# Culturally Sensitive Social Robotics for Africa

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**Abstract.** Respectful human-robot interaction is informed by local culture. This article describes an on-going project to equip Pepper humanoid social robots with the ability to interact verbally and non-verbally with people in Rwanda and South Africa in a culturally sensitive manner. We describe an exercise to acquire Rwandan cultural knowledge by means of an online survey, targetting spatial, verbal, and non-verbal communication. Each type of knowledge in the survey is structured using a cultural knowledge ontology. We describe the development of a complete system architecture which uses this cultural knowledge to interact with people, illustrating the approach with one specific example in which a Pepper robot gives visitors a short tour of a robotics laboratory. The system is implemented in the Robot Operating System (ROS) by developing a package of ROS nodes that provide functionality for overt attention (based on detection & localization of sounds, people, and faces), speech understanding and production, animate behavior, deictic, iconic, and symbolic gesture, and navigation. The robot mission is coordinated by a ROS behavior controller node that interprets the use case scenario specified by a behavior tree.

**Keywords:** Social robotics · Human-robot interaction · Cultural sensitivity · Pepper humanoid robot · ROS.

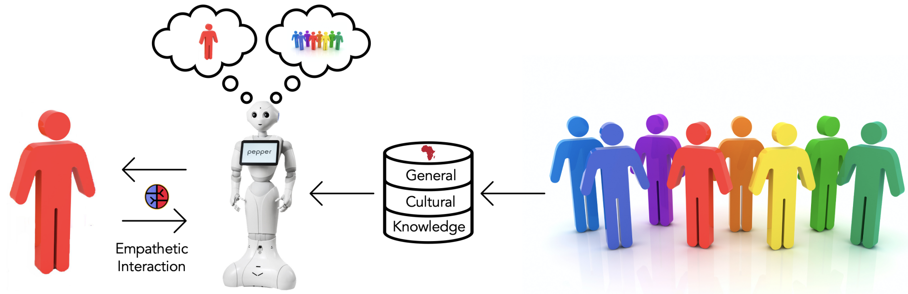


Fig. 1: Based on surveys to acquire cultural knowledge about acceptable modes of communication, the CSSR4Africa project is working to equip Pepper humanoid robots with the ability to interact sensitively and politely with people in Africa using spatial, non-verbal, and verbal modes of communication (graphic inspired by [9]).

## 1 Introduction

A growing body of research underscores the importance of incorporating cultural factors in human-robot interaction (HRI) to enhance user acceptance, trust, and engagement [30,23,27,22,31,20]. In Africa, a continent comprising 54 countries with rich cultural diversity, HRI must also be informed by local cultures [2,28]. The continent's varied cultural landscape encompasses different perceptions of time and space, diverse social norms, and a multitude of languages and non-verbal communication styles. These factors significantly influence how technology, such as social robots, are perceived, trusted, and adopted across different African communities.

Culturally Sensitive Social Robotics for Africa (CSSR4Africa)[4] is a three-year research project, currently at the end of year two, with the goal of equipping social robots with the ability to interact sensitively and politely with people in Africa; see Figure 1. The objectives of the project are (i) to identify the verbal and non-verbal social and cultural norms of human interaction that are prevalent in Africa, (ii) to encapsulate them in the behavior of social robots so that they can engage with African people in a manner that is consistent with their expectations of polite social interaction, and (iii) to demonstrate these culturally-sensitive social robot behaviors in two use cases: giving a tour of a university laboratory and giving directions to visitors at the reception of a university.

While the case for culturally competent robots is widely accepted [9,19], and while there are studies on cultural differences in embracing robots in the West and East, e.g., [18,5,8], similar studies of the cultural factors that impact

[4] www.cssr4africa.org

on acceptance in Africa have not been reported [4].[5] The overall goal of the research described here is to redress this situation.

Given constraints in time, effort, and funding, the scope of the project is restricted to the cultures and social practices that are prevalent in Rwanda and South Africa, the countries where the principal investigators currently reside.

## 2 Cultural Competence vs. Cultural Sensitivity

A culturally competent robot has at least five elements [8], as follows.

1. Cultural knowledge representation.
2. Culturally sensitive planning and action execution.
3. Culturally aware multimodal human-robot interaction.
4. Culture-aware human emotion recognition.
5. Culture identity assessment, habits, and preferences.

