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Development of Differential Suspension Wheeled System for Telepresence Robot in Rural Hospital Area

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***Abstract*— The shortage of healthcare population is spread around the world especially in developing countries. Telepresence robot is an excellent option to solve this problem by telepresence system. For additional, the stability of robot is an importance key to success for telepresence mission.**

This research presents a differential suspension designed for telepresence robot to make telepresence system is able to reach most places in hospital. Platform was measured the stability of suspension system with teleoperated function and autonomous function in simulated environment. The inertial measurement unit was used to measure stabilization of system. The suspension system is able to improve stability and reduce shock force when robot was passing uneven terrains.

I. Introduction

Recently, world has been effected with a huge problem in ratio of population to healthcare population. The shortage of healthcare population especially in developing countries who have limited facility in medical education has been an issue. World Health Organization (WHO) displayed an interested density numbers of physicians per 1000 population. Ratio numbers are only around 0.16 – 4.3 in Asia and 2.0 – 2.45 in US. [1]. The density numbers among countries display an unbalanced distribution of medical treatment. Although many countries have high ratio of physicians per population, physician especially specialized doctors usually work only inside metropolis. Therefore, it effects patient in rural area are unjustified in medication treatment. Additionally, some specific cases make patients have to move out form their residence to metropolis for diagnosis. Moreover, this problem makes additional cost from transportation and logistics system.

Telepresence is a system that makes operators have experience of being at the real location of robot from remote area. The basic physical sensations such as vision, motion, and audition from robot environment are transferred by wireless communication to operator. Robot operates like an avatar of operator in remote area and using video streaming for communication between both sites. Operator is able to feel physically present on robot site and control motion of robot. Normally, telepresence system is integration between robotic system and teleconference system [2, 3, 4].

Many publications issued about using telepresence system to facilitate communication in medical applications [5, 6, 7, 8]. Although many telepresence robotic systems are available on market, but almost of them are not compatible with rural hospital. In additional, robots were operated in specific workspace because the limitations from design. For example, RP-Vita from InTouch Company was designed with omi-directional wheels. Omi-directional wheels have advantage in directional movement without any rotation, but it limits robot stability. Omi-directional wheels are able to move only small step and smooth surface. Therefore limitation of movement is directly affected to functions and it makes non-reasonable to pay with cost of robot especially in developing country. Thailand is the one of developing countries which has a shortage of healthcare population problem. Thailand has numbers of physicians per 1000 population around 0.393 (in 2010) [1]. Most of physicians in Thailand are working inside metropolis [9]. Normally, rural hospitals in Thailand are non-standardization building as in Fig. 1.

a.

b.

Figure 1. The slove example in hopital stadard envionments and real hospital environment a) standard slope in hospital building standard guild [10] b) slope in rural hospital environments.

As discussed in previous paragraph, the robot platform is an importance key to success telepresence function. Concept of research is to design and develop telepresence system that work in non-perfect hospital environments. Practical

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operation at rural hospital requires a basic and stable system by designing a novel suspension for telepresence robot. This paper is talking about a concept of designing robot in terms of mechanic on suspension system, and navigation system.

II. Material and Method

A. System Overview

Robot was designed to facilitate communication between physicians and patients by using integration of telepresence system and vital signs measuring system. System stores patient data in central server inside hospital. Using cloud computing to manage data and services of client and display data thought web application. Web application is designed to facilitate communication by steaming vital signs data, text chatting and video communication via wireless communication as in Fig.1. Data was separated to 2 types consist of global data and local data. The global data consists of position of robot, patient vital signs data, video communication, and text chatting. Second is local data, which do not update to station. Local data consists of robot pathway, local obstacle, and map. Robot has offline mode and online mode. Offline mode operates for local control. Robot is able to control via joystick, move follow people, create map, and self-localization. Online mode, robot is able to control by command from station.

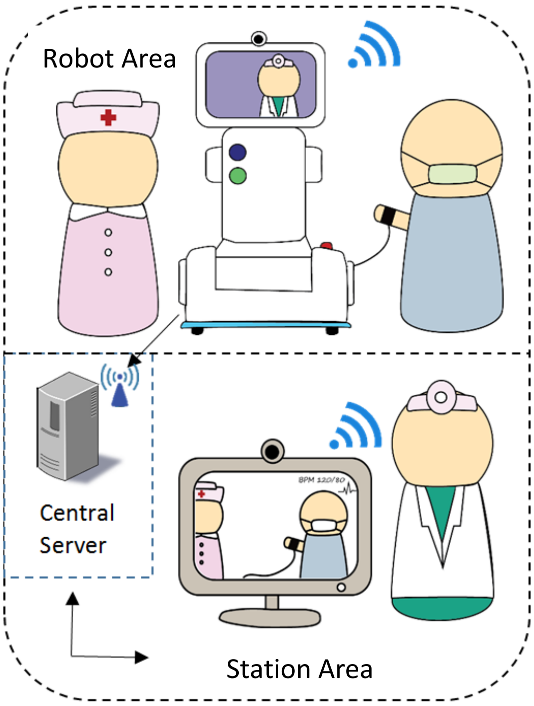


Figure 2. System overview separates into 3 part consist of robot area, cental server and station area. Central server is a server to manage web appilcation. Station area is a opertion workspace of physicain.

