Culturally Sensitive Human-Robot Interaction: A Case Study with the Pepper Humanoid Robot

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***Abstract*—Socio-cultural factors play a significant role in achieving the trust and acceptance required to realize the potential of artifiical intelligence and robotics. Consequently, culturally sensitive human-robot interaction is essential for the adoption of social robots in Africa. Three elements must be present to achieve this: cultural knowledge representation, culturally sensitive planning and action execution, and culturally aware multimodal human-robot interaction. This paper presents a system architecture for culturally sensitive human-robot interaction in Africa that addresses these three elements, an initial set of software interaction primitives, and a practical demonstration of culturally sensitive human-robot interaction using the Pepper humanoid robot.**

***Index Terms*—social robotics, human-robot interaction, culture sensitivity, innovation, trust, adoption.**

I. Introduction

Africa needs technological innovation in artificial intelligence (AI) and robotics to drive its socio-economic development [1]–[3]. Humans will increasingly interact with artificial intelligence technologies. Social robots are one such technology that is essential to solving some of the continent's critical challenges. To be trusted and adopted, technological inventions must be sensitive to socio-cultural norms [4]–[9]. The same is true for social robots if they are to be effective. Humans use spatial, non-verbal, and verbal communication when interacting with others. Socio-cultural norms affect the nature of the robot's nonverbal and verbal expression, as well as its appearance and spatial behavior. Consequently, they determine the acceptance of social robots and the effectiveness of their interaction. While there are studies on cultural differences in the acceptance of robots in the Global North, similar studies on cultural factors affecting acceptance in the Global South have not been reported [9], [10].

The objectives of this paper are threefold: (i) to identify the verbal and non-verbal social and cultural norms of human interaction that are prevalent in different countries in Africa, (ii) to show how they can be encapsulated in the behavioral patterns of social robots so that they can engage with African people in a manner that is consistent with their expectations of acceptable social interaction, and (iii) to demonstrate these culturally-sensitive social robot behaviors in a university laboratory tour.

The outcome of this work is a set of software interaction primitives, a system architecture comprising the components required for culturally sensitive human-robot interaction in Africa, and a ROS-based[1] reusable and reconfigurable application that generates a small extendible set of culturally sensitive behaviors.

II. The Need for Culturally-Sensitive Human-Robot Interaction

The current wave of technological advancement, often referred to as the Fourth Industrial Revolution or Fourth Machine Age, is being driven by artificial intelligence (AI) and robotics globally [11]. Social robots, like AI technologies, have the potential to change the way we live. People will interact more with social robots in their everyday life. For instance, the recent COVID-19 pandemic demonstrated the potential of robots in the health sector, with Rwanda successfully deploying them in hospitals and at the airport to contain the spread of the disease [12].

Human-Robot Interaction (HRI) is a subfield of social robotics that focuses on the interactions between humans and robots in society [13]. Social robots are needed in hospitals for diagnoses, medical checkups, in schools to assist teachers and help students learn, especially in countries where the students-teacher ratio is very high [14]. Social robots are also needed in open spaces such as malls and museums to guide people or entertain them. However, for such interactions to be effective, people must trust robots, and this trust depends on the social infrastructure [15]. Social infrastructure encompasses the social and cultural norms and conventions, beliefs, perceptions that dictate how people behave, and the practices they consider appropriate or inappropriate [9]. Therefore, understanding and incorporating cultural sensitivity into human-robot interaction is critical for fostering trust and promoting the adoption of social robots in diverse cultural settings.

Many definitions of culture have been reported in the literature but we choose the one from Lee and See [16] that emphasizes expectation. They define culture as "a set of social norms and expectations that reflect shared educational and life experiences associated with national differences or distinct

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[1]ROS stands for Robot Operating System

cohorts of workers" [16]. Meeting expectations can lead to humans trusting one another. Similarly, social robots must meet socio-cultural expectations to be accepted as fully social beings and to be trusted.