This research project focusses on the first three of these, i.e., the generation of *culturally sensitive* robot behavior, i.e., polite, respectful behavior, adhering to the social norms of the culture in which the robot is operating. We do not address the challenge of learning these behaviors from observation, i.e., learning cultural knowledge through interaction. Instead, the approach in the CSSR4Africa project is to catalogue the behaviors based on ethnographic research, create a cultural knowledge base, and use that cultural knowledge during interactions. In graphic terms, we restrict our research to the scenario on the right-hand side of the Pepper robot in Figure 1.

## 3 African Cultural Knowledge

The first task to be completed before a social robot can exhibit cultural sensitivity is to compile a compendium of cultural knowledge regarding actions and behaviors that are either culturally sensitive or insensitive. We accomplished this by means of an online survey using a questionnaire created with the aid of a cultural knowledge ontology.

The cultural knowledge ontology has three parts, corresponding to spatial interaction, verbal interaction, and non-verbal interaction. Each part comprises specific elements of cultural norms and behaviors. For example, spatial interaction includes distance and positioning, while non-verbal interaction includes eye contact, facial expressions, and hand movements. Verbal interaction covers aspects like word choice, voice tone, and conversation turn-taking. The ontology is restricted to the actions that the Pepper robot can perform. It omits forms of non-verbal communication that are important in human-robot interaction, e.g., facial expressions, such as eyebrow and mouth gestures. We adopt a simple

[5] The survey by Lim et al. mentions Egypt, Tunisia, Libya, and Sudan but only to compare perceptions with the Gulf region when interacting with an Arabic robot [21].

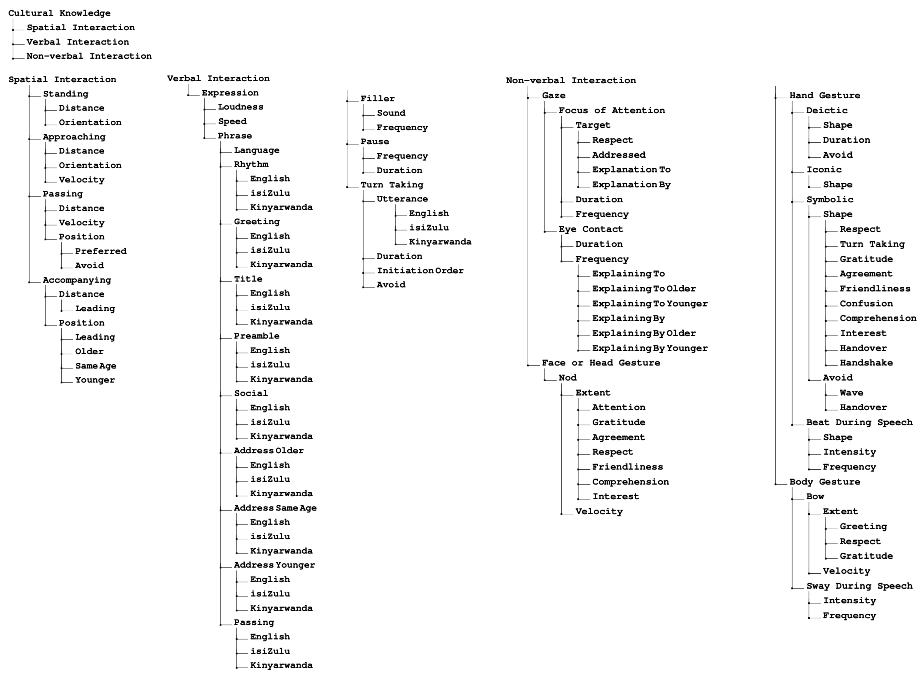


Fig. 2: Cultural knowledge ontology for spatial, verbal, and non-verbal interaction.

approach to defining the cultural ontology, one that represents the ontology as a tree of concepts, as shown in Figure 2. This approach provides us with a straightforward way to specify the parameter values for each element in the ontology: we represent the cultural knowledge with a simple list of key-value pairs, where a key is constructed from the name of a leaf nodes in the ontology tree and the name of its parent. The values, derived from the knowledge elicited in the survey, can be either quantitative numeric values or qualitative symbolic values, which are interpreted to produce culturally sensitive behavior.

