Developing a framework to examine the importance of cultures in Human-Robot Interactions

Computer Science Project (40 credits) Final Report

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Abstract

This report presents the development and evaluation of an innovative Human-Robot Interaction (HRI) framework that integrates cultural awareness into robot behaviors. The research aims to foster more nuanced and empathetic interactions between humans and robots by incorporating aspects of national culture and identity, such as language, gestures, and social norms. The study combines a mixed-method approach, including software development, experimental design, and theoretical exploration within the multidisciplinary fields of robotics, computer science, and cultural studies. The research involved creating a series of culturally informed interaction scenarios within the OfficeBots HRI simulation environment. These scenarios were designed to evaluate the framework's capacity to modify robot behaviours based on different cultural contexts—specifically catering to participants from China, Hong Kong, and England, including a participant of Malaysian descent in England. The primary behaviours altered by the framework included language selection, gestural communication, hospitality gestures, and movement dynamics. The framework was assessed through experiments involving 15 participants who interacted with robots programmed to exhibit culturally congruent behaviours. Quantitative data such as proximity, and qualitative data from participant observations and feedback, were collected and analysed. The results showcased the framework's technical proficiency and highlighted the positive reception of culturally adaptive behaviours by participants, notwithstanding the need for clearer cultural signifiers to optimize user recognition and comprehension. This report underlines the critical role of cultural adaptability in HRI and discusses the theoretical implications, practical applications, and potential for future research. Limitations are acknowledged with a reflective consideration of the framework's scalability and the prospect of incorporating more dynamic, real-time cultural adaptations. The evaluation concludes with recommendations for extending the HRI framework to enhance cultural sensitivity and personalized user experiences in robotic interactions.

Keywords: Human-Robot Interaction, Cultural Robotics, Social Robotics, Responsible AI, Responsible Robotics

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This journey through the realms of Human-Robot Interaction (HRI) and Cultural Robotics wouldn't have been possible without the unwavering support from those who accompanied me. I extend my heartfelt thanks to them all.

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Next, I would like to acknowledge the insightful feedback and sharp insights from my Inspector, Dr Luca Arnaboldi. The feedback on my project played an instrumental role in refining my project, ultimately enhancing the quality of the final output.

I also wish to express my deep gratitude to the Alistair Harvey Foundation. Their generous provision of a full scholarship enabled my study at the University of Birmingham. The trustees' confidence in my capabilities has been a substantial driving force in my progress.

Opting for the University of Birmingham, I paid homage to the enduring, albeit closed, Centre for Contemporary Cultural Studies (CCCS), whose pioneering theories have profoundly sculpted my path as a former Cultural Studies major. Echoing Raymond Williams [13] at my juncture of culture and technology, I reflect, 'I don't know how many times I've wished I'd never heard the damned word culture.' Despite this, the fusion of these disciplines continues to ignite, shape, and catalyse interdisciplinary scholarly dialogue worldwide.

Lastly, I'd like to extend my deepest gratitude to my partner, Miss Karmen Zheng, who is currently engaged in her own academic challenges in Hong Kong, within the intersection of Cultural Studies and Animal Studies. Despite the geographical distance, her unwavering belief in me and steadfast support have been a rock throughout this journey.

It is with great hope that I anticipate my research making a significant contribution to the field and paving the way for future explorations and discoveries.

Abbreviations

AI	Artficical Intelligence
HCI	Human-Computer Interaction
HRI	Human-Robot Interaction
ROS	Robot Operating System
ROS4HRI	Robot Operating System for Human-Robot Interaction

Contents

List of Figures

List of Tables

CHAPTER 1

Introduction

The rapid integration of robotic agents into human-centric environments has stimulated an emerging discourse on Human-Robot Interaction (HRI). No longer confined to industrial settings as task-oriented automatons, modern robots are increasingly merging into the fabric of diverse sociocultural landscapes. A prime example of this integration is the multifaceted roles robots are assuming, from guides in the Lincoln Centre for Autonomous Systems [3], to instrumental aids in education and social care [11]. Beyond operational functionalities, the emerging domain of social robotics calls for nuanced human-robot interactions that respect the complex mosaic of human culture.

Recognising the importance of cultural dimensions, this project aims to explore the impact of cultural differences on HRI, with a specific focus on the greeting behaviours of culturally adaptive robots within an OfficeBots environment, which was made possible through the ROS4HRI framework. As contemporary workspaces evolve into multicultural environments, the need to calibrate robotic behaviours—starting with the fundamental act of greeting—to align with diverse cultural etiquettes and practices has become increasingly critical. Consequently, this study seeks to understand the complex nature of robots adapting to culturally diverse greetings, aiming to enhance both the effectiveness and sociocultural acceptance of robotic agents in multi-ethnic office settings.

The ROS4HRI framework, currently under peer review, serves as the foundation for this investigation. Designed to introduce uniform interfaces and conventions for HRI within the Robot Operating System (ROS), ROS4HRI aims to address the limitations of previous implementations, promoting code reusability, experiment replicability, and knowledge sharing across the HRI research community. The proposed research futher investigates the potential of ROS4HRI to simulate spatial interactions in OfficeBots—an interactive 3D simulation designed for HRI research and education. Within this digital platform, researchers can instantiate, customise, and control robotic avatars, setting the stage for empirical user studies focused on robots' culturally attuned communication exchanges with participants.

While the unification of the HRI research framework is promising, it is unfortunate that it still lacks consideration of the cultural aspects of robots. In response to this, the project aims to extend the ROS4HRI framework to incorporate and consider culturally aware robots by developing a CulturalHRI framework that invites researchers to collaboratively contribute.

CHAPTER 2

Literature Review

This literature review critically evaluates pertinent studies in the domain of Human-Robot Interaction (HRI), with an emphasis on the cultural adaptability of robots. The increasing integration of robots in diverse sectors signals the importance of investigating their cultural competence. The review encompasses various dimensions of HRI, including investigations of social robots, implications of bias in artificial intelligence, the field of cultural robotics, and the requirement for an open-source framework tailored to Cultural HRI research. Pulling from these themes, the review frames the present landscape of HRI research and acknowledges potential future areas of exploration. It should be noted that the development of culturally adaptable robots extends beyond making headway in technical prowess - it necessitates an in-depth examination into issues such as bias, ethics, and societal implications inherent to AI technologies.

