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ARIS 1.0: An Autonomous Multitasking Medical Service Robot for Hospital Environments

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***Abstract*— Introducing robotics in the healthcare sector revolutionizes medical services by providing advanced treatments, medication management, and robotic assistance while overcoming resource limitations. In the current healthcare domain, an intermediate robotic communication platform is essential for distributing equal medical services, facilitating remote consultations, and maintaining the integrity of medical education, especially in rural areas and during pandemics. This work introduces ARIS, a multitasking medical service robot designed for telemedicine aspects and to facilitate remote medical education activities such as ward rounds. The prototype called ARIS 1.0 was developed, including a three-wheeled omnidirectional mobile platform, a torso and a novel movable neck mechanism with a face. The prototype robot can generate an online summarized report using its integrated language interaction and IoT-based vital sign extraction modules. The ROS-based semi-autonomous navigation facilitates the robot to be an assistive agent, allowing it to either accompany doctors or visit patients individually. Ultimately, ARIS 1.0 serves telepresence and novel regional language capabilities, specifically Sinhala-based self-communication features. This enables inter-party communication among doctors, medical students, and patients. The functionalities of ARIS 1.0 were validated in an emulated indoor environment to evaluate their feasibility. The results indicate that ARIS 1.0 is feasible for providing remote medical services. Furthermore, the paper discusses several promising research directions related to the proposed concept.**

I. INTRODUCTION

Pandemic situations like COVID-19, Zika Virus epidemic, Ebola, and SARS are the major causes of remodeling medical education, patient monitoring, and diagnosis operations [1]. The world is now moving into an automated era revolutionizing all sectors through robotics, including healthcare operations to uphold integrity even in pandemic situations. Having an intermediate communication platform that enables medical authorities to connect with the hospital environment remotely is crucial for several reasons: emergency consultations, access to specialized expertise, continuity of care, equal resource distribution even in rural areas, pandemic preparedness, telemedicine, and enhanced disaster response [2]. Moreover, remodeling medical education through robotics is another necessity, especially in ward round sessions. Ward round, a practical session offered for medical students, is an interactive discussion between the patient, doctor, and medical students along with the patient consultations [3]. In this regard, large gatherings around patients disturb the hospital environment and pose a high risk of spreading germs within the community. Also, achieving equal participation for individuals at the far end of the group poses challenges as communication and collaboration become difficult. In this context, local hospitals require remote operation systems to ensure equitable distribution of medical services, even in rural healthcare settings, particularly during pandemics.

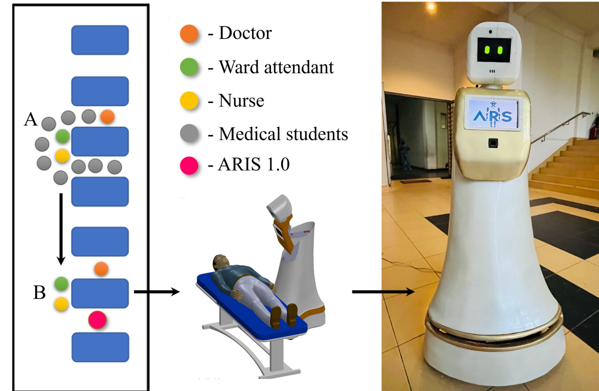

Fig. 1: From conventional ward rounds (A) to the proposed method (B).

This paper presents ARIS 1.0, specifically designed for conducting ward rounds in a maternity hospital and contributing to telemedicine aspects. That ensures the integrity of medical services in Sri Lankan hospitals and can potentially extend this concept worldwide (see Fig. 1). In this regard, the service robot concept was selected by considering the importance of aesthetic appearance and human-robot interaction to uphold the mentalities of the patients positively. ARIS 1.0 is integrated with a three-wheeled omnidirectional mobile platform, a torso, and a novel three Degrees of Freedom (DOF) neck mechanism with a face and controlled by the Robotic Operating System (ROS).

The contributions of this paper are as follows.