The survey questionnaire, in English and Kinyarwanda,[6] comprises three parts: (1) personal information for demographic balance, (2) validation of previously gathered cultural knowledge from a preliminary survey of 23 people from eight African countries [32], and (3) identification of culturally sensitive and disrespectful behaviors, allowing us to confirm and refine our understanding of Rwandan cultural norms within the broader context of African cultural knowledge.

Before launching the survey of the general public in Rwanda, it was piloted at Carnegie Mellon University Africa (CMU-Africa) over a two-month period.

[6] The questionnaire is available online in Kinyarwanda (https://bit.ly/3TJX4K2) and English (https://bit.ly/4aqCVhs).

| Question | Consensus Cultural Knowledge |
|---|---|
| 2-1 | To show respect, one should lower gaze when greeting someone older |
| 2-6 | One should use an open palm of the hand to point to people and objects |
| 2-7 | One should not point an upward facing palm of the hand at someone |
| 2-9 | To show respect, one should bow slightly when greeting someone older |
| 2-12 | One should not use the left hand to hand something to someone |
| 2-14 | To show respect, one should shake hands with the right hand and use the left arm to support the right forearm when doing so |
| 2-16 | To show respect, one should bow slightly and lower gaze when greeting someone older |
| 2-24 | One should not talk loudly to an older person |
| 2-26 | One should not walk between two or more people who are conversing |
| 3-2 | One should say 'Muraho' or 'Hello' when acknowledging someone while passing them |
| 3-3 | One should pass behind a group of two or more people |

Table 1: Consensus answers to a sample of the questions in the cultural knowledge survey.

We collected 108 responses in English and 35 in Kinyarwanda. The pilot also helped improve the questionnaire, particularly in clarifying cultural terminology and adjusting question sequencing.

After conducting the survey, we cleaned and organized the collected responses to identify consensus answers to each question, and then mapped each consensus answer to the cultural ontology keys. Five of the fifty-seven questions in the cultural knowledge survey yielded no consensus — three in Part 2 and two in Part 3 — leaving fifty-two consensus answers to populate the culture knowledge base. This necessitated that the original ontology be extended to ensure each knowledge item, i.e., each consensus answer, has at least one corresponding entry in the ontology tree (some consensus answers gave rise to more than one entry). If several survey answers mapped to a single leaf node in the original ontology tree, the ontology was extended by appending suffixes to the leaf labels, e.g., `symbolicShapeRespect` instead of `symbolicShape`. This results in an ontology tree with at least one leaf node for each consensus answer. The ontology tree also has several leaf nodes for which there is no associated knowledge, either because no consensus answer emerged, or because no survey question addressed that element of the ontology. The extended ontology is shown in Figure 2. A sample of consensus answers to the survey questions is shown in Table 1.

## 4 Culture Knowledge Base

Table 2 lists the knowledge associated with a sample of the keys derived from the ontology tree in Figure 2. The culture knowledge base replaces this knowledge with numeric and symbolic values that are used directly by the robot mission interpreter (see Section 6) and passed as arguments in the ROS service requests

| Key | Cultural Knowledge |
| --- | --- |
| `passingPositionPreferred` | Pass behind a group of two or more people |
| `passingPositionAvoid` | Walk between two or more people who are conversing |
| `expressionLoudness` | Do not talk loudly to an older person |
| `phrasePassingEnglish` | Say 'Hello' to acknowledge someone when passing them |
| `phrasePassingKinyarwanda` | Say 'Muraho' to acknowledge someone when passing them |
| `focusOfAttentionTargetRespect` | Lower your gaze and bow slightly |
| `deicticShape` | Use an open palm to point at people and objects |
| `deicticAvoid` | Do not point an upward-facing palm at someone |
| `symbolicShapeHandShake` | Handshake with the right arm supported by the left hand & bow |
| `symbolicAvoidHandover` | Do not use the left hand without using the right hand |
| `bowExtentGreeting` | Bow slightly when greeting someone older. |
| `bowExtentRespect` | Bow slightly |

Table 2: Key-knowledge pairs for specifying culturally sensitive actions using the extended ontology, i.e., using the ontology depicted in Figure 2.

it issues to the nodes in the system architecture to achieve culturally sensitive behavior.