B. Robot Feature

The specifications of robot are listed in table 1. Robot platform is integrated with laser rangefinder (Hokuyo URG-04LX-UG01) for navigation and localization system. Robot has inertial measurement unit (IMU) to provide Euler angles from XSENS Company (Xsens Awinda). Main processing unit of system is fanless industrial computer (AXIOMTEK eBOX560-880-FL fanless computer) at base of robot which uses Linux OS (Ubuntu 14.04). The robot operating system (ROS) is used for data processing. Microcontroller is designed base on PID30F4011. Vital sign measuring system consists of 5 leads ECG, SpO2, body temperature, blood pressure monitor, and heart rate. On upper part of robot is integrated with 2 camera, 1 speaker, 1 microphone and 14 in touch screen laptop (Sony VAIO Flip) to display graphic user interface, vital sign from patient, and operate robot. All of information which gets by robot is displayed in web application. Skype program is selected to use for video communication program in first generation.

TABLE I. Overall Feature of Robot

Robot Platform	
Drive system	Differential wheeled robot with 4 damping casters
Wheel size	20.0cm diameter
Casters size	8.0 cm diameter
Robot dimensions	55x55 cm (W x D)
Height	150 cm fixed
Weight	50 kg. with 2 hour full time operation battery
Maximum speed	1.0 Meter per second
Battery type	NiMH battery, 24 V
Sensors	2 Microphone (1 fixed in robot and 1 handheld) 2 Cameras (1 forward facing webcam and 1 handheld HD camera) 1 Laser scanner
Operating system (Robot platform)	Linux OS (Ubuntu 14.04 with Robot Operating System ROS in jade version)
Telepresence and Vital Signs System	
Screen Size	14 in touch screen monitor
Robot operation system	Goal on mouse click in static map Handheld joystick command Arrows keys in robot station with acceleration profile
Vital signs measuing system	Blood Pressure, Body temperature, 5 leads electrocardiogram, SpO2, Heart rate
Operating system (Telepresence system)	Window 8.1

C. Robot Platform Design

Normally, robot use simultaneous localization and mapping (SLAM) algorithm as a base of navigation system. SLAM estimates robot location by using several different types of sensors, and the most common sensing system is laser rangefinder. Laser rangefinder has advantages in high sampling rate, small size of data and non-reflex of laser to material, but there is limitation in plane workspace. Only 1 plane workspace of sensor will affect navigation system and mapping system, if platform is not stable in terrain. In order to solve this problem, platform was designed with suspension system which is able to reduce shocking force to system.

Platform requirements were listed according to global standard for hospital building and international organization for standardization (ISO) [11, 12]. The ratio of slope is limited to 1:12 and continues does not longer than 6 m, door dimensions have to bigger than 90 cm, step is not higher than 2 cm with maximum 45 degree on slope of step [10]. Although the requirements are listed by global standard, but in practical using, many rural hospitals do not follow all detail in standards as in Fig.1.

Platform was developed by differential wheeled system because it has high stability in rough terrain, long lifetime operation, and easy to maintenance when compare with omni-directional and synchronous system. Platform consists of 2 drive wheels with suspension system and 4 suspension casters as in Fig. 3. Suspension casters were selected in type of rubber shock absorbing from FOOTMASTER Company (GDS-100A-SF) with maximum dynamic weight at 100 kilograms. Torque from motor is transferred to drive wheels by belt from upper layer to reduce platform size. Platform dimensions are designed according to building size from hospital building standard guide.

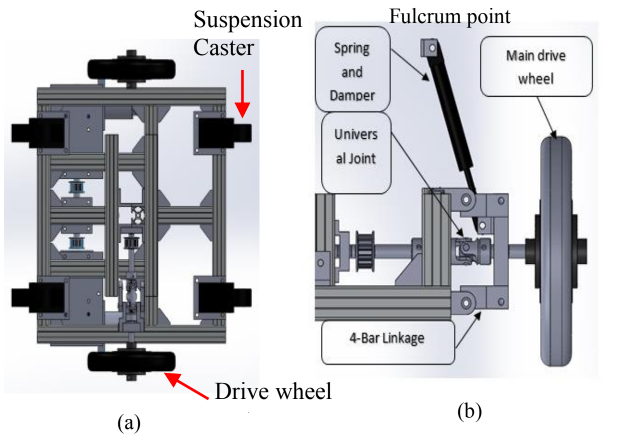


Figure 3. Bottom view of robot platform consist of 4 spring and damping casters and 2 main drive wheel and suspension system (left). The suspension system for main drive wheel (right).