- Introduces ARIS 1.0, a medical service robot for navigating in hospital environments semi-autonomously;
- A novel 3DOF neck mechanism with an onboard

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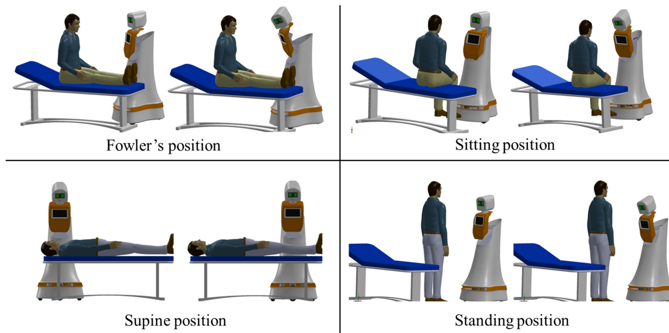


Fig. 2: Neck movements for different postures.

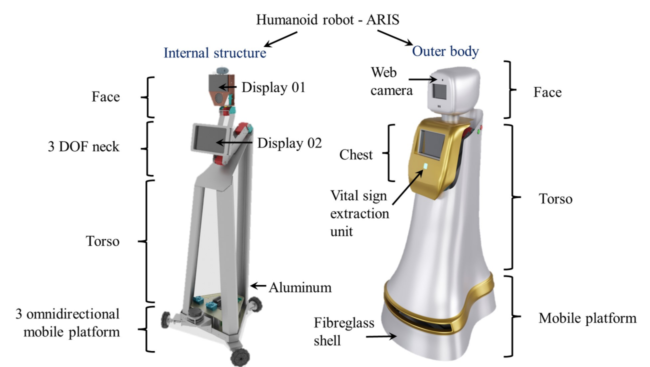


Fig. 3: Overview of the robot.

camera is introduced, allowing clear visual feedback extraction during patient consultations (see Fig. 2);

- For inter-party communication, the robot introduces regional language capabilities, specifically Sinhala-based self-communication, along with telepresence features;
- An online database populates the extracted vital sign data that can be accessed through a web application;
- These concepts were validated by testing the features of ARIS 1.0 within an emulated indoor environment.

The following sections of the paper address related works, proposed service robot concept, kinematic and dynamic analysis, mechanical design and fabrication, control and autonomy, results and discussion, along with a conclusion.

II. RELATED WORK

Several research works have contributed significant advancements to the service robots in the context of remote medication. Arent et al. [4] developed an assistive robot named ReMeDi, through which doctors could conduct patient consultations via observations, auscultations, and ultrasound examinations. This robot featured a video conferencing system, virtual reality, and haptic interfaces. The robot called Tommy, developed by Bartosiak et al. [5], had telepresence capabilities and the vital signs extraction feature to predict the health conditions of the patients. Moreover, RoboDoc was a smart robot designed by Khan et al. [6] that had a vital sign extraction feature, e-steth probe for remote consultations through haptic feedback, and real-time data transmission capabilities. Furthermore, Alvarez et al. [7] implemented a Nurse-Bot, a robot that monitored and updated the vital signs data to the attending physician.

In the medical education scenario, Mill et al. [8] developed a wearable device with cameras, such as body-worn cameras or smart glasses, to enable real-time sharing of clinical experiences with students. This approach improved medical education by offering remote clinical practices.

However, the existing literature lacks a standalone system integrating remote medication and distance medical education activities, i.e., ward rounds, into a single platform. As an advancement, ARIS 1.0 is applicable for both aspects, consolidating several features into a single unit. Those features are novel Sinhala-based verbal communication, semi-autonomous navigation with telepresence features, and a novel neck design to adapt to the postures of the patients.

III. PROPOSED SERVICE ROBOT CONCEPT

Given the busy and spatially limited nature of hospital environments, it is imperative to prioritize a compact and stable navigation system [9]. In this regard, ROS-based semi-autonomous navigation integrated with the three-wheeled omnidirectional mobile platform was implemented so that the robot can drive without having a turning radius by utilizing real-time mapping and localization techniques (see Fig. 3). The proposed work includes the basic features required to have interactive remote experiences with the hospital. Considering the importance of having visual feedback, a camera mount was developed to address seven different postures of the patient, namely supine, prone, lateral, sitting, standing, Fowler's and semi-Fowler's positions [10] (see Fig. 2). To achieve a clear view, the camera is autonomously moved by the 3 DOF novel neck mechanism integrated with the robot.