In human-human interactions, people use verbal, nonverbal, and spatial cues to communicate. These cues follow certain norms and conventions. Effective human-robot interaction should also use the same cues. Therefore, to be effective, social robots should understand human interaction cues, and exhibit behaviors that reflect the socio-cultural norms of their human counterparts. This is not easy because humans do not express themselves explicitly most of the time. Social robots should also anticipate human expectations while interacting with them [9], [16]. A robot able to understand humans expectations, recognize emotions and behave accordingly and independently are culturally competent social robots. Human-robot interaction must reflect the social robots' cultural competency for them to be trusted and accepted by humans. Bruno et al. [6]–[8], [17] state that a culturally competent social robot should have five elements, as follows.

A culturally competent human-robot interaction requires five elements:

1) *Cultural knowledge representation*: this refers to the ability to store cultural knowledge and to reason about it.
2) *Culturally sensitive planning and action execution*: this refers to creating and adapting plans based on the cultural identity of the interaction partner.
3) *Culturally aware multimodal human-robot interaction*: this refers to the ability to adapt the way of interacting (in terms of gestures, choice of phrases, tone and volume of voice, etc.) to the user's cultural identity.
4) *Culture-aware human emotion recognition*: this refers to the robot's ability to detect and interpret their interaction partner emotional state using their sensors.
5) *Culture identity assessment, habits, and preferences*: this refers to the robot's capability to adapt to cultural knowledge and get new knowledge.

In addition, a culturally competent social robot should ideally be able to recognize intentions and have some capacity for forming a theory of mind [9].

Complete cultural competency is beyond the scope of this paper. We address instead culturally sensitive human-robot interaction, which includes the first three elements of cultural competence: (i) *cultural knowledge representation*, (ii) *culturally sensitive planning and action execution*, and (iii) *culturally aware multimodal human-robot interaction*. Thus, culturally sensitive human-robot interaction is concerned with the different ways in which robots behave with people based on cultural knowledge that reflects the cultural identity of the society to which they belong. Culture-specific knowledge, can be encapsulated in a parameterized software or knowledge ontology for use in a knowledge representation and reasoning system when selecting culturally dependent human behavior [17]. This knowledge can reflect general traits of a given culture or it can be derived by learning from the behavior of people with whom the robot interacts. In this work, we use the former approach. Fig. 1 illustrates the concept of a culturally sensitive robot, inspired by the work of Bruno et al. [7], [17].

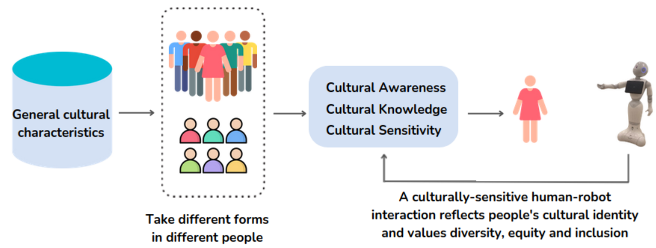

Fig. 1. Key elements of a culturally-sensitive robot.

In summary, human-robot interaction must be culturally sensitive if robots are to be viewed by humans as full social agents and have effective interactions.

III. Culturally-Sensitive Human-Robot Interaction for Africa

Africa, like most countries in the world, needs robotics to support various industries and sectors, such as healthcare, education, and agriculture, through social robots and human-robot interactions [14], [18]. However, as noted above, for human-robot interaction to be effective in Africa, it must be culturally sensitive. Human-robot interaction is typically based on sociocultural preferences of the Global North; the preferences in the Global South are not necessarily the same. We need to identify what they are and then develop HRI patterns of behaviours reflecting verbal, nonverbal and spatial cues based on Africa's socio-cultural context. These cues mainly include proxemics, localization and navigation, socially appropriate positioning, initiation of interaction, communication of intent, gaze, eye movement, deictic, iconic, symbolic, and beat gesture, mimicry and imitation, touch, posture and movement, and interaction rhythm and timing. Social robots should be programmed to be sensitive to these social cues for effective human-robot interaction.

Africa is a diverse continent with approximately 1500 to 2000 officially recognized languages spoken by the 3000 ethnic groups [19]. The diversity is also regional, and in most cases there are different cultures, social norms, religious beliefs and languages within a given country. This makes it challenging to find the factors that might influence the acceptance of social robots in Africa without in-depth ethnographic research. While recognizing that such ethnographic research is essential to find the cultural factors,[2] we conducted a preliminary survey of twenty-three people, including sixteen men and seven women aged between twenty and twenty-five years old from eight countries in Africa, to create a sample of

[2]A detailed ethnographic study is planned for the next phase of the project. While the ultimate goal of this research is to achieve cultural sensitivity in countries at all stages of development, we will restrict our focus initially to Rwanda and South Africa.

twenty-five socio-cultural norms or traits relevant for human-robot interaction in Africa [9]. The eight countries in the survey are Benin, Burundi, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, and The Gambia. Table I presents a sample of this African cultural knowledge.