2.1 Cultural Adaptability in Human-Robot Interaction (HRI)

The integration of robots into various aspects of daily life is a growing trend, transcending their conventional roles as mere machines into more socially interactive entities [11]. The effectiveness of robots in these roles hinges on their ability to adapt to the cultural backgrounds of the individuals they interact with [6]. As such, cultural adaptability has become a paramount concern in Human-Robot Interaction (HRI).

2.2 HRI Research and Social Robots

Tobis et al.'s study [12] investigates the acceptance of service robots in eldercare, emphasizing the role of social support, relational coordination, and technology readiness. Cultural adaptability becomes paramount in contexts such as eldercare, where robots must cater to the specific cultural needs and expectations of elderly users. Understanding how cultural factors influence robot acceptance is crucial for the design and deployment of robots in diverse settings. Bartneck et al.'s work [1], on the other hand, introduces measurement instruments for anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. These instruments provide a structured approach to assess user perceptions of robots in culturally diverse contexts. Understanding how users anthropomorphize robots differently across cultures can guide the design of culturally adaptable robots. Mutlu et al. [8] explore the significance of human-like gaze behaviour in robots. Gaze behaviour is culturally nuanced and plays a pivotal role in communication. The ability of a robot to adapt its gaze behaviour to the cultural expectations of users can profoundly affect the quality of interactions. While this research aims not to deploy robot during human-robot interaction, it is believed that such metrics are significant to the future development of the field.

2.3 The Influence of Bias in Artificial Intelligence on Cultural HRI

As social robots become increasingly prevalent in real-life settings, claims of their cultural awareness abound. However, given that these robots are powered by AI, it's essential to acknowledge the persistence of cultural bias in AI research. While Lim [6] examined 50 HRI cultural robot research studies, a unifying framework was notably absent, and the research focus did not prioritize responsible robotics.

Scheuerman et al.'s [10] investigation into automated facial analysis serves as a fundamental entry point into the discussion on bias. Their study underscores the role of these technologies in perpetuating historical gender classifications and racial biases, particularly through the essentialisation of facial features. The technology's perpetuation of historical gender classifications by essentialising facial features raises critical questions about the implications of such practices. The authors' call for critical examination of cultural and historical contexts resonates with the broader theme of understanding the roots of bias in AI.

Similarly, Prates et al. [9] examined machine translation, offering insights into the societal implications of biased algorithmic outputs. Unveiling a notable inclination towards male defaults, this study highlights the societal implications of biased algorithmic outputs, emphasizing the critical need for debiasing techniques in translation tools. As language plays a crucial role in shaping gender bias, the study brings a full circle to the initial exploration of biases in facial analysis.

Gupta, Parra, and Dennehy's [4] article, on the other hand, provided interesting insight into how individuals' responses to biased AI recommendations unveil how culture – namely collectivism, masculinity, and uncertainty avoidance – shape individuals' responses to biased AI recommendations. This echoes Hagendorff [5], who emphasized that gender bias not only lies in the production of AI but also in its users, inviting researchers to recognize the intricate interplay between technology and culture.

2.4 Cultural Robotics

The above studies echo with Brandão, Mansouri, and Magnusson's [2] editorial, written from the perspective of robotics, shed light on the importance of considering the ethical and social implications of AI in general. The editorial attempts to provide a socio-technical perspective on AI's societal impacts with a comprehensive discussion that encompasses physical safety concerns, biased conceptions of gender and race, and the development of responsible and trustworthy robotics and AI. The emphasis on the socio-technical perspective and issues of bias, transparency, and fairness provides a comprehensive lens to evaluate the responsible development and deployment of AI technologies. As the editorial emphasizes the need for a socio-technical perspective, it invites researchers to consider the broader societal impacts and ethical considerations that underpin responsible AI development, going beyond a mere technical perspective.

Lim et al. [6] emphasize the importance of the role of culture in shaping HRI, advocating for a global perspective in robot design and interaction. Through surveying existing literature in the field, Lim et al. concluded that cultural nuances significantly influence how robots are perceived and accepted by users from diverse backgrounds. This is particularly crucial in multicultural environments, where robots are expected to interact with users representing a spectrum of cultural norms.

As such, Mansouri [7] calls for an epistemic analysis of cultural theories in robotics and AI methods, providing a theoretical foundation for understanding the role of culture in human-robot interactions. The exploration of how robots can adapt and learn from cultural interactions over time is a promising avenue for future research.

2.5 Developing an Open-Source Framework for Cultural HRI Research

Progress has been made in constructing a cohesive framework for HRI research. The ROS4HRI framework, launched in October 2022, establishes standardized topics and conventions explicitly designed for HRI. These focus on "traditional" HRI dimensions such as face detection and body tracking. However, cultural aspects have not received the same level of attention.

In light of the intersections between cultural adaptability in HRI and the implications of bias in AI, there is a pressing need to develop an open-source framework for Cultural HRI research. This framework should integrate insights from both fields and provide guidelines for the responsible development and deployment of culturally adaptable robots.

CHAPTER 3

Objective

Building upon the observed methodological disparities and theoretical advancements in the field of Human-Robot Interaction (HRI), this study is fuelled by the overarching aim to develop a comprehensive framework that can systematically capture and address the cultural dynamics at play in HRI contexts. The specific objectives of the research are:

- To Assess Culturally Adaptive behaviours: Examine and assess how culturally adaptive greeting behaviours by robots can enhance their interaction with humans in a multicultural office setting.
- To Utilize the ROS4HRI Framework: Enhance the emerging ROS4HRI framework to standardize and streamline the experimentation process in HRI research.
- To Conduct Empirical Studies: Blend qualitative and quantitative research methods, including ROS-based experiments, surveys, and comprehensive user studies, to appraise user perceptions and acceptance of culturally adaptable robotic behaviours.
- To Inform Robot Design Processes: Produce insights that inform design processes and user experience considerations for robots operating within culturally diverse human environments.
- To Advance Cultural Robotics: Shed light on how nuanced cultural factors impact the design, function, and acceptance of socially intelligent robots.