The robot may also need to say other things were not captured in the cultural knowledge survey to prompt the user, reply to the user, or just ensure flow in the dialogue. We include them in the cultural knowledge base as a set of utility verbal interaction phrases, rather than embed them in the robot mission interpreter software.

## 5 Use Case Scenario Specification

The complete system is being validated in two use cases scenarios, a lab tour guide and receptionist. Detailed walk-throughs of both scenarios, including a decomposition into a time sequence of elementary robot actions, can be found in [29]. Algorithm 1 is a brief outline of the lab tour use case in the form of a pseudo-code algorithm. The location and descriptions of each stop on the tour, and the order in which they are to be visited, is provided in an environment knowledge base. The map of the environment is provided separately as an input to the Gesture, Speech, and Navigation subsystem described in the next section. Note that failure handling is omitted from the pseudo-code encapsulation in Algorithm 1.

**Algorithm 1** Robot behavior for the lab tour use case

```
Ensure: The CSSR4Africa ROS system has been launched.
Ensure: The Pepper robot stands at the greeting location in the robotics laboratory.
  repeat
      repeat
          Make natural movements
          Attention ← social mode, detecting faces
          if a face is detected then
              Look at the visitor and adjust pose
          end if
      until face detected
      Make an iconic gesture for welcome
      Say "Hello! Welcome to the Robotics Lab!"
      repeat
          Attention ← seek mode, detecting mutual gaze
      until Mutual gaze established
      repeat
          Say "Would you like a tour of the lab?"
          Listen to the visitor and wait for a response
          if the response is not "Yes" or "No" then
              Say "I only understand yes or no"
          end if
      until the visitor says "Yes" or "No" or the robot has prompted three times
      if the visitor says "No" or does not respond then
          Say "Maybe another time"
      else
          repeat              ▷ The robot starts the tour and visits each exhibit in turn
              Query environment knowledge base for location, description,
              and keys of cultural knowledge to be used at that location
              Say "Please follow me"
              Navigate to location
              repeat
                  Attention ← social mode, detecting faces
                  if a face is detected then
                      Look at the visitor and adjust pose
                  end if
              until face detected
              Say "This is <lab equipment to be described>"
              Make deictic gesture toward the object
              Look at the object
              Look at the visitor
              Say "<description of lab equipment>"
          until All locations have been visited   ▷ The last location is where the robot
      end if                                      ▷ ends the tour and thanks the visitor
  until The application is terminated
```

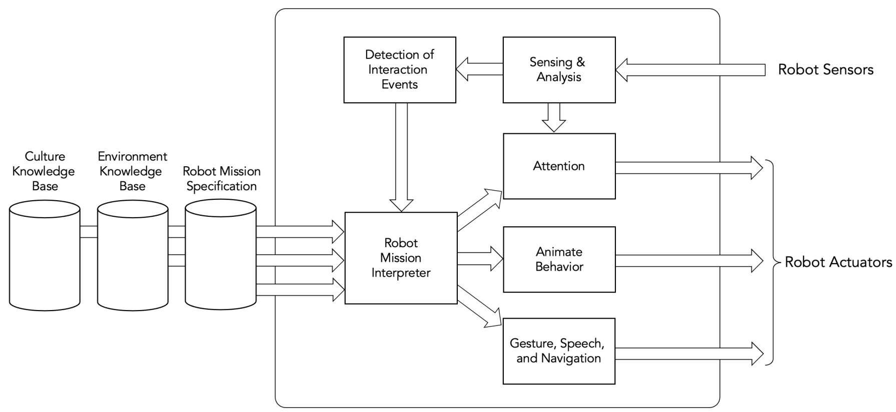


Fig. 3: High-level system architecture comprising six subsystems and three external data sources; see text for details.

## 6 System Architecture

The system architecture is specified at two levels of abstraction: a high-level architecture, identifying major subsystems and data sources, and an implementation-level architecture, comprising a suite of interconnected ROS nodes. The high-level architecture is shown in Figure 3. It comprises six subsystems and three external data sources. Two of the six subsystems are concerned with sensing (Sensing & Analysis and Detection of Interaction Events), three with actuation Attention, Animate Behavior, and Gesture, Speech, and Navigation), and one with control (Robot Mission Interpreter). The three external data sources are the Culture Knowledge Base, the Environment Knowledge Base, and the Robot Mission Specification.

