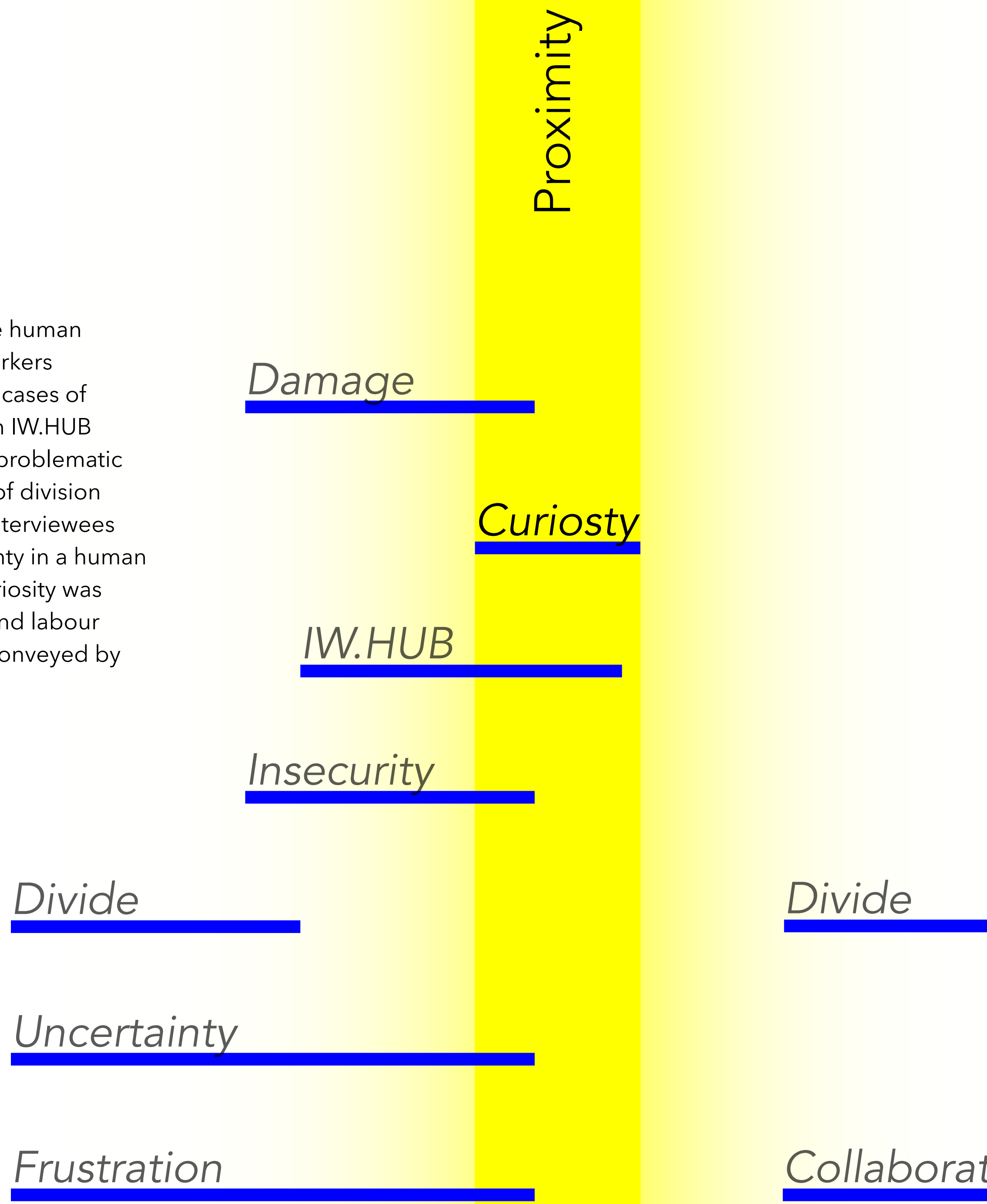


Figure 11. Proximity of “Curosity” to problematic codes.