With these objectives, the study aims to provide actionable insights and empirical benchmarks that can guide the development and deployment of culturally agile robotic systems.

3.1 Significance

This research proposition carries broader implications that transcend individual robotic interactions, with several dimensions of significance:

- Cultural Sensitivity in Robotic Design: Increase awareness and understanding of the critical role that cultural nuances play in shaping HRI. Inspire the inclusion of cultural considerations in the early stages of robotic design to enhance acceptability and practical utility of robots in diverse environments.
- Unification of Cultural HRI Research: Establish a unified research methodology that offers consistent interfaces and response mechanisms for culturally informed HRI studies. Foster a collaborative research ecosystem that enables code reusability, facilitates experiment replication, and encourages knowledge sharing across various HRI projects.
- Empirical Research Contribution: Bridge the current gap between the wealth of theoretical discourse and the lack of empirical evidence concerning cultural influences in HRI. Provide a substantial empirical dataset that supports theoretical claims and encourages continued scholarly investigation.
- Social and Professional Integration: Enhance the quality of human-robot interactions in professional settings, thereby improving the social integration of robotic agents in the modern workforce. Contribute to the development of culturally inclusive technologies that can accommodate the cultural diversity within global office environments.

In doing so, this study aspires to catalyse a paradigm shift in HRI research, where culture is no longer a peripheral consideration, but a pivotal element in crafting more empathetic, responsive, and effective robotic systems for the future.

3.2 Contribution

This research aims to develop a general framework that enables researchers to explore the intersection of robotics and culture. This framework acts as a flexible base on which various parameters relevant to cultural considerations can be adjusted to accommodate a spectrum of studies. Essential to this development is the integration of simulated environments alongside empirical research to glean insights into the cultural dynamics of HRI.

3.2.1 Simulation Program Customisation

A key element of this work involves setting up a dynamic simulation program designed for user-guided research. This program supports parameter alteration, giving researchers the flexibility to design studies around specific cultural subtleties. This customization broadens the scope of HRI research, initiating paths for various applications across different cultural scenarios.

3.2.2 Extension of ROS4HRI to Encompass Cultural Aspects

A significant part of this undertaking involves the enhancement of ROS4HRI, emphasising cultural characteristics. This project aims to insert global cultural aspects like nationality and national culture into the technical sphere of HRI. This advanced feature merges the technical capacity of ROS4HRI with the complex and often subjective facets that shape cultural interaction and perception. By consolidating these tools under the domain of culture-centric research, this work attempts to encourage exploration and understanding of how robots can be developed more culturally in line and hence, more proficient at working with humans across diverse settings.

CHAPTER 4

Methodology

This project takes a mixed-method approach to investigate the influence of culture on Human-Robot Interaction (HRI), with a focus on national identity as a case study through which to explore cultural differences. The choice to examine cultural impacts through national identity is driven by the distinct and observable characteristics that are deeply rooted within this framework, such as language, social norms, and symbols. These aspects are readily identifiable and offer a strong foundation for designing interaction scenarios that can be systematically evaluated. This approach aims to provide insights into the broader field of cultural adaptability in robotics by studying interactions within the context of a diverse and tangible element of culture — nationality. The methodology comprises a combination of pre-experiment surveys to understand participants' cultural backgrounds and expectations, culturally infused interaction scenarios within a simulated environment, and post-experiment evaluations to gauge the perceptions and experiences of the participants. These stages are designed to collect both qualitative and quantitative data, allowing for a comprehensive analysis of cultural influences on HRI.

4.1 Experimental Design

4.1.1 OfficeBots Environment

The experiments will utilize the OfficeBots simulation, which enables controlled observations of HRI in an office setting. The environment lends itself to a standardized and repeatable research design.

4.1.2 Robot Behaviour Modification and Scenarios

The study will employ three robots, each assigned a set of behavior modifications corresponding to their "nationality" based on predefined user inputs. These

Figure 4.1: Robot configured according to user input

nationalities—China, Hong Kong, and the UK—each present unique cultural considerations for language, proximity etiquette, and hospitality norms.

Interaction Scenarios

1. **Language Adaptation:**
   - A robot representing China will communicate in Simplified Chinese.
   - A robot representing Hong Kong will use Traditional Chinese.
   - A robot representing the UK will interact using British English.
2. **Cultural Hospitality:**
   - Each robot will offer beverages associated with their country (water, Hong Kong-styled milk tea, and English tea), reflecting the cultural norm of drink offerings as a form of hospitality.
3. **Proximity Norms:**
   - Adhering to cultural norms regarding personal space, robots will maintain varying distances when approaching participants, respective to their assigned nationality.

By embedding these scenarios into our research design, we gain valuable insights into how cultural adaptations impact user comfort, engagement levels, and overall perception of the robot's social intelligence.

Customization for Cultural Interactions

The robots will be programmed with variances in language and behavioral cues based on cultural insights from the pre-experiment survey. Scenario variations

Figure 4.2: An example of Chinese robot behaviour

will elicit and measure the adaptability of these culturally informed robot behaviors.

4.2 Participant Recruitment

The recruitment process targeted the selection of 15 participants, divided into three distinct cultural groups: Chinese, Hong Kong, and British. Each group consisted of five individuals, ensuring a balanced representation within the sample. This intentional sampling approach aimed to facilitate a focused examination of cultural behaviours and preferences within these culturally homogeneous cohorts.

4.2.1 Recruitment Methodology

Participants were recruited through a multifaceted approach that incorporated elements of both systematic sampling and snowball sampling techniques. While systematic sampling principles guided the structured identification and selection of individuals from the target cultural groups, personal networks and referrals were utilized through the application of snowball sampling.

Systematic Sampling

Systematic sampling principles were applied to ensure the comprehensive representation of the target cultural groups. This involved establishing clear criteria for participant selection and utilizing multiple recruitment channels to systematically identify eligible individuals. By adhering to systematic sampling principles, the study aimed to minimize bias and enhance the validity of the research findings.

4.2.2 Snowball Sampling

In addition to systematic sampling, snowball sampling techniques were utilized to capitalize on personal networks and referrals. Existing participants or contacts within the researcher's network may have referred additional individuals who met the study criteria. This facilitated the identification of potential participants who may not have been reached through traditional recruitment channels alone. While snowball sampling contributed to the expansion of the participant pool, it was integrated into the recruitment process alongside systematic sampling methods to ensure a comprehensive and diverse sample composition.