TABLE I
A SAMPLE OF AFRICAN CULTURAL KNOWLEDGE [9].

No.	Socio-cultural Norm or Trait
1	All interactions should begin with a courteous greeting.
5	To show respect, one should bow slightly and lower gaze when greeting someone older.
8	One should use an open palm of the hand to point to people and objects.
10	One should not use the left hand to point to anything.
19	One should not make persistent eye contact with an older person.
21	To show respect, one should shake hands with the right hand and use the left arm to support the right forearm when doing so.
23	One should not walk between two or more people who are conversing; it is considered rude to do so.
25	Behaviours should focus on fostering social connections and relationships; they should not be purely functional.

IV. INTERACTION SOFTWARE PRIMITIVES FOR HUMAN-ROBOT INTERACTION IN AFRICA: A CASE STUDY WITH THE PEPPER HUMANOID ROBOT

In Section III, we outlined culture-specific behavioral requirements necessary for effective and culturally sensitive human-robot interaction in an African sociocultural context. To ensure that social robots are capable of predictable, effective, and engaging interactions that align with African sociocultural norms, we need to embed them in reconfigurable and reusable interaction primitives that can be used when developing social robot behaviors for interaction in Africa. To implement the interaction primitives, we have anchored culturally sensitive behaviors in a specific interaction scenario (a tour of a university laboratory) that describes an interaction between a guest and Pepper, a humanoid social robot, the necessary robot capabilities or skills, and the instances of cultural sensitivity, derived from the culture-specific knowledge in Table I. This scenario is summarized in Table II.

One of the goals of this work is to create adaptable and reusable software primitives that can be utilized to design reliable, effective, and engaging behaviors for human-robot interaction in Africa. Drawing on the scenario outlined in Table II, we have identified several software interaction primitives and their corresponding parameters. Each software primitive is a function that has a distinct set of parameters, e.g., bow(angle, velocity, elevation). The software interaction primitives are divided into four categories: iconic gestures, deictic gestures, gaze, posture. These primitives are summarized in Table III, but it is important to note that the list can be extended as needed, based on the specific requirements of the scenario. For example, we

[3] The format of the university laboratory tour scenario follows the style of the scenarios in [6].

TABLE II
UNIVERSITY LABORATORY TOUR SCENARIO [3]

Description: A guest visits the CMU-Africa campus. She stopped by the CMU-Africa robotics lab. The social robot Pepper gives a tour of the lab. Initial lab setting: The humanoid robot Pepper is in the lab. The only other occupant of the lab is a lecturer.		
Scenario	Robot skills	Culture-sensitivity
The guest enters the robotics lab Guest: Hello! My name is Hilary. Can you please tell me what you do here?	Moving (head, arms, torso, hip)	[Culture-generic]: Pepper knows that you should initiate a greeting and welcome a guest.
Professor Busogi welcomes the guest and introduces what students study and work on in the lab. He kindly asks the guest to come up to the robot as he introduces the Human-Robot Interaction (HRI) research project that is going on in the lab		[Culture-specific]: Pepper knows that in Africa you should initiate a polite greeting by bowing your head and chest. [Culture-generic]: Pepper knows that you should extend your hands to greet and welcome the guest and make eye contact when greeting someone.
Mrs Hilary nodded to agree Mrs Hilary: Sure Professor! *Mrs. Hilary is now 2.5m away from Pepper.* *Pepper moves half a meter towards Mrs Hilary. Pepper initiates a courteous greeting by slightly bowing his/her/its torso and head. Pepper lowers gaze while greeting Mrs Hilary.* *Mrs Hilary greets Pepper back by extending her hands for a handshake.*		[Culture-specific]: Pepper knows that in Africa you extend your right hand, not your left, to greet people. Pepper also knows that bowing your head and lowering your eyes a little is a sign of respect, especially if you are the younger interaction partner. Lack of eye contact is disrespectful because it shows divided attention during the interaction. Also, maintaining eye contact with an older person is considered rude. It is better to look down. Finally, the younger interaction partner should not initiate a handshake because it is considered rude.
Pepper extends the right hand and uses the left arm to support the right forearm. Pepper keeps an intermittent eye contact. Pepper alternates between looking at Mrs Hilary's neck and down. Pepper removes his hands from Mrs. Hilary's as she initiates the stopping handshake. Pepper slightly bows his/her/its head and body and makes a welcoming gesture with both arms. Then Pepper reorients and uses an open palm to point Professor Busogi as a sign of handing over.		[Culture-generic]: Pepper knows that adopting the right posture and gesture is essential in a social interaction. [Culture-specific]: Pepper knows that in most African cultures, it is considered rude to point your finger at someone. You should open your palm instead. [Culture-generic]: Pepper knows that it is important to maintain an appropriate social distance when interacting with people in the lab.