Stationary vital sign extraction methods are widely emphasized in hospital environments. Still, portable IoT-based medical data extraction systems, which are rarely implemented, are more suitable due to the impracticality of installing numerous stationary systems in large ward areas [11]. Therefore, a portable self-navigating platform with a vital sign extraction unit was implemented to extract vital signs into a real-time web application. The proposed robot has novel Sinhala-based self-communication skills that enable the robot to communicate with patients up to a limited word count, which is utilized when extracting vital signs from the patients. Having regional language capabilities is more important in both interactive aspects and during the pandemics to work as a stand-alone system. Additionally, web and mobile applications were developed for manual controlling purposes, allowing the full control of the robot to be in the hands of the doctors. Moreover, a web-integrated telepresence platform allows medical officers to connect remotely with the hospital. Furthermore, integrating safety features was also considered, and the trajectory of the neck mechanism was also derived, maintaining a uniform distance between the patient and the robot (see Fig. 2).

IV. KINEMATIC AND DYNAMIC ANALYSIS

This section emphasizes the kinematic analysis of the robot conducted, mainly focusing on the neck and the

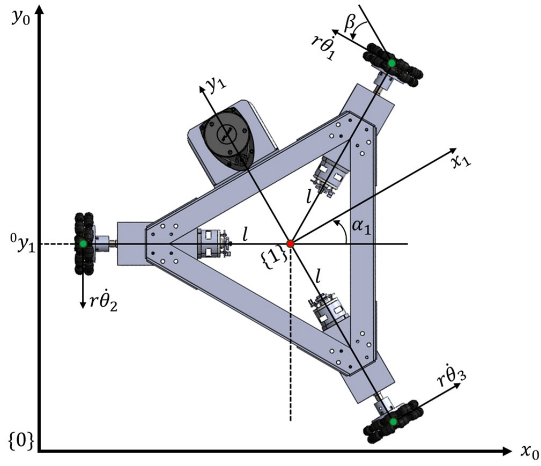


Fig. 4: Kinematics of mobile platform.

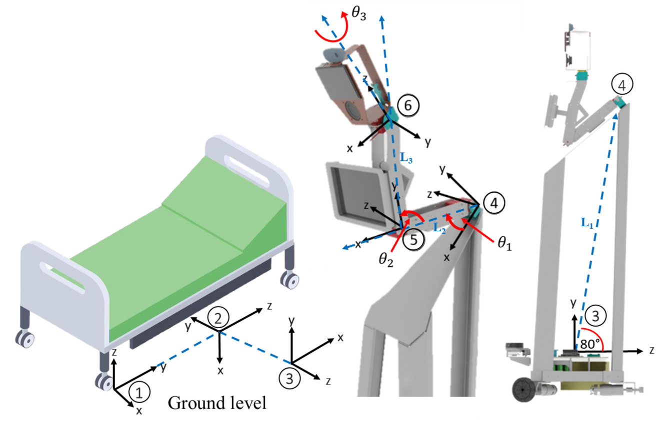


Fig. 5: Frames assignment to derive kinematics of the robot.

mobile platform. The Kinematics model of the three-wheeled omnidirectional mobile platform is shown in Fig. 4. The equation 3 is useful when implementing the navigation and mobility system [12].

Transformation matrix from world to robot frame with notation, 0 = world frame, 1 = robot frame , $\dot{\theta}$ = wheels' angular velocities , β = an orientation angle with respect to its longitudinal axis, α_1 = orientation angle of the robot, l = the distance between the center of the mobile platform and center of each wheel, r = radius of the wheels, $\begin{bmatrix} {}^0x_1 & {}^0y_1 \end{bmatrix}$ = absolute position vector, θ_i = rotation of the i-th motor.