4.3 Data Collection

Pre-Experiment Survey

Survey Design and Implementation: Participants will first complete a pre-experiment survey designed to gather demographic information, cultural background, prior experiences with robots, and expectations for social robot interaction.

Post-Experiment Survey and Feedback

User Study: A post-experiment survey will collect immediate participant feedback about the robot interactions. This survey measures perceived cultural accuracy, engagement, and the overall acceptability of the robot behaviors.

4.3.1 Ethical Considerations

Prior to participation, all users will be briefed on the study's objectives, their role, and rights as participants, including confidentiality and the option to withdraw at any point without repercussion. The study will ensure that all ethical protocols and guidelines are rigorously followed.

4.4 Experiment Procedure

To rigorously evaluate the interactions between humans and culturally aware robots, this research includes a series of systematic experiments conducted within a controlled environment. This section describes the setup of these experiments, including the recruitment and briefing of participants, the execution of interaction scenarios, and the data collection methods used to record and assess the behavior of both the robots and the human subjects.

4.4.1 Briefing and Instructions

Upon recruitment, participants received a detailed briefing about the study's objectives and the nature of their involvement. They were assured of confidentiality and informed of their right to withdraw from the study at any time. Informed consent forms were obtained from all participants. Instructions were provided outlining how subjects should interact with the robots, emphasizing that they should behave as they would naturally in a real-world office setting.

Additional clarifications and training were provided to ensure comfort with the OfficeBots simulation environment and to eliminate any unfamiliarity with the simulation software that might impact the experiment's outcome.

4.4.2 Execution of Interaction Scenarios

Interaction scenarios were designed to elicit culturally specific behaviors in both participants and robots. These scenarios included:

- A greeting interaction, where the robot would approach and greet the participant using language cues pertinent to the participant's cultural context.
- A hospitality interaction, where the robot would offer a choice of drinks typical to the participant's culture.
- A personal space interaction, with the robot entering and maintaining a culturally appropriate distance during conversation.

The scenarios were conducted in random order to reduce the expectancy effect, and each participant went through interactions with all three culturally programmed robots to observe comparative responses.

4.4.3 Ensuring Fidelity and Replicability

All experiments were conducted in the same OfficeBots environment to ensure fidelity and to allow for data comparability. Precise documentation of software settings, robot behaviors, and participant interactions were maintained, promoting study replicability.

4.4.4 Ethical Handling of Data

Throughout the study, all data collection and analysis methods adhered strictly to ethical standards. Participant data was treated with the confidentiality, securely stored, and made accessible only to the research team. Personal identifiers were removed from all datasets to maintain anonymity in line with ethical research guidelines.

CHAPTER 5

Software Design and Implementation

This section discusses the existing tools in robotics and HRI research, namely Robot Operating System (ROS), ROS4HRI, and OfficeBots, and elaborates on the design principles and implementation specifics of the culturally aware robotic framework, which builds upon the foundational ROS and its extension ROS4HRI for Human-Robot Interaction (HRI) research.

5.1 Robot Operating System (ROS)

The Robot Operating System (ROS) is a flexible, open-source framework that has become a cornerstone in robotics software development. This middleware provides fundamental services for hardware abstraction, low-level device control, implementation of commonly used functionality, message-passing between processes, and package management. Its utility in facilitating message passing and service calls through topics and services has catalysed the advancement and democratization of robotics research and development.

5.2 ROS4HRI

With the advent of the ROS4HRI extension in October 2022, the application of ROS has further expanded into the domain of Human-Robot Interaction. This enhancement to ROS standardizes topics and conventions specifically tailored for HRI, encompassing critical functionalities such as face detection, body tracking, and other key interactive features. ROS4HRI serves as an invaluable bridge between the traditionally robotic-centric focus of ROS and the nuanced requirements of social robotics.

5.3 OfficeBots

OfficeBots emerges as an innovative tool to facilitate HRI research, manifesting as a 3D simulation environment modelled after an office. Supporting both research and educational endeavours, OfficeBots enables users to navigate a virtual space featuring interactable objects and robotic agents. Through this tool, researchers can experiment with robot augmentation, behavioural modification, and interaction in a controlled, reproducible setting that closely mirrors real world scenarios.

5.4 Architecture

The system architecture is structured as a multi-tiered framework, where each layer fulfils distinct functions and interacts through well defined interfaces:

- **ROS Core:** Serving as the fundamental communication medium, ROS facilitates message passing between nodes and manages services and actions within the robotic environment.
- **ROS4HRI:** Extending core ROS functionalities, ROS4HRI introduces dedicated nodes and topics for human-robot interaction capabilities, enriching the system with features like motion tracking and body movement detection.
- **Culturally Aware Extensions:** These custom nodes and services, developed atop ROS and ROS4HRI, imbue robotic behaviours with cultural awareness. They enable adaptations based on participant input regarding nationality and cultural preferences. Notably, the implementation integrates the factory pattern, anticipating future extensions to explore additional cultural values such as race and gender.

5.4.1 Factory Pattern

This project strategically employs factory pattern in achieving flexibility and scalability within the framework. It enables dynamic object creation without the need for specifying their exact classes. Applied in both the robot and database components, this pattern allows for seamless customisation and adaptation to diverse cultural contexts.

Robot Factory

The robot factory dynamically creates instances of robot objects based on specific criteria such as the cultural context or nationality of users. This flexibility empowers the framework to instantiate different types of robots with varied behaviours tailored to specific cultural parameters.