The implementation-level system architecture, realizing the six subsystems in the high-level architecture, are implemented in ROS Noetic on Ubuntu 20.04, each subsystem comprising one or more ROS nodes, as shown in Table 3. We describe the ROS node implementation of each subsystem in the sections that follow.

### 6.1 The Sensing & Analysis Subsystem

This subsystem comprises four ROS nodes: `robotLocalization`, `personDetection`, `faceDetection`, and `soundDetection`.

The `robotLocalization` node estimates the pose of the Pepper robot in a Cartesian world frame of reference. The module achieves this through a combination of relative and absolute position estimation techniques, including odometry, IMU data, and triangulation using visually detected ArUco marker visual landmarks.

| Subsystem | ROS Nodes |
|---|---|
| Sensing & Analysis | robotLocalization, personDetection, faceDetection, soundDetection |
| Detection of Interaction Events | speechEvent, tabletEvent |
| Attention | overtAttention |
| Animate Behavior | animateBehavior |
| Gesture, Speech, and Navigation | gestureExecution, robotNavigation, textToSpeech |
| Robot Mission Interpreter | behaviorController |

Table 3: ROS nodes comprising each subsystem in the high-level system architecture; see Figure 4 for the implementation-level system architecture specified as a network on interconnected ROS nodes.

The personDetection node detects and localizes people in the camera's field of view, while the faceDetection node detects and localizes human faces and determines whether mutual gaze is established between the Pepper robot and the human user through head pose estimation.

The soundDetection node detects and localizes conspicuous sounds within a robot's hearing range. It provides two outputs: the direction of arrival of the sound, and a filtered audio signal, thereby enabling the robot to focus its attention on sound sources. It interfaces with the speechEvent node in the Detection of Interaction Events subsystem, facilitating automatic speech recognition in both Kinyarwanda and English, and with the overtAttention node in the Attention subsystem.

### 6.2 The Detection of Interaction Events Subsystem

This subsystem comprises two ROS nodes: speechEvent and tabletEvent.

The speechEvent node deploys a speech-to-text model using deep neural networks that enables speech utterances in Kinyarwanda and English languages captured by Pepper's microphones to be transcribed into written text.

The tabletEvent node provides an alternative way of interacting with the user, allowing the use to respond to spoken prompts by tapping a graphic user interface instead of using automatic speech recognition provided by the speechEvent node.

### 6.3 The Attention Subsystem

This subsystem comprises just one ROS node, overtAttention, that enables the robot to dynamically direct its attention towards salient features in its environment, primarily during social interactions, and to scan its surroundings when not actively engaged. Based on input from the faceDetection and soundDetection nodes, as well as an internally-generated saliency map, it directs the robot's gaze