$$\begin{bmatrix} {}^0\dot{x}_1 \\ {}^0\dot{y}_1 \\ \dot{\phi}_1 \end{bmatrix} = \underbrace{\begin{bmatrix} \cos\alpha_1 & -\sin\alpha_1 & 0 \\ \sin\alpha_1 & \cos\alpha_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{{}^0R_1} \begin{bmatrix} {}^1\dot{x}_1 \\ {}^1\dot{y}_1 \\ \dot{\phi}_1 \end{bmatrix} \tag{1}$$

$$\underbrace{\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix}}_{\dot{\theta}} = \frac{1}{r} \underbrace{\begin{bmatrix} -\sin\beta & \cos\beta & l \\ -\sin\beta & -\cos\beta & l \\ 1 & 0 & l \end{bmatrix}}_{H} \begin{bmatrix} {}^1\dot{x}_1 \\ {}^1\dot{y}_1 \\ \dot{\phi}_1 \end{bmatrix} \tag{2}$$

$$\underbrace{\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix}}_{\dot{\theta}} = \frac{1}{r} \underbrace{\begin{bmatrix} -\sin(\beta+\alpha_1) & \cos(\beta+\alpha_1) & l \\ -\sin(\beta-\alpha_1) & -\cos(\beta-\alpha_1) & l \\ \cos\alpha_1 & \sin\alpha_1 & l \end{bmatrix}}_{H[{}^0R_1]^{-1}} \begin{bmatrix} {}^0\dot{x}_1 \\ {}^0\dot{y}_1 \\ \dot{\phi}_1 \end{bmatrix} \tag{3}$$

A forward kinematics model of the robot using the DH parameter was developed as shown in Fig. 5 and Table I. From that, the position of the camera, motor rotation ranges, and moving range of the mobile platform were identified. The dimensions of the robot were determined based on the standard size of the hospital bed, the gap of two beds, and the dimensions of a 95th percentile human [13].

Inverse kinematics equations for novel neck mechanism were derived using a geometrical approach and expressed by equation 4-9. The aforesaid dimensions and these equations were used to program the trajectory controller for the neck. Equations of the inverse kinematics can be categorized into two modes based on the arrangements of the mobile platform and the neck mechanism. One mode is automatically selected after identifying the current posture of the patient. Mode 1 is used when the patient is in Fowler's or semi-Fowler's or standing or sitting position, while mode 2 is utilized for prone or supine or lateral position (see Fig. 2).

TABLE I
DH TABLE - FORWARD KINEMATICS

$\boldsymbol{\theta}$	d	a	$\boldsymbol{\alpha}$
90°	Y_0	0	90°
90°	X_0	0	-90°
-90°+ θ_1	$L_1 sin(80°)$	$L_1 cos(80°)$	90°
180°+ θ_1+ θ_2	0	L_2	0
θ_3 - θ_1	0	$-L_3 cos(80°)$	90°
θ_4	$L_3 sin(80°)$	0	0

Mode 1 - Used in Fowler's or Semi-Fowler's or sitting or standing position. Required to find θ_3 , θ_2 , X_0 , Y_0 for given end effector (camera) position x , y , z (see Fig. 6a).

$$\theta_1 = \theta_2 = \sin^{-1}(\frac{z - 115\sin(80°) - 25sin(80°)}{25}) - 220° \tag{4}$$

$$\theta_3 = -\theta_2 + 140°, Y_0 = y \tag{5}$$

$$X_0 = x - 140cos(80°) - 25\cos(80° + \theta_2) \tag{6}$$

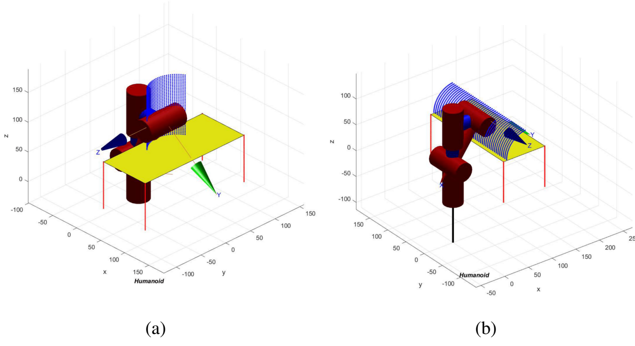
Mode 2 - Used in prone or supine or lateral position. Required to find θ_3 , θ_2 , X_0 , Y_0 for given end effector position x , y , z (see Fig. 6b).