Database Factory

Similarly, the database factory is responsible for generating database connections tailored to specific database types (e.g., PostgreSQL). By abstracting the

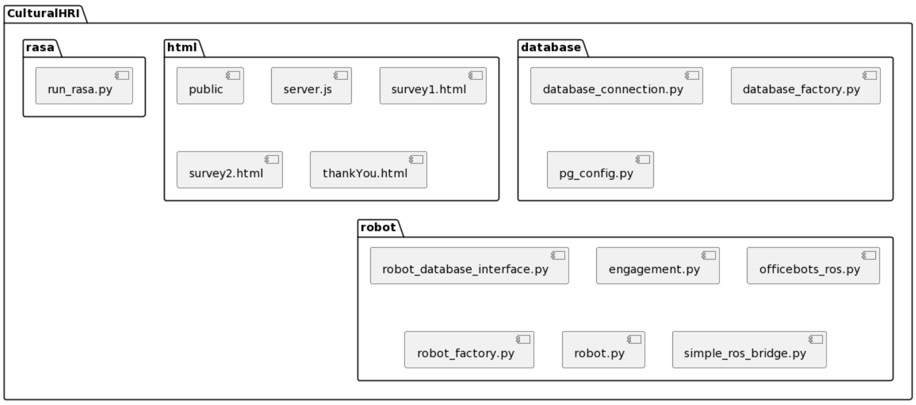

Figure 5.1: System Architecture of the Culturally Aware Robotic Framework.

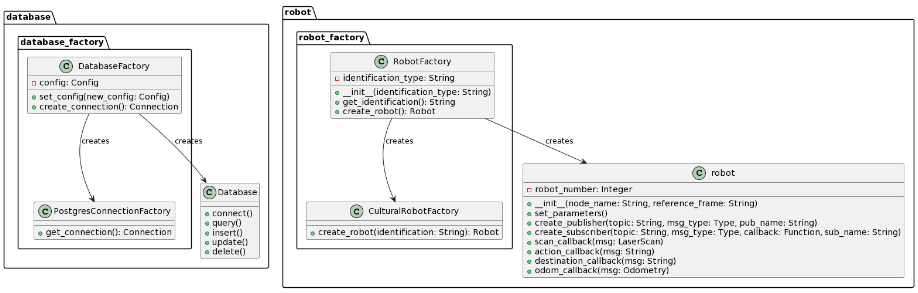

Figure 5.2: Factory Pattern Implementation in the Framework for easy extension and customisation.

process of connection creation, it allows for seamless switching between different database systems or configurations, enhancing adaptability for future experiments.

By employing the factory pattern in this project, the framework enables easy manipulation, extendibility, and customisation of the creation of database connections and robots without modifying existing code. Such a pattern enables a more flexible and adaptable implementation for future changes and experiments involving different cultural values or behaviours.

5.5 Programming Languages and Technologies

To fulfil its functional and experimental objectives, the project harnesses a diverse array of programming languages and software stacks:

- **Python:** Primarily utilized for ROS node development, Python defines robot behaviours through subscribers and publishers. Additionally, it integrates with RASA Conversational AI for natural language interactions and Flask web framework for HTTP request handling and survey data processing.
- **JavaScript:** Drives frontend development for surveys, facilitating a dynamic user interface, and is utilized on the backend for data collection and relay to the Flask server and robotic framework.
- **SQL:** Employed to structure the Postgres database schema storing survey data essential for configuring robot behaviours aligned with cultural contexts.
- **C#:** Powers the OfficeBots environment within the GoDot game engine, enabling high-fidelity simulation for HRI studies and implementing multilingual support for cultural interaction within the simulation.

5.6 Integration and Communication

The project's integration strategy ensures smooth communication between the survey interface, data storage, and the robotic environment:

- **Data Flow:** Survey responses collected via the JavaScript frontend are stored in the Postgres database. SQL queries retrieve this data, which is then passed through the Flask interface to ROS, facilitating the translation of survey responses into robotic actions.
- **ROS Bridge:** Serving as the conduit between web-based components (Flask server) and ROS/ROS4HRI systems, the ROS Bridge facilitates seamless communication.
- **Simulation Interaction:** C# scripts within the GoDot game engine translate transmitted data into live changes, updating robot behaviour in the OfficeBots environment to reflect cultural adaptations.

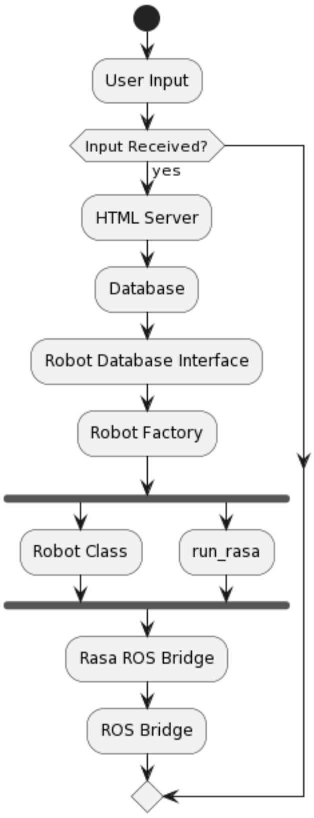

Figure 5.3: Data Flow and Communication between the Survey Interface, Database, and Robot Class.

5.7 Development Environment

Modular development is adopted to allow independent testing and deployment:

- **Version Control:** Git effectively manages code changes and collaboration.
- **Development Tools:** Various IDEs and editors are employed, tailored for respective languages such as PyCharm for Python, and Visual Studio Code for JavaScript and C#.
- **Testing Frameworks:** Utilization of unit-testing and integration testing frameworks ensures the reliability and correctness of individual components and their integration. The employment of the factory pattern anticipates future extensions, providing a flexible and scalable framework for cultural adaptation in HRI experiments.

5.8 Testing

Utilization of unit-testing and integration testing frameworks ensures the reliability and correctness of individual components and their integration. The employment of the factory pattern anticipates future extensions, providing a flexible and scalable framework for cultural adaptation in HRI experiments.

In the testing phase, unit tests were conducted for individual functions and classes within these scripts. Integration tests were also performed to assess the interaction between these components. Notably, the testing process revealed the reliability of the framework, particularly in scenarios where the `RobotFactory` class interacts with the `DatabaseFactory` class.

5.8.1 Unit Testing

The database module comprises scripts responsible for managing database connections and configurations. Similarly, within the robot module, scripts oversee robotic engagement, interface with databases, and control robot behaviour. Additionally, the rasa module contains scripts dedicated to running the Rasa conversational AI platform.

The factory pattern plays a crucial role within the robot and database modules. For instance, the `RobotFactory` class in the `robot_factory.py` script facilitates the creation of various types of robots, while the `DatabaseFactory` class in the `database_factory.py` script enables the creation of different database connections.