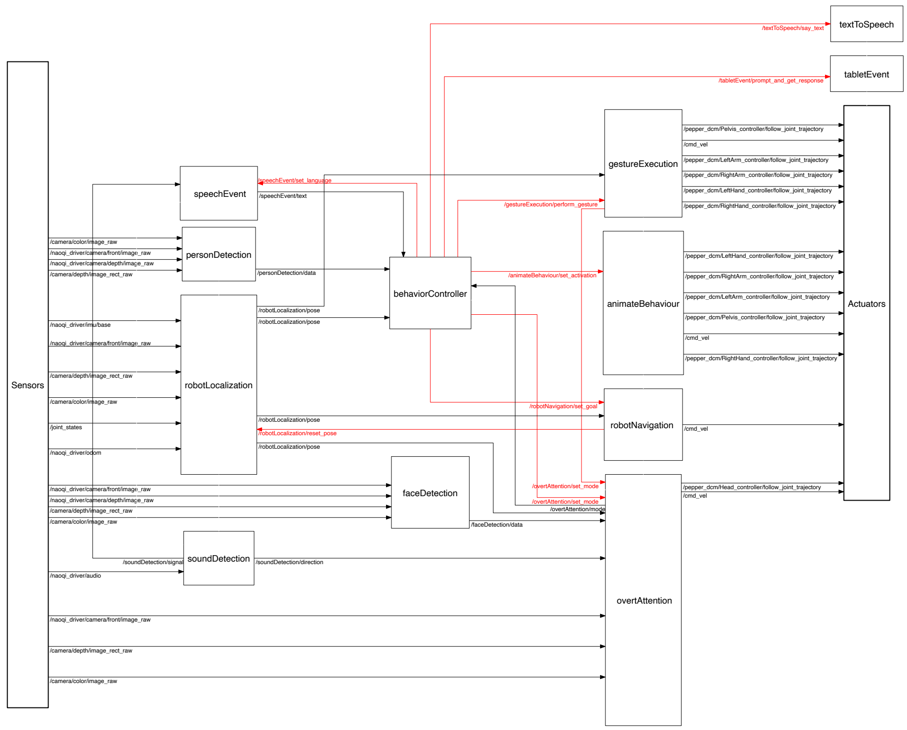


Fig. 4: Detailed system architecture comprising 12 ROS nodes. Black connectors depict published ROS topics; red connectors depict ROS service requests.

by controlling the head azimuth and elevation angles, and the robot pose to re-centre the head after changing the head gaze. It operates in different modes, paying attention to features of general interest, to human faces in general, or to human faces exhibiting mutual gaze, i.e., the situation where the robot and the human are looking at each other. It also allows the gaze to be directed to a specific location in the robot's environment.

### 6.4 The Animate Behavior Subsystem

This subsystem also comprises just one ROS node, `animateBehavior`, which enhances the robot's lifelike appearance by generating subtle body movements to flex the robot's hands and slightly rotate its base around the vertical axis. Head movements are handled by the Attention subsystem.

### 6.5 The Gesture, Speech, and Navigation Subsystem

This subsystem comprises three ROS nodes: `gestureExecution`, `robotNavigation`, `textToSpeech`.

The gestureExecution node enables the Pepper robot to perform a range of hand and body gestures: deictic, symbolic, and iconic hand gestures, and bowing and nodding body movements. Hand gestures are executed so that they exhibit biological motion, since this has been shown to enhance people's engagement when interacting with the robot [1]. The node interfaces with the robot localization system, so that deictic gestures accurately indicate the location of points of interest in the robot's environment. Additionally, it interfaces with the Attention subsystem to direct the head to the same location to which the robot is making a deictic gesture.

The robotNavigation node enables the Pepper robot to traverse its environment autonomously. It employs different path planning algorithms, including Breadth-First Search (BFS), Dijkstra, and A*. Navigation is executed by identifying waypoints along the planned path and controlling the robot to locomote from waypoint to waypoint. A key feature of this node is the capacity to incorporate culturally sensitive proxemics, derived from the Rwandan culture knowledge base. This functionality ensures that the robot maintains appropriate social distances when navigating around humans, enhancing its adaptability and acceptance in human-centered environments. It interfaces with the robotLocalization node to ensure the navigation path is registered with the robot's environment, continuously updating its pose with real-time data.

The textToSpeech node provides the functionality for converting English and Kinyarwanda text to speech.

### 6.6 The Robot Mission Interpreter Subsystem

The behaviorController node is a central component in the CSSR4Africa system architecture. It interprets and executes the robot mission, specified using behavior trees [14,13,15,16], and queries the culture knowledge base and environment knowledge base, as required. It interfaces directly with ten ROS nodes: animateBehavior, faceDetection, gestureExecution, overtAttention, robotLocalization, robotNavigation, speechEvent, tabletEvent, and textToSpeech.

### 6.7 Programming by Demonstration

A stand-alone ROS application has also been developed to provide the robot with the ability to learn gestures through manual teleoperation or human demonstration, employing RGB-D camera technology to map human skeletal movements onto the robot's joint system, i.e., programming by demonstration [7,12], also known as learning from demonstration [3].

In addition there are a suite of unit tests to verify that sensor data is successfully acquired on each sensor topic, and to verify the accurate and reliable functioning of the robot actuators: head, arms, hands, legs, and wheels.