$$\theta_1 = \theta_2 = \sin^{-1}(\frac{z - 115\sin(80°) - 25sin(80°)}{25}) - 220° \tag{7}$$

$$\theta_3 = 185° - \theta_2, Y_0 = y \tag{8}$$

$$X_0 = x - 115\cos(80°) - 25(\cos(80° + \theta_2) - \cos(125°)) \tag{9}$$

As design challenges, it is necessary to maintain the center of mass of the robot within a stable region and



(a) (b)

Fig. 6: Point cloud generation of the camera with a minimum focusing distance of 6cm. (a) Sitting position, (b) Supine position.

TABLE II
RESULTS - DYNAMICS ANALYSIS

Measurement	Value
Torque required for a motor in mobile platform	0.42 Nm
Footprint of the mobile platform	60 cm in Diameter
Torque required for the first motor in neck	7.5 Nm
Torque required for the second motor in neck	3.38 Nm
Maximum acceleration of the neck before failure	450 deg/s^2

determine any singularity points of the neck mechanism. The dynamics simulations were conducted using MATLAB and SOLIDWORKS to overcome these challenges and to determine the required motor torques for the mobile platform and the neck mechanism. Moreover, the simulations were used for validating the stability of the robot by applying an impulse force, selecting the footprint, and determining the maximum acceleration before reaching the failure. The internal structure of the robot, with the outer body represented as point masses, was utilized as the 3D model during the simulation process. Having a 1.5 safety factor, Table II illustrates the extracted results from the dynamic analysis.

V. MECHANICAL DESIGN AND FABRICATION

Before the fabrication stage, appropriate materials were selected by considering the weight of the overall body, motor torques, cost, and the available manufacturing methods. Aluminum was chosen over steel box bars to reduce the weight of the internal structure, while fiberglass molding was preferred for outer body fabrication due to its high strength-to-weight ratio, cost-effectiveness, and ability to form complex shapes compared to plastics or Polylactic Acid [14], [15]. For assembling the components, steel brackets were used due to their high strength and ease of shape. Based on the design and fabrication aspects, ARIS 1.0 can be divided into distinct sections shown in Fig. 3 and Fig. 7.

Based on that, the three-wheeled omnidirectional mobile platform was fabricated using 3 mm thick Aluminium L angles, while screws and steel brackets were used to mount the structure. Motors were indirectly coupled to the wheels through bearing and coupling to eliminate the effect of axial loading. Internal torso fabrication was performed using a 2 mm Aluminium sheet. Simulation results indicated that incorporating bent edges into the three inclined beams en-

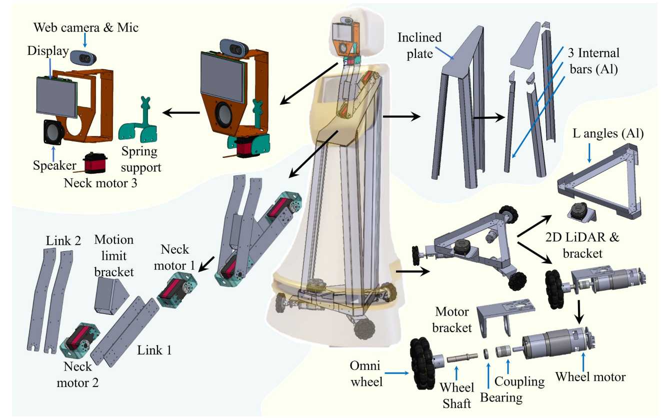
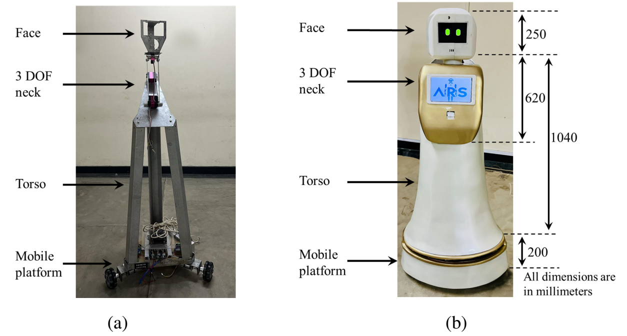


Fig. 7: Exploded View of the Robot.