Discussion

A detailed literature review identified several key opportunities and challenges that human robot interactions (HRIs) have for not only industrial applications but also the broader robotics field. However, the literature discussed lacked information regarding the industrial context to fulfil the research question. Primary research conducted was able to gather specific information related to industrial applications of autonomous mobile robots (AMRs), filling gaps in the literature. This discussion aims to comparatively analyse the literature from the research conducted.

Conclusions can be drawn from literature and tacit understanding from our primary research. Curiosity from warehouse workers highlights a need to understand the robot further, however the typical proximity of curiosity and problematic codes suggest a failure when that interaction occurs. Literature discusses a similar concept when investigating existing interface design. Highlighting that although these devices are getting better, interfaces between the human and robot are typically left for operators with technically proficient skill sets (Follett, 2014; Red Dot Design Award: KUKA SmartPAD-2, 2018). A failure identified between primary and secondary research, as the nature of an AMR is mobile, suggesting that the need to create better interfaces that require little to no prior knowledge is prefered going forward.

Furthermore uncertainty promotes misunderstanding which is then found to be problematic. Whilst misunderstanding does only account for one third of problematic codes, the misunderstanding of an interface or interaction can lead to many frustrations and divisions found by the primary research. The need to remove that misunderstanding and build expectations is of importance. Wills et al (2016) highlights this issue in literature, finding that human satisfaction was found to be lower with the uncertainties found from a static robot when compared with a responsive robot in a HRI. Mutlu et al (2009) discusses the intentions and emotional behaviours that leaking nonverble information can have, specifically through the use of eye gazing. Bartneck et al (2020) also affirms these findings, discussing opportunities to remove misunderstanding in HRIs. Further research has shown that movement of an object in space has improved similar communication in a human machine interaction (Cauchard et al., 2016).

Participant 1 reveals to us problems found in existing applications, finding that HRIs that don’t take into account the needs of the human, fail to deliver positive outcomes. Lack of awareness, or perceived awareness leads to feelings of the robot being rude leading to frustration on the human part. This is then exacerbated by fast paced environments such as those of automotive manufacturing, Participant 2 tells us that frustrations appear between humans and robots during periods of robotic failure. However, literature argues for potential solutions, Bartneck et al (2020) discusses the benefits simple mimicry can have, explaining that mimicry by nature promotes positive affection in that relationship.

Design Implications

The research conducted from interviews and literature discussed has been able to inform design opportunities surrounding the context of this report. By looking at interaction and interface design at a broader scope outside of the industrial sector, we are able to offer novel solutions that have exclusively been studied in domestic and commercial settings. The findings discussed have highlighted areas of attention that the IW.HUB should take into consideration when designing new solutions for the platform.

MUST

- Consider any user who may have the chance to interact with the IW.HUB.
- Allow for users to understand its current status and mission goals.
- Be suited for an industrial application

SHOULD

- Consider social norms found in human to human interactions.
- Consider cultural requirements.
- Consider failure modes and what they might convey.

MUST NOT

- Reduce function of the IW.HUB.
- Require large documentation to understand.

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Micro-Culture Considerations

The current version of the IW.HUB has shown to divide people working close to the device with coding suggesting that teach-illiteracy being cited as the contributing factor. As such considerations should not only take into account cultures internationally but also the micro-cultures found within a warehouse environment. Hall et al. (1968) and Bartneck et al. (2020) confirm these findings from primary research. The micro-culture within a warehouse have requirements that must be adhered to, taking into account proximities the IW.HUB has with people in its environment as well as defining its own social space. Curiosity has also been a contributing factor to many frustrations, with examples of curiosity surrounding the IW.HUB leading to problematic experiences. While people working with and around the IW.HUB can become curious, those interactions can sometimes lead to frustration causing potential for damage to the IW.HUB or the environment. These usually are as a result of misunderstanding or insecurity of the IW.HUB which typically are the cause of a negative type of curiosity. Opportunities arise from this curiosity however, lending to design implications such as those discussed in literature related to mimicry described by Bartneck et al (2020). Interventions that could mimic or reflect its surroundings could instill confidence that the IW.HUB is aware of its surroundings, building expectations and satisfying curiosity.