During testing, it was noted that the database module effectively manages database connections and configurations, while the robot module adeptly handles robotic engagement, database interfacing, and robot behaviour control. Additionally, the rasa module efficiently executes the Rasa conversational AI platform.

The implementation of the factory pattern within the robot and database modules proved to be instrumental. For example, the `RobotFactory` class in the `robot_factory.py` script seamlessly generated various types of robots, while the `DatabaseFactory` class in the `database_factory.py` script efficiently created different database connections.

The versatility of the factory pattern was demonstrated by simulating scenarios where non-existent classes such as `GenderRobot` and `RaceRobot` were requested for instantiation. Despite these classes not being present in the current implementation, the factory pattern demonstrated its flexibility and adaptability by handling such requests without errors or disruptions.

This exercise showcased the potential benefits of the factory pattern for future extension experiments. By allowing for the dynamic creation of objects without specifying their exact class, the factory pattern is well-suited for accommodating new types of robots or database connections as the framework evolves. This capability becomes particularly valuable in the context of cultural adaptation in Human-Robot Interaction (HRI) experiments.

In future experiments exploring gender-specific or race-specific robot behaviours, the factory pattern can facilitate the seamless integration of new, non-implemented classes such as `GenderRobot` and `RaceRobot`. This allows researchers to easily extend the framework to incorporate culturally sensitive interactions tailored to specific gender or race identities.

5.8.2 Integration Testing

Integration testing represents a pivotal stage of software assessment wherein individual units are amalgamated and examined collectively to uncover any operational anomalies stemming from their interaction.

In the context of this Human-Robot Interaction (HRI) framework project, integration testing assumes significance in assessing the seamless collaboration among various components. This evaluation encompasses scrutinising how the robot's behaviour adapts in response to different cultural parameters or how it interfaces with the database.

Systematic testing of such interactions ensures the cohesive operation of the framework's components, thereby ensuring a reliable and seamless user experience. Moreover, integration testing aids in identifying and rectifying any potential inconsistencies or issues in the integration process before deployment.

To conduct integration testing effectively, various test scenarios were devised to replicate real-world interactions between distinct modules of the framework. For instance, scenarios were evaluated where the robot retrieved cultural parameters from the database to inform its behaviour, or where the robot's state was stored and later retrieved for analysis.

CHAPTER 6

Result

A total of 15 participants took part in the experiment, with their consent. Participants came from both China (CN), Hong Kong (HK), and the United Kingdom (GB), with some identifying differently for their cultural background.

6.1 Participant Demographics

- 5 were born in China.
- 4 were born in Hong Kong.
- 6 were born in the United Kingdom.

6.2 Long-time residence were

- 3 resided long-term in Hong Kong.
- 10 resided long-term in the United Kingdom.
- 2 resided long-term in China.

While all of them currently reside in the United Kingdom (GB), it's notable that one of the participants, despite being born in and having spent a significant amount of time in the United Kingdom, identifies their cultural background as Malaysian (MY). This observation underscores the distinction between geographical origin and cultural identification.

6.3 Robot Preference

Participants were asked about their robot preference:

Category	Frequency	Percentage (%)
Consent Rate	100%	
Country of Birth	CN (China)	33.3
	HK (Hong Kong)	33.3
	GB (United Kingdom)	33.3
Long-Time Country	CN (China)	26.7
	HK (Hong Kong)	26.7
	GB (United Kingdom)	46.7
Current Country of Residence	GB (United Kingdom)	100
Cultural Background Identification	CN (Chinese)	46.7
	HK (Hong Kong)	40.0
	GB (British)	33.3
	MY (Malaysian)	6.7

Table 6.1: Summary of Pre-Experiment Survey Data

- 5 participants preferred the first robot due to its behaviours adapting according to their backgrounds.
- 10 participants preferred the second default English robot because they found its language more familiar and understandable.

These preferences are associated with their backgrounds and familiarity with the English language.

Robot	Participants	Reason for Preference
First Robot	5	behaviours adapt according to participants' backgrounds
Second Default English Robot	10	Language is more familiar and understandable

Table 6.2: Robot Preferences

6.4 Robot Behaviours

Participants indicated their liked behaviours in the robots:

- All participants appreciated the "Conversation Language" of the robots.
- 5 participants specifically highlighted the "Proximity" as a liked behaviour in the first robot.

Robot Behaviours	Number of Participants
Conversation Language	All
Proximity (First Robot)	5

Table 6.3: Participants' liked behaviours in the robots

6.5 Robot Performance Ratings

Participants' performance ratings varied, demonstrating different perspectives on how they evaluated the robots:

- 9 participants rated the robots as "Good".
- 2 participants rated the robot's performance as "Average".
- 1 participant rated the robot's performance as "Poor" due to language barriers as they could not understand Chinese.

Performance Rating	**Number of Participants**
Good	9
Average	2
Poor (due to language barriers)	1 (Participant 15)

Table 6.4: Participants' performance ratings of the robots

CHAPTER 7

Discussion

The experiment engaged 15 participants from China (CN), Hong Kong (HK), and the United Kingdom (GB). Notably, one participant, despite being UK-born and residing in the UK, identified as Malaysian (MY), highlighting the complex relationship between geographical origin and cultural identification.

From the experiment, it is apparent that participants' robot preferences varied: some favoured the first robot for its adaptive behaviors, while a majority preferred the second default English robot for its familiar language. These findings underscored the influence of cultural background and language familiarity on human-robot interaction.

Regarding robot behaviours, all participants appreciated the "Conversation Language," with some also favoring the "Proximity" behaviour of the first robot. These insights provide valuable feedback for future cultural robotics design.

Participants' evaluations of robot performance varied, with most rating it as "Good." However, a minority found it "Average," suggesting areas for improvement. The rating of "Poor" due to language barriers highlighted the importance of language accessibility.

The case of the participant identifying as Malaysian (MY), despite being born in and having a significant history in the United Kingdom, raises pertinent considerations regarding the influence of national culture on robot preference. This observation challenges the assumption that national culture alone serves as an adequate criterion for predicting participants' preferences and interaction dynamics in cultural robotics.