(a) (b)

Fig. 8: Robot with dimensions after fabrication. (a) Internal structure, (b) Outer structure.

hanced the structural strength of the system. Therefore, the corners were bent inwards to increase the strength of the structure. The novel 3 DOF three-bar open linkage neck mechanism was designed to move based on the postures of the patient. It was constructed by using 2 mm Aluminium sheets, while bearings were used in required joints to prevent unnecessary tilting movements. The internal face was fabricated using 2 mm Aluminium sheets after considering the mountings and required strength to hold the display, web camera, speaker, and microphone. The internal structure of the robot after the fabrication is shown in Fig. 8a.

The outer body was constructed using a fibreglass moulding process and mounted to the internal structure by using screws and bracketing as shown in Fig. 8b [15].

A. Safety features

Since ARIS is a collaborative robot, it is vital to have safety measures to ensure proper operations, especially in hospitals where the robot may interact closely with medical staff and patients. To achieve that, an emergency button is placed on the outer body of the robot, facilitating easy access to the button in emergencies [16]. To avoid unnecessary collisions in surroundings, a 2D LiDAR sensor is integrated with the mobile platform. Additionally, limit switches are placed at the maximum and minimum spans of the links in the neck mechanism to restrict the motion. Furthermore, electric fuses, common ground, proper wiring insulation, and rated electrical components were used during the wiring.

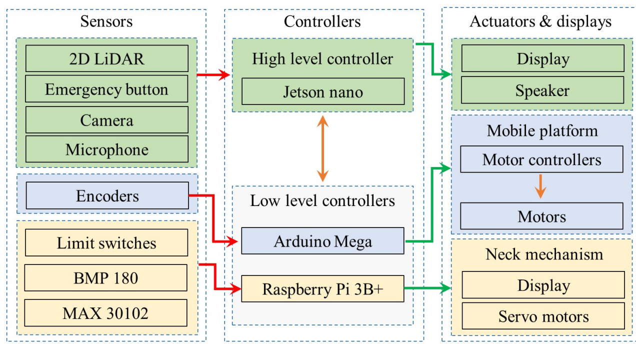
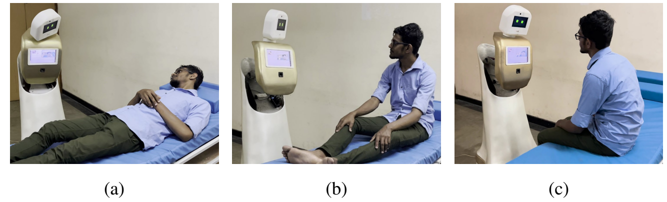


Fig. 9: Architecture of the control system.



(a) (b) (c)

Fig. 10: Neck movements after robot fabrication. (a) Supine position, (b) Fowler's position, (c) Sitting position.

VI. CONTROL AND AUTONOMY

ARIS 1.0 is operated via a distributed control system as illustrated in Fig. 9. It comprises the Jetson Nano with the ROS Noetic framework acting as the high-level controller and Arduino Mega and Raspberry Pi 3B+ as low-level controllers. The Arduino Mega performs tasks like encoder reading extraction, omni-wheels control, and data transmission to the high-level controller. On the other hand, the Raspberry Pi 3B+ manages and restricts neck movements using limit switches, extracting vital signs, and displaying the facial expressions of the robot via a connected display. Moreover, Jetson Nano is equipped with a 2D LiDAR sensor for navigation, a camera, and a microphone for communication, along with a dedicated display for assessing the developed web application. Communication between the high-level and low-level controllers is facilitated through serial protocols while the high-level controller communicates with the web application through the Message Queuing Telemetry Transport (MQTT) protocol.