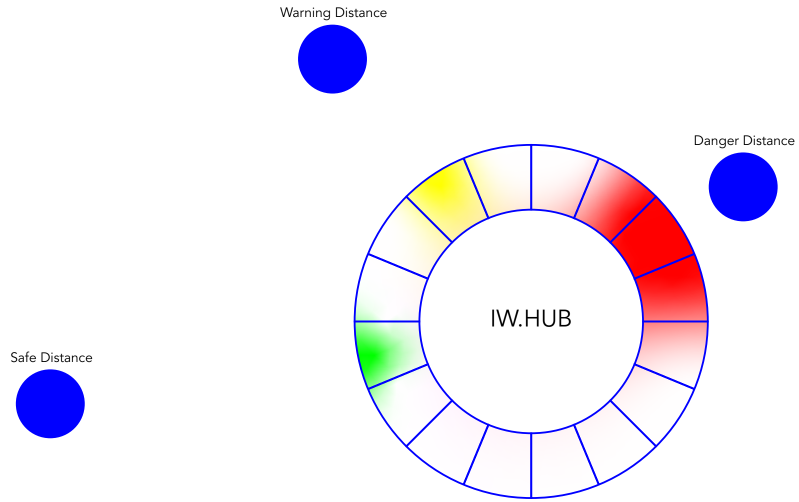

Figure 11. Example of mimicry in a design intervention.

Further information can also be conveyed via mimicry, using common cultural signifiers based on colour to add another dimension of interaction. Through the existing use of sensors available on the IW.HUB, options to not only mimic the position of an user, but the distance they are from the IW.HUB could be conveyed. Examples could be using red as an index that the object being mimicked is close and needs to consider my presence. Strobing effects could be used to gain attention. Whereas, the colour green would indicate that you are at a safe distance. Technology allows us to change these colours based on location to suit cultural context, for example Japan uses blue as a signifier of go/proceed instead of green for traffic lights (Backhaus, 2013).

Expectations

Building on this idea of curiosity, the means to build and manage expectations are critical to the IW.HUBs perceived performance. Problems exist in the current system where participants have agreed that displaying intent is an important behaviour to convey. Both Cauchard et al (2016) and Mutlu et al (2009) attempt to solve this issue through the use of devices that can affect physical space, whether spatial or non-verble. Building on Mutlu et al (2009)'s research, the use of non-verble signifies such as eye gazing to convey intent has proven to be effective. Backed by Bartneck et al (2020), eye gazing techniques could be used in an addition to the IW.HUB platform to enable a human robot interaction that could build a relationship in a shared space. Examples include the direction of an "eye" pointing at a warehouse worker to gain attention and create a link of understanding that both entities are aware of each other's presence in an environment. This tacit understanding is a powerful tool, thanks to its ability to cross cultures internationally as eye contact can be assumed as a form of non-verble awareness of each party.