plan on implementing primitives for proxemics and spatial positioning, such as approach_human(pose_relative_to_human) and maintain_distance(pose_relative_to_human).

TABLE III
INTERACTION SOFTWARE PRIMITIVES

Type of Interaction	Software Primitives	Description of Cultural Parameters
Deictic gestures	`show_head_gaze_eye_contact(robot_joint, angular_velocitie, waypoints)` `show_head_gaze_joint_attention(robot_joint, angular_velocitie, waypoints))`	*joint*: Array of robots joints names. The robot joints are actuated for it to describe a motion. e.g. LShoulderPitch, LShoulderRoll, HeadPitch, HeadYaw.
Symbolic gestures	`welcome(robot_joints, angular_velocities, waypoints)` `greeting_arm_extension(robot_joints, angulart_velocities, waypoints)`	*angular_velocities*: array of angular_velocities (in rad/s) for each joint specified in the *robot_joints* parameter.
Gaze	`show_head_gaze_eye_contact(robot_joint, angular_velocities, waypoints)` `show_head_gaze_joint_attention(robot_joint, angular_velocities, waypoints)`	*waypoints*: 2D array specifying a sequence of joint values (in rad) for each of the joints specified in the *robot_joints* parameter.
Posture	`bow(robot_joints, angular_velocities, waypoints)`	

V. SYSTEM ARCHITECTURE

A system architecture for a culturally-sensitive human-robot interaction is presented in Fig. 2. It has two main subsystems and two external knowledge bases. The two subsystems are the *Robot Sensing & Interpretation subsystem* and the *Robot Behaviors* subsystem.

The *Robot Sensing & Interpretation* subsystem comprises two components:

1) Sensing & Analysis.
2) Detection & Classification of Events.

The Sensing & Analysis component is responsible for the detection and localization of people, faces, eyes, gaze direction, hands, sounds, and the robot itself (to allow the robot to navigate its environment).

The Detection & Classification of Events component is responsible for detecting and classifying events in the robots environment, including speech, gestures, approach, engagement, and retreat events on the part of the interaction partner, and mutual gaze.

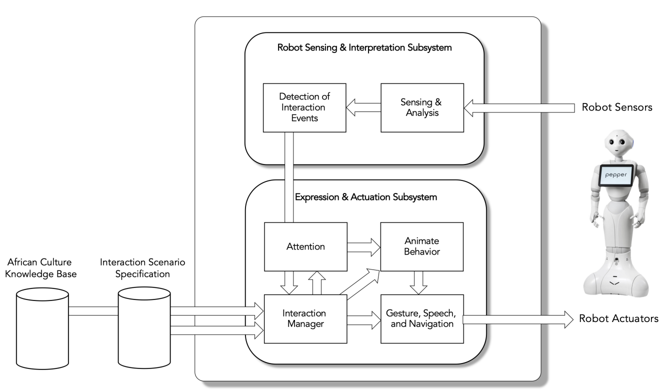

Fig. 2. System architecture of the different elements for culturally-sensitive human-robot interaction.

The Robot Behaviors subsystem comprises four components:

1) Reactive Behavior
2) Attention
3) Interaction Manager
4) Expression & Actuation

The Reactive component is responsible for producing minor movements that give the impression that the robot is active and paying attention, such as subtle body sway, hand flex, slight turns to the left or right, attention inhibition of return so that the robot fixates on different objects, and attention habituation, so that the robot does not fixate on a single object for too long.