The drawback in relying solely on national culture as a determinant of robot preference becomes apparent when considering the complexities of individual identity and cultural hybridity. Participants' cultural backgrounds are often multifaceted and may encompass elements beyond their national origins, such as language, upbringing, education, and personal experiences. In the case of the Malaysian participant, their cultural identification diverged from their national origin, highlighting the inadequacy of using nationality as a sole criterion for understanding preferences in human-robot interaction.

Extending this discussion, it is essential to recognize that cultural identity is fluid and dynamic, shaped by a myriad of factors that extend beyond geographical boundaries. Factors such as globalization, migration, and exposure to diverse cultural influences contribute to the formation of hybrid cultural identities, complicating traditional notions of cultural categorization based on nationality. As such, the assumption that participants' national culture dictates their interaction preferences overlooks the nuanced interplay of various cultural factors that inform individuals' perceptions and behaviors.

Furthermore, the emphasis on national culture as a criterion for robot preference risks perpetuating stereotypes and essentializing cultural identities. Such an approach may overlook the diversity within national cultures and the individual differences that exist among participants from the same cultural background. By oversimplifying cultural identities, researchers run the risk of overlooking important nuances and failing to account for the diversity of preferences and experiences within and across cultural groups.

While the sample size of 15 participants may not be sufficient for generalization, the study framework provides a basis for further research in cultural human-robot interaction (HRI). The Malaysian case underscores the need for additional research to better understand cultural dynamics in HRI. Further investigations with larger and more diverse samples are necessary to validate findings and develop robust frameworks for understanding cultural dynamics in HRI.

Moving forward, researchers in cultural robotics must adopt a more nuanced and inclusive approach to understanding participants' preferences and interaction dynamics. Rather than relying solely on national culture, researchers should consider a broader range of factors, including language proficiency, acculturation level, personal experiences, and individual preferences. By adopting a culturally sensitive and contextually grounded approach, researchers can better capture the complexities of human-robot interaction dynamics and design systems that are inclusive, adaptable, and responsive to diverse cultural contexts and individual preferences.

CHAPTER 8

Evaluation

Expanding on the Discussion, this section assesses the framework's usefulness for ongoing cultural HRI research and identifies potential limitations and extensions.

8.1 Critical Evaluation of the Framework

Examining the framework in action reveals areas for refinement, particularly in how cultural elements are represented by the robot. Clearer delineation of culture-specific behaviours could improve recognizability and enhance the educational value of interactions. Additional visual or auditory cultural cues may be necessary to make implicit cultural references explicit to all users.

8.2 Limitations

Despite the potential of the framework, it's important to recognise its limitations. Cultural expressions are influenced by probabilistic tendencies rather than deterministic rules, meaning that certain assumptions may not align with every individual within a cultural group.

While the framework offers significant advancements in culturally aware robotics, several challenges warrant consideration:

- Risk of Cultural Stereotyping
- Accuracy and Recognition
- Continuous Update
- Complexity
- Resistance to Robot Personalisation

In the following, each of these limitations will be discussed in detail:

8.2.1 Risk of Cultural Stereotyping

Although the overarching aim is to foster respectful and personalised interactions, the risk of inadvertent cultural stereotyping cannot be overlooked. For instance, not every individual will align with the gender communication styles identified, and not everyone from a specific racial or ethnic group would adhere straightforwardly to the associated cultural norms. Employing broad cultural tendencies as rules, rather than guidelines, could lead to overgeneralizations and potentially offend users.

8.2.2 Accuracy and Recognition

The challenge of accurately recognizing and interpreting a user's gender and cultural cues solely based on interaction is a monumental task. Any misinterpretations can lead to inappropriate behaviour by the robot, resulting in user discomfort.

8.2.3 Continuous Update

Continuous Update: Cultures are not static entities but evolve and fluctuate over time, influenced by various socioeconomic factors. In fact, to Williams [14], a cultural theorist, it "is one of the two or three most complicated words in the English language." Ensuring that the framework remains updated with these cultural transitions presents a considerable challenge.

8.2.4 Complexity

The inherent complexity of human culture, with its myriad identities, nuances, and norms, may pose significant obstacles to replicating fully in an artificial intelligence system. While it may be feasible to achieve a general understanding and adaptability, capturing the intricate details of every sub-culture may remain elusive.

8.2.5 Resistance to Robot Personalisation

Some users may find the level of personalisation required for culturally aware HRI uncomfortable, interpreting the robot's cultural adaptability as unnatural or contrived.

Despite these potential limitations, the framework's design and ongoing development are driven by a commitment to learn from each interaction, thereby gradually improving its competence in engaging with users across diverse cultural identities.

CHAPTER 9

Future Extension

The framework, as demonstrated, serves as a foundation for further research into cultural aspects of HRI. Its modular design and adaptable nature make it a valuable platform for future studies exploring intercultural communication and its impact on user-robot dynamics.

9.1 Potential Extensions and Applications

The framework has the potential to accommodate interactions beyond national and geographical cultural boundaries, including variations in gender and race cultures.

9.1.1 Gender Culture

The framework could extend its capabilities to incorporate gender culture. Unlike national cultures, where variations are typically geographically bound, gender cultures exhibit differences within the same geographical area and have unique communication styles, decision-making behaviours, and social norms.

For example, the framework could tailor interactions by adjusting the robot's language and gestures based on the user's gender. It could consider variations in language directness, formality, emotional expressions rooted in different gender cultures.

Enhancing the Framework's Functionality

To enhance the framework's functionality, incorporating a gender identity spectrum as part of encoding cultural identity would be beneficial. This integration would facilitate more individualised interactions that consider the user's specific gender identity. For example, for users who identify as non-binary and might not align with traditional gender-based communication styles, robots could adopt a neutral language style and refrain from using gender-coded gestures.

Crucially, the framework must avoid stereotyping or making assumptions based on gender. Instead of treating gender identities as rigid programming rules, knowledge about gender identities should form the basis for respectful interactions. This aspect also needs to be dynamically adjusted and updated based on user interactions, fostering a process of continuous learning.

This mechanism would enable not only the identification and understanding of gender identities but also the nuanced modulations needed for respective interactions. By highlighting continuous learning and adaptability, the framework could cater to a wide range of gender identities and allow for comprehensive, personalised, and respectful interactions in various contexts.