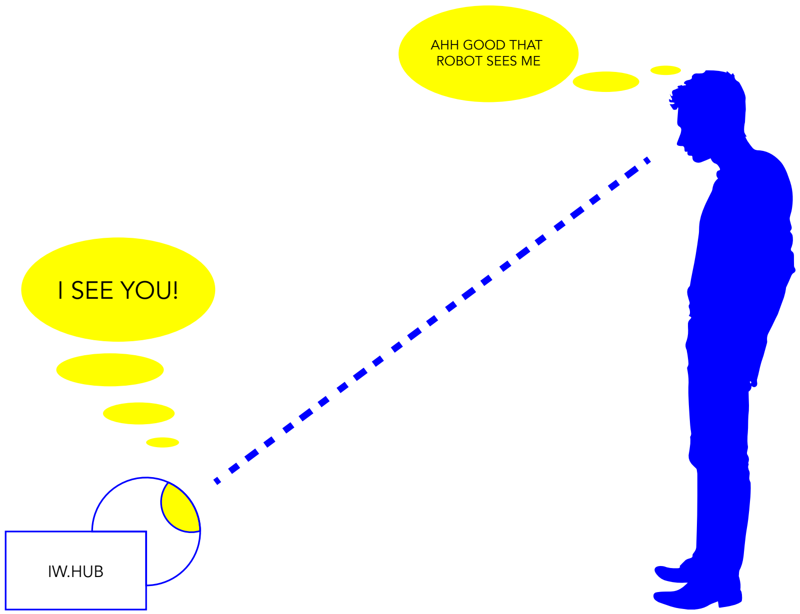

Figure 12. Example of eye gazing.

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Uncertainty

Expanding briefly on the uncertainty discussed by participants across the primary research phase. It was discussed by Participant 3 that operators can have a hard time maintaining these devices in the field.

Uncertainty

Complexity

> So yeah, it's like, from robot becoming stuck, to I'm in the app, diagnosing what the problem is, is quite a long chain of events, like yeah , *get your laptop, get your phone out, Enter your credentials, try and find the robot on the map, and then identify what the problem is.*

Figure 13. Quote from participant 3, talking about the diagnosis process.

Quoted in figure 13, it appears the existing process may be complex in how one can diagnose and resolve an issue related to an IW.HUB. Proximity of uncertainty to complexity tells us they are able to feed off each other. The quote tells us that this is a process problem: get your laptop out, get your phone, find your credentials, identify and locate that robot on a world map, and then you can finally identify problems. As mentioned, this is quite a long chain of events to solve, what sometimes could be a simple solution. Opportunities arise around this process of diagnosis and resolution with the aid of design solutions. As previously discussed, interfaces typically are poorly designed when it comes to industrial equipment and the IW.HUB is as equally guilty of this in its own way (Follett, 2014). Thus, solutions looking at streamlining this process are necessary not only to improve operator satisfaction, but also reduce the overhead incurred to affected users in the warehouse who may have to pick up after a disabled IW.HUB. Investigations into augmented reality (AR) devices or identification systems could be used to solve the described problems with relative ease. Examples of AR systems could include mixed reality elements through the use of portable devices to display important information and provide controls over a given IW.HUB such as: status, current mission, intended path, etc. Indefications systems on the IW.HUB may be also implemented to speed the process, enabling quick referencing to broken AMRs in the field by not just operators but also warehouse workers.

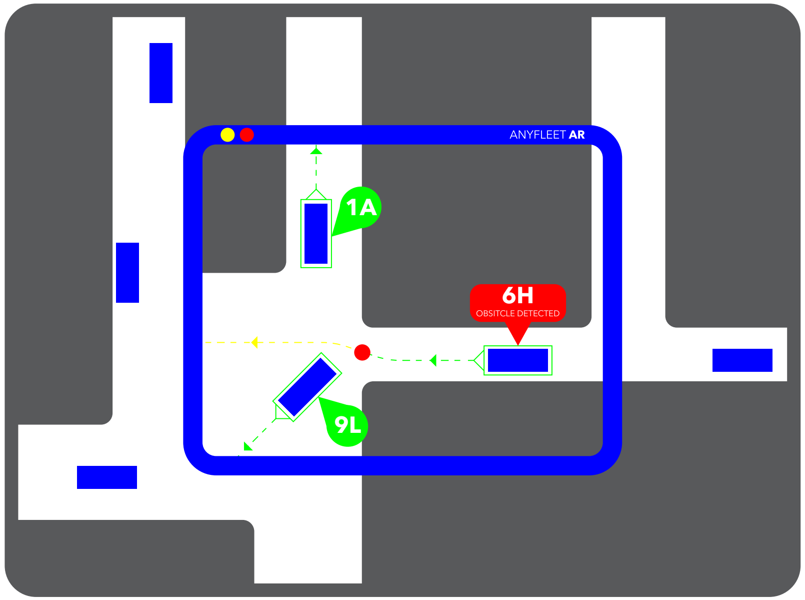

Figure 14. AR example of devices used to display AnyFleet data.