The Attention component is responsible the generation of a gaze scan path based on a salience function predicated on socially relevant features, such as faces, eyes, mouths, and hands.

The Interaction Manager component is responsible for interpreting the scenario script and generating culturally-sensitive interaction behaviors on the basis of the African culture ontology and knowledge base.

The Expression & Actuation component is responsible for executing the gaze scan path, hand gestures, body gestures, converting text to speech, and navigating the robot to relevant positions and orientations (poses).

The two external knowledge bases are the *African Culture Knowledge Base* that stored information of the kind shown in Table I and the Interaction Scenario Specification. This knowledge base describes a social interaction between the Pepper humanoid robot and a human or group of human interaction partners. The *Interaction Manager* component uses this scenario and translates it into the requisite culturally-sensitive robot behaviors using the *African Culture Knowledge Base*.

VI. CASE-STUDY: A CULTURALLY-SENSITIVE UNIVERSITY LABORATORY TOUR OF THE PEPPER HUMANOID ROBOT

The system architecture and the constituent components that are required for a culturally-sensitive human-robot interaction have been implemented for a culturally-sensitive laboratory tour with the Pepper humanoid robot.

Pepper is a social robot designed by Aldebaran Robotics in 2014 and later acquired by SoftBank Robotics in 2015 and the United Robotics Group in 2022. While the system is still under development, three culturally-sensitive behaviors have been generated and tested on Pepper: welcoming, greeting and exhibiting hand gestures to show something. Figure 3 summarizes the demonstrations carried out. All the generated behaviors are based on the scenario in Table II and reflect cultural sensitivity in Africa. Fig. 3 (a) shows a greeting gesture. Pepper opens the palms of both hands with a slight tilt of the head to show respect. In Fig. 3 (b), Pepper extends his right hand, moves his left arm back as a sign of formalism, and bows his torso and head slightly to show respect. In Fig. 3 (c) and Fig. 3 (d) Pepper exhibits a hand gesture showing the robot arm. This behavior has two levels. First, Pepper makes eye contact to invite the interaction partner to attend what Pepper is showing (see Fig. 3 (c)), and, second, Pepper and the guest engage in joint attention in (see Fig. 3 (d)) to show a shared interest in what Pepper is showing.

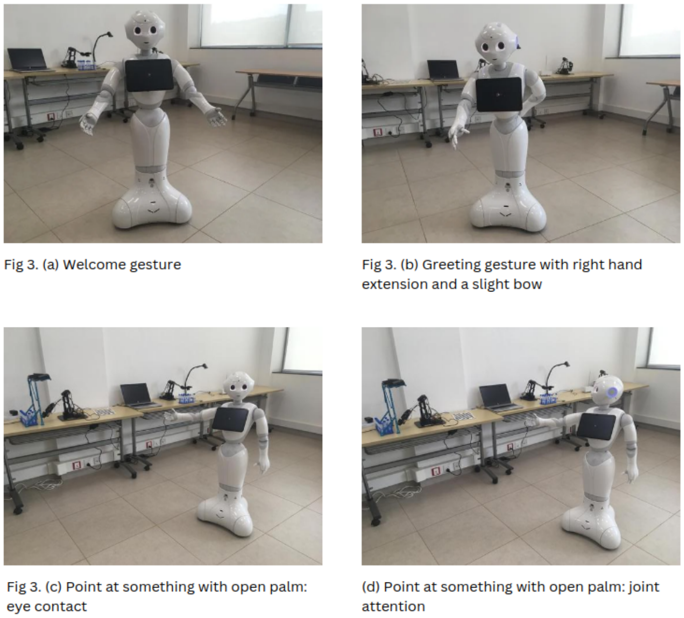

Fig 3. (a) Welcome gesture

Fig 3. (b) Greeting gesture with right hand extension and a slight bow

Fig 3. (c) Point at something with open palm: eye contact

(d) Point at something with open palm: joint attention

Fig. 3. The Pepper humanoid robot exhibiting culturally-sensitive gestures.

VII. Evaluation

To assess the cultural sensitivity of the gestures in Figure 3, we have created an evaluation questionnaire based on the Robotic Social Attributes Scale (RoSAS). RoSAS is a scale-based metric to measure how humans perceive robots [20].