9.1.2 Race Culture

Racial and ethnic cultures often have distinct sets of norms, languages, non-verbal expressions, religious practices, and traditional customs. A truly inclusive HRI framework requires sensitivity to these variations.

The proposed framework can accommodate different racial cultures, similar to nationality. Racial and ethnic cultures have their unique social norms, languages, and non-verbal expressions. The framework's functionality allows robots to adjust their language selection, gestural communication, and hospitality gestures to correspond with specific racial cultures, enabling real-time adaptations to the user's racial-cultural background and enhancing personalisation along with user experiences.

To illustrate, consider the variation in communication styles in different racial or ethnic cultures. In certain Asian cultures, direct eye contact might be viewed as confrontational or disrespectful, particularly when interfacing with individuals of higher status or older age. However, in numerous Western cultures, avoiding eye contact could be seen as an indicator of less confidence or lack of trustworthiness.

Body language and gestures also manifest as highly influenced by race culture. For example, a gesture or body language that may be considered normal or respectful in one culture could be deemed offensive in another.

Enhancing the Framework's Functionality

The proposed HRI framework could learn the user's racial or ethnic background and adjust its communication style, eye contact practices, body language, and gestures accordingly. For instance, with a user from a culture that values high-context communication, the robot could become more reliant on non-verbal cues and less dependent on explicit verbal instruction.

Just as with gender culture, the framework must be cautious to avoid stereotyping or making presumptive judgments based on the user's race or ethnicity. It's noteworthy that not all individuals within a certain cultural group will share the same traits or cultural norms.

The recognition and acknowledgment of mixed-race identities is also significant, considering that these individuals may have unique cultural practices stemming from various racial cultures. Similar to gender culture, race culture knowledge should be used as a basis for respectful interaction rather than rigid rules. Once more, the emphasis is on the framework to continue learning and adjusting based on user interactions' feedback.

CHAPTER 10

Conclusion

In conclusion, this project has developed a culturally aware robotic framework that demonstrates significant potential for enhancing human-robot interaction (HRI) research using nationality identity/national culture as case study. By leveraging the foundational principles of the Robot Operating System (ROS) and extending its capabilities with ROS4HRI, the project created a flexible platform enabling further research in accommodating cultural nuances in robotic behaviour.

The framework's modular design and adaptable nature, made possible by the use of factory pattern, enable it to serve as a valuable testbed for future studies exploring the complex interplay between culture and HRI dynamics. While the framework exhibits promising utility, it is essential to acknowledge its limitations and the ongoing challenges associated with accurately representing and adapting to diverse cultural contexts.

Through ongoing research and interdisciplinary collaboration, this project aims to address these challenges and further refine the framework's capabilities. This will pave the way for culturally aware robots to integrate into various social settings, enriching human experiences and fostering meaningful interactions across cultural divides.

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CHAPTER 11

Appendices

4/8/24, 7:07 AM Human-Robot Interaction: Exploring Proximity Preferences and Cultural Influences

Human-Robot Interaction: Exploring Proximity Preferences and Cultural Influences

Consent Form

Before you begin, please read the following information about your participation and rights.

Introduction: You are invited to participate in a research study conducted by a final year Computer Science Student at the University of Birmingham. Before you decide, it is essential that you understand why the research is being conducted, what will happen during the study, and any potential risks or benefits involved. Please take the time to read the following information carefully. If you have any questions, feel free to ask.

Purpose of the Study: This research aims to investigate human-robot interactions with a focus on proximity preferences and cultural influences in a simulated office setting. Your participation will contribute to our understanding of how individuals from diverse backgrounds perceive and interact with robots.

Procedures: If you agree to participate, you will be asked to: Engage in interactions with a robot in a simulated office environment. Complete surveys before and after the interactions. Provide demographic information, including your country of birth, current country of residence, and any additional countries where you have lived for an extended period.

Risks and Benefits: There are minimal risks associated with participating in this study. Potential benefits include contributing to research that may inform the design of more culturally sensitive human-robot interaction systems.

Confidentiality: Your personal information will be kept confidential. Your data will be anonymized and aggregated, ensuring that individual participants cannot be identified in any published results.

Voluntary Participation: Your participation in this study is entirely voluntary. You may choose to withdraw at any time without penalty or consequence. Your decision to participate or withdraw will not affect your current or future relationship with the researchers or the institutions involved.

Contact Information: If you have questions about the research or your rights as a participant, you can contact Mr Manni Cheung, at m.cheung@bham.ac.uk.

Consent: I have read and understood the information provided in this consent form. I have had the opportunity to ask questions and have received satisfactory answers. I voluntarily agree to participate in this research study.

By clicking "I Agree", you confirm that you understand the above information and agree to participate in the research.

I Agree

localhost:3000/survey1 1/1

Figure 11.1: Sample Consent Form.

Pre-experiment Survey

Country of Birth:

Algeria

Current Country of Residence:

Algeria

Is there a country that you have been living in for more than 3 years (other than the two above)?

Not Applicable

Cultural Background Identification:

- **Country of Birth**
- **Current Country of Residence**
- **Country that you have been living in for a long time**

Submit

Figure 11.2: Sample Pre-Experiment Survey Questions.

4/8/24, 7:07 AM Human-Robot Interaction: Exploring Proximity Preferences and Cultural Influences

Post-experiment Survey

1. Which robot do you like?

- ○ **The First one**
- ○ **The Second one**

2. Please provide more details on why you gave the answer in the previous question.

3. Which Aspects of the Robot's Behaviour Did You Like?

- ☐ **Conversation Language**
- ☐ **Proximity**
- ☐ **Other (Please Specify)**

4. Please provide more details on why you gave the robot the rating you did in the previous question.

5. How would you rate the robot's performance?

- ○ **Excellent**
- ○ **Good**
- ○ **Average**
- ○ **Poor**
- ○ **Very Poor**

6. Please provide more details on why you gave the robot the rating you did in the previous question.

7. Are there specific behaviours or features you would like to see improved or added?

Submit

localhost:3000/survey2 1/1

Figure 11.3: Sample Post-Experiment Survey Questions.