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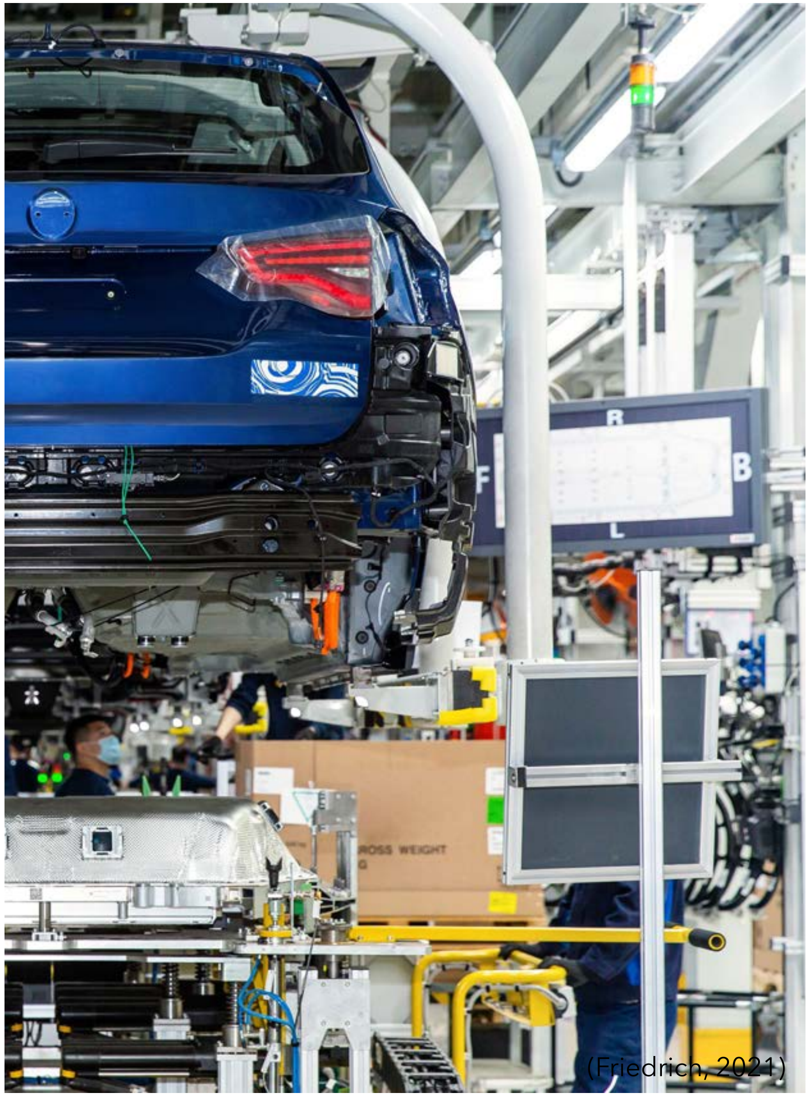
Conclusion

With industry 4.0 on the horizon, and technology in the process of transforming how we perceive the modern industrial factory. The success of many of these technologies will be dependent on the effective deployment of conscious interaction and interface design. Thus the research presented here was conducted to identify the factors that can both make a successful design and highlight what may cause a design to fail.