RoSAS is inspired from the GodSpeed [21] questionnaire and rates the attributes of social perception of robots on eighteen attributes, e.g, awkward, interactive, social, strange, and competent, on a seven-point Likert scale. Out of the eighteen attributes included in the RoSAS scale, we only considered five as indicators of cultural sensitivity, namely *Compassionate*, *Interactive*, *Social*, *Competent*, and *Reliable*.

TABLE IV
RoSAS survey results

Items \ Scores	1	2	3	4	5	6	7	Num Replies
Compassionate	0	2	1	2	2	1	3	11
Interactive	0	2	2	3	0	1	2	10
Social	1	0	1	0	4	2	2	10
Competent	0	1	1	3	2	1	2	10
Reliable	0	0	2	2	4	0	2	10
Total Score	1	5	7	10	12	5	11	51

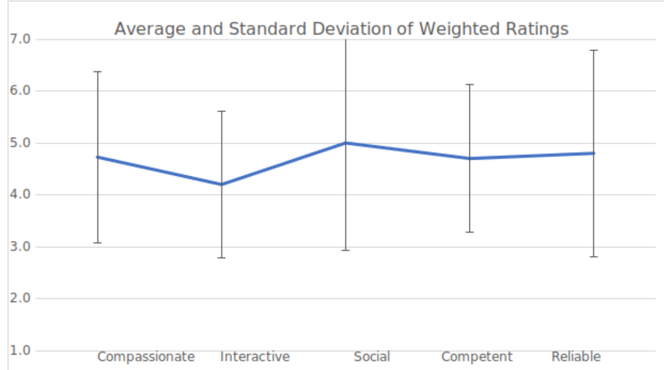

Fig. 4. Average and standard deviation of weighted ratings.

Thirty-five people participated in the survey; see Table IV for the results. To interpret these results, we computed the weighted average rating of the RoSAS scores; see Equation 1.

$$\bar{x} = \frac{\sum_{i=1}^{7} w_i x_i}{\sum_{i=1}^{7} w_i} \tag{1}$$

$\bar{x}$ is the weighted average rating, the weights w_i are the rating values, and x_i are the RoSAS scale scores. Figure 4 shows the average and standard deviation of these weighted average ratings for the five attributes *Compassionate*, *Interactive*, *Social*, *Competent*, and *Reliable*. All the attributes have a weighted average rating greater than the mid-scale score of 4. Most of the participants found Pepper *Compassionate*, *Social*, *Competent*, and *Reliable* but less *Interactive*. This is consistent with our expectations of a positive evaluation of culturally-sensitive robot behaviors. The fact that Pepper has not engaged in two-way interaction and was only exhibiting gestures may explain the lower rating for the *Interactive* attribute. The standard weighted deviation of the weighted ratings in Fig. 4 shows that the *Competent* and *Interactive* attributes have the lowest variability with values of 1.4. The *Compassionate*, *Social* and *Reliable* attributes have values of 1.7, 2.1 and 2.1, respectively. It is important to note that this evaluation was based on a small sample of behaviors and that the exercise was merely a trial, and involved a small number of respondents. As such, we anticipate less neutral responses when we evaluate a full set of culturally-sensitive behaviors in the tour scenarios with a much larger group of respondents.

VIII. Conclusion

Effective human-robot interaction requires social robots to adapt their behaviors to the preferences of their human interaction partners. In a culturally sensitive context, this means implementing culture-sensitive knowledge representation, planning and action execution, and multimodal human-robot interaction. To achieve this, we developed a set of software interaction primitives based on a preliminary catalog of African culture-specific knowledge, and proposed a system architecture of the different elements required for culturally-sensitive human-robot interaction in Africa using ROS middleware. Our proposed system architecture, based on a laboratory tour scenario in an African socio-cultural setting, has been implemented and demonstrated with three culturally-sensitive behaviors. It remains to carry out a detailed ethnographic study to identify a complete knowledge-base of cultural knowledge, to expand the set of software primitives, to extend the suite of culturally-sensitive behaviors, and to evaluate the efficacy of these behaviors through extensive empirical tests involving people from different African cultures, initially restricting our focus to Rwanda and South Africa.

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