## 7 Use Case Scenario Implementation

We have adopted behavior trees as our methodology for specifying the robot mission, e.g., the lab tour use case scenario. A behavior tree consists of nodes arranged in hierarchical tree structure with key components including a root node, control flow nodes (sequence, selector, and decorator), conditional nodes, and action nodes [15]. The root node is the starting point of the behavior tree. The execution begins here and traverses depth-first through the tree. The control flow nodes determine the flow of execution. Sequences execute child nodes from left to right, returning success only if all children succeed. They are used for "do all tasks in order" behaviors. Selectors (also known as fallbacks) execute child nodes from left to right, returning success when one child succeeds. They are used for "try until success" behaviors. Decorators modify the behavior of their child nodes (e.g., repeat, invert, and limit execution).

Leaf nodes are the actionable and evaluative endpoints of the tree and can be action nodes which perform specific tasks (e.g., move to a location or pick up an object) or condition nodes that check certain conditions or states (e.g., battery level or obstacle detection).

The behavior tree for the lab tour use case was designed with Groot2, an IDE for the BehaviorTree.CPP library [14,13] allowing interactive creation and editing of behavior trees. It produces an XML specification of the behavior tree that is read and executed by the BehaviorTree.CPP library, linked from the `behaviorController` ROS node. Each behavior tree action node interfaces with one of the ten ROS nodes mentioned in the previous section, either subscribing to ROS topics or calling ROS services.

## 8 Discussion

As noted above, we have adopted a simple approach to specifying the cultural knowledge ontology. There are superior approaches, e.g., the OWL-2 language used by Bruno et al. [10]. Similarly, there are also more powerful ways to construct a culture knowledge base than the ontology-based key-value approach we have adopted, e.g., using first-order logic to represent the culture facts and the rules that define how this knowledge can be used, e.g., as the CRAM cognitive architecture does [6]. However, we defer exploring these more sophisticated approaches until the first proof-of-principle CSSR4Africa system has been fully tested.

When planning the work described in this paper, we assumed that a ROS package existed which would provide all the software required to access the Pepper sensors and control the Pepper actuators. This assumption proved to be invalid. Most developers use Choreograph, the visual programming interface provided with the robot. This necessitated the development of a complete suite of ROS modules to provide the requisite functionality. These are now encapsulated in the `pepper_interface_tests` ROS package and used in the `cssr_africa` ROS package, both of which are freely available on the CSSR4Africa software respository on GitHub [26]. We also assumed that the quality of the data produced by the sensors on the Pepper robot would be sufficient for our needs. This also turned out not to be valid, requiring the installation of a RealSense camera [17] on the head of the robot, and a Lidar laser rangefinder near the base of the robot to provide reliable sensor data.

As is evident from the ROS system architecture depicted in Figure 4, the CSSR4Africa system is complex,[7] involving twelve concurrently operating ROS nodes, and many topics and services, all communicating in real time. Dealing effectively with this complexity required the adoption of software engineering standards, and rigorous adherence to them in the design, development, implementation, testing, and documentation of each ROS node, and the adoption of a strict process of quality assurance when submitting CSSR4Africa software for integration. The practice, which was pivotal to the success of the system engineering aspect of the endeavour, is supported by several resources, including a reference manual of software engineering standards, a comprehensive installation manual providing step-by-step instructions for setting up the development environment and controlling the Pepper robot in both physical and simulated environments, the procedures used in CSSR4Africa to validate and test software prior to integration into the CSSR4Africa software repository. All of these resources are available on the CSSR4Africa website [11].

## 9 Conclusion

We stated at the outset that the overall goal of the project is to redress the lack of focus on African cultures when developing social robots with cultural sensitivity and cultural competence. The work done to date lays a solid foundation for the achievement of this goal. As noted above, the pilot survey yielded 108 responses in English and 35 in Kinyarwanda. While this is certainly useful, a more extensive survey of the general population is needed before we can claim that the cultural knowledge base is comprehensive and representative. The survey also needs to be conducted in South Africa with isiZulu speakers. In the meantime, our objective is to promote awareness of the work through the African Engineering and Technology Network (Afretec) [25], a pan-Africa alliance of eight technology-focussed universities, by dissemination to a broader audience through the CSSR4Africa website [11], and by making the software outlined in this paper openly available on the CSSR4Africa software repository [26].

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**Disclosure of Interests.** The authors have no competing interests to declare that are relevant to the content of this article.

[7] We use the term "complex" in the loose sense of a system with many parts and interconnections, rather than the alternative sense of a system that is self-organizing and emergent [24].

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