Primary research was conducted with industry professionals and researchers on the cutting edge of what human robot interactions (HRI) could look like for the future. Analysis of over 300 minutes of transcribed interviews afforded vast breadth and depth of rich information that has informed design implications for future product concepts and interventions. Secondary literature research opened discussions about what is possible with existing technology and revealed the impact HRI can have to either improve or deteriorate human behaviour.

Design implications presented, however brief, open opportunities for discussions into how various uses of novel interactions can signal positive affection towards industrial autonomous mobile robots (AMRs). Future work should consider opportunities of research available in wearable technology and its use in the industrial context as a method of interactions per-human, reducing complexity on already complex AMRs.



(Friedrich, 2021)

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Appendix

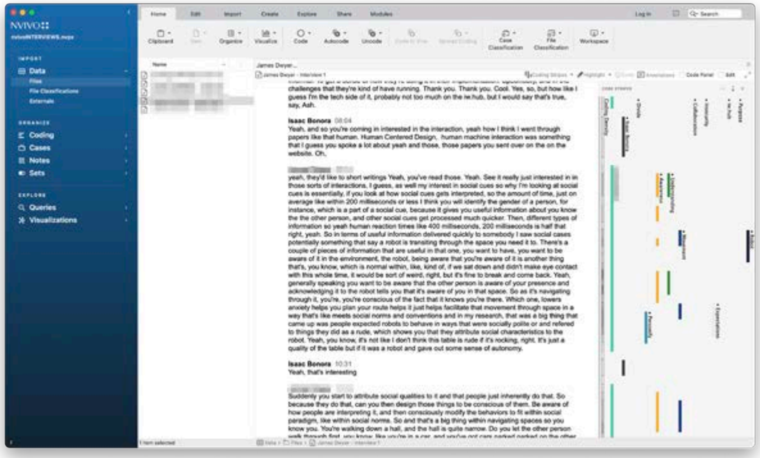
1.0 - Interivew Transcripts

Raw transcripts from interviews were chosen by the QUT Design Academy and the BMW Group to be protected by a non-disclosure agreement. Permission to receive transcripts will need to be done with prior approval from Academy Lead.

1.1 - Interview Coding Frequency Table

COUNTA of Sub-Code			*Interviewee Real*				
Category	*Code*	*Sub-Code*		Ashleigh Meintjes	Dylan Sheppard	James Dwyer	Grand Total
Tacit	Considerate	Empathy				1	1
		Priority			1		1
		Polietness				2	2
		Pleasent				3	3
		Trusting				3	3
		Purpose				4	4
	Considerate Total				1	13	14
	Projection	Attribution			1	2	3
		Curiosity			3		3
		Personify		1	3	13	17
	Projection Total			1	7	15	23
	Collaboration	Movement		1		8	9
		Collaboration			8	9	17
	Collaboration Total			1	8	17	26
Tacit Total				2	16	45	63
Contextual	Complexity	Computer-Illiterate	1		3		4
		Barrier		5			5
		Complexity		2		3	5
	Complexity Total		1	7	3	3	14
	Perceptual	Planning		1		3	4
		Social Norm				6	6
		Expectations		1		8	9
		Understanding		1	3	15	19
		Awareness			3	19	22
	Perceptual Total			3	6	51	60
Contextual Total			1	10	9	54	74
Problematic	Misunderstanding	Apprehension		2			2
		Unawareness				2	2
		Misunderstanding		5		1	6
		Uncertainty			7	4	11
	Misunderstanding Total			7	7	7	21
	Irreverence	Abnormal				1	1
		Failure		2		1	3
		Rudeness				3	3
		Damage		1	1	2	4
		Insecurity		2	5	4	11
		Frustration		3	7	4	14
		Divide		1	7	10	18
	Irreverence Total			9	20	25	54
Problematic Total				16	27	32	75
Grand Total			**1**	**28**	**52**	**131**	**212**

1.2 - Coding Software, NVivo



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