A. Navigation of the robot

A semi-autonomous navigation system was developed, allowing the robot to be controlled via a mobile application or autonomously navigate from one place to another. Usually, the navigation is conducted by using multi-sensory systems, but the uniqueness of this work lies in utilizing a single sensor (2D LiDAR) to have both odometry and map data while remapping all the unwanted ROS topics in the hector SLAM [17]. Hector SLAM is used for mapping, and Adaptive Monte Carlo Localization (AMCL) [18] is applied for localisation while the Hector SLAM and move base packages are used to get odom data and applied as a navigation package respectively [17]. As a contribution, a novel program was developed for velocity transformation to omni-wheels based on the kinematics equations. Furthermore, a new Python script was developed to define the Odom-base link relationship using the scan data of the LiDAR sensor. When the robot is near the goal, the move base package is paused to avoid inappropriate holonomic motions, and another Python script is executed to reach the goal position. Excluding the sensor fusion, a low computational and accurate model was developed and validated in both simulated and experimental environments.

B. Vital sign extraction unit

MAX 30102 oximeter and BMP 180 sensors are integrated to measure vital signs such as heart rate, oxygen saturation, and temperature (see Fig. 3). The extracted data is transmitted using MQTT and stored in an Amazon Web Services (AWS) DynamoDB table by subscribing to the corresponding MQTT topic within the AWS IoT Core. Then, real-time data visualization is implemented on the web application.

C. Inter-party communication

This section describes the communication methods maintained among patients, medical officers, and the robot. A telepresence platform is utilised to maintain communication between doctors–medical students, and medical students–patients. Sinhala-based self-communication features have been added to enable robot-patient communication.

The telepresence platform enables medical officers and students to observe patients remotely via the robot. The dedicated website was implemented to incorporate this platform, which was developed using Jitsi. The front end of the website was programmed using the React framework, while AWS was utilized as the back end. Communication between the back-end and front-end is established using AWS WebSocket API. Moreover, the website includes the vital sign data of the patients, their registration data, and neck control features.

To work as a standalone system, a novel methodology is introduced in which the robot initiates conversations with patients in the Sinhala language by asking predefined questions regarding their medical history and current conditions. Following these interactions, a comprehensive report, including a summary of the conversation and the gathered vital sign data, is generated. The process of the Sinhala-based language model is shown in Algorithm 1, where the speech coming from the patient is converted to text, translated to English using Google Cloud Translation API, and then transferred data to OpenAI with a specific prompt designed to generate a concise summary [19]. After receiving the reply, it is translated back to Sinhala, and the text is converted to speech, which is the reply from the robot. The conversation summary is then stored in the system's database, facilitated by AWS DynamoDB, and can be accessed via the web application.

VII. RESULTS AND DISCUSSION

ARIS 1.0 was tested to verify the functionalities, and the following sections include each result in detail.

Algorithm 1: Self - Communication Model

1 **Input:** $beds$, $questionnaire$, $category$, $summary$
2 **Output:** $summarized_report$
3 **for** $bed_no \leftarrow 0$ **to** $beds$ **do**
4 | $chat_text \leftarrow$ initiate blank text
5 | Greet patient by name
6 | **for** $i \leftarrow 0$ **to** *length of* $questionnaire$ **do**
7 | | Ask question from $questionnaire$
8 | **end**
9 | $chat_text \leftarrow chat_text +$ translated conversation
10 **end**
11 Ask for permission to get vital signs from patient
12 $vital_response \leftarrow$ translate response
13 $vital_prompt \leftarrow category + vital_response$
14 $vital_perm \leftarrow$ feed $vital_prompt$ to OpenAI
15 **if** $vital_perm = yes$ **then**
16 | $vital_sign_data \leftarrow$ ask for vital signs
17 **end**
18 **else if** $vital_perm = no$ **then**
19 | Say thank you and leave
20 **end**
21 **else**
22 | Ask for vital signs again
23 **end**
24 $report \leftarrow summary + chat_text + vital_sign_data$
25 $summarized_report \leftarrow$ feed $report$ to OpenAI

A. Neck mechanism with telepresence platform

The robot is capable of moving its eyes and neck (see Fig. 10). The telepresence feature with a main web server was tested, connecting with the robot remotely. Additionally, a vital sign extraction unit and real-time data transmission were validated after extracting the vital signs of a person.

Figure 11a and Figure 11b show the view of the patient to a medical student who logged in remotely and the autonomous movement of the neck when a patient is in the supine position and sitting position, respectively.

B. Robot navigation

In navigation, the created map was imported for autonomous navigation and localization. After being given a goal from RVIZ, the robot reached that place autonomously. The calculated navigation accuracy of the robot is ± 30 cm from the goal position. This value was obtained by taking an average of robot movement to 10 different goal positions. Figure 12a and Figure 12b show the obstacle avoidance and robot autonomous navigation, respectively.

C. Regional language (Sinhala-based) self-commiunication

Moreover, the Sinhala-based self-communication feature was assessed by providing ambiguous responses from the user's end. The robot successfully recognized them and provided appropriate replies, ensuring a coherent conversation. This conversation is also presented in the video [20], which clearly shows the human-robot interaction.

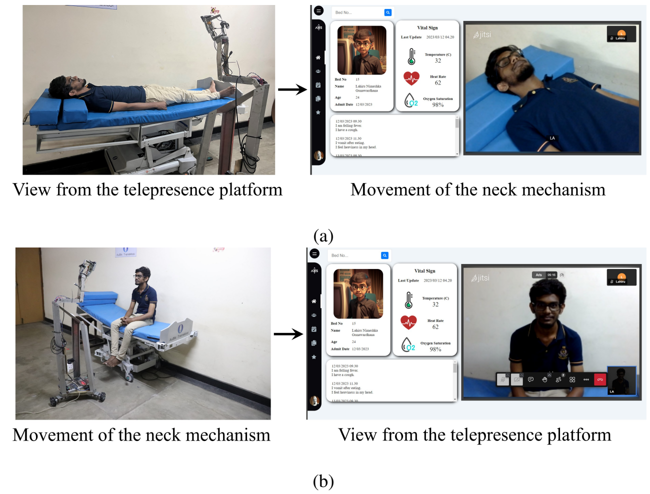


Fig. 11: Patient in different positions from telepresence platform via developed web server. (a) Supine position, (b) Sitting position.

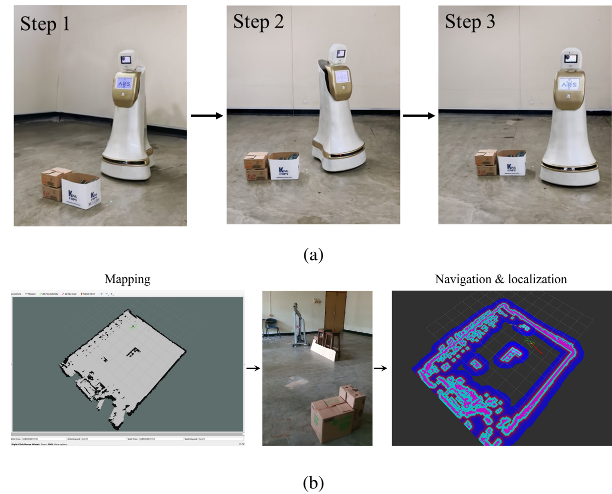


Fig. 12: Autonomous navigation. (a) Steps followed, (b) Obstacle avoiding.

Overall, the robot was tested and validated its feasibility in an indoor environment for different configurations [20].

VIII. CONCLUSION

The paper focuses on a medical service robot to assist with remote ward rounds and enhance telemedicine facilities. The mechanical structure and the autonomous navigation of the robot operate as anticipated. Inter-party communication features facilitate seamless interaction, while the developed web interface and mobile application enable control and visualization of extracted data from the robot. Testing sessions were conducted in an emulated indoor environment to confirm the feasibility and functionality of the proposed robotic system. Integrating tactile-based remote palpation, introducing a robotic arm and storage compartment for equipment handling, improving language models, and validating the robot in a clinical environment can be mentioned as future works of the proposed system. Altogether, ARIS 1.0 showcases high potential to establish as a standalone intermediate communication agent in hospital environments.

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