Suspension system of drive wheel consists of 4 bar linkages and gas spring as in Fig. 4a. 4 bar linkages provide functions to fix distance between fulcrum point and gas spring axis and make drive wheel always be perpendicular to terrain when gas spring contracts as in Fig. 4b. Suspension system is used to enable drive wheel to move in vertical axis with with 4 centermeters in workspace. Gas spring generates reaction force depent on angular of fulcrum point to gas spring axis. In order to calculate parameter of gas spring in system by using gas spring reaction force equation (equation 1).

$$\left|F_{Gas\ Spring}\right| = \left|-F_N * \cos\alpha\right|\frac{\gamma}{\beta} \quad (1)$$

where γ is distance between fulcrum point and center of gravity. β is distance between fulcrum point and axis of gas spring. Distances β and γ are equal according to platform design, so reaction force of gas spring is equal to normal force as in equation 2. On initial step, center of gravity is located at robot base and between 2 drive wheels and the drive wheels are attached with terrain before caster, so weight is applied directly to suspension system of drive wheel.

$$\left|F_{Gas\ Spring}\right| = F_N * \cos\alpha \quad (2)$$

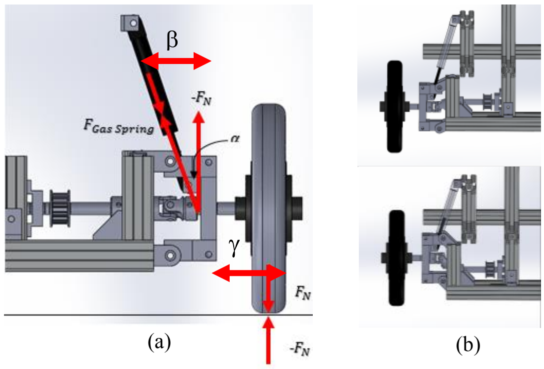


Figure 4. a) Free body diagarm of suspension system in drive wheel, b) Simulation of suspension workspace.

Where F_N is normal force, $F_{Gas\ spring}$ is gas spring reaction force, and x is displacement of gas spring. α parameter is an operation angle of 4 bar linkage structure to gas spring. α is lower than 20 degree by mechanical of 4 bar linkages. Mechanisms of 4 bar linkages make suspension system cannot move up from initial point more than 3 cm. Therefore, we select gas spring from stroke displacement and range of gas spring force (Fig. 5). Gas spring model GSS15050C from MiSUMi Company was selected which has 5 centimeter in displacement and 15.0-17.8 kilogram force as in Fig. 5.

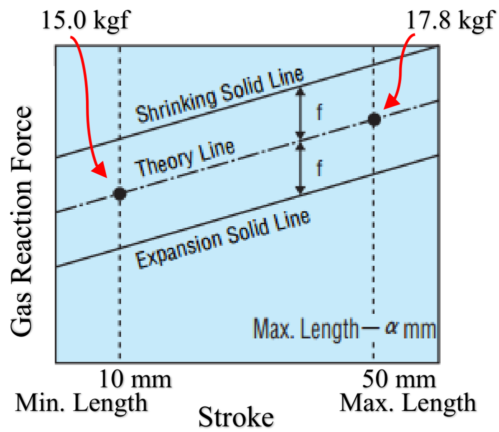


Figure 5. Gas reaction force charaterictic graph of gas spring (x axis is stroke, y axis is reaction force) [13].

D. Robot Control and Navigation Architecture

Robot processing unit consists of 2 pasts, first is low level system, and second is high level system. Low level system is based on PIC 30F4011, 1 master and 2 slave units. Master unit receives command from high level system by UART protocol. Master unit transfers command to slave units by I2C communication. Slave units are connected with encoder sensor and current sensor from each motor as in Fig. 6. Sensors provide feedback data to PID speed control system. Timer is used in order to process speed control system and communicate with master unit. Interrupt timer of slave unit is set to 50 milliseconds. Robot high level architecture is based on Linux OS and Window OS. Linux computer was designed with ROS for mapping system, localization, path planning and communicate with low level system. Speed commands are transferred to low level system every 50 milliseconds. Speed feedback is displays on GUI in Window computer. Window computer is used to display GUI and vital signs on robot monitor as in Fig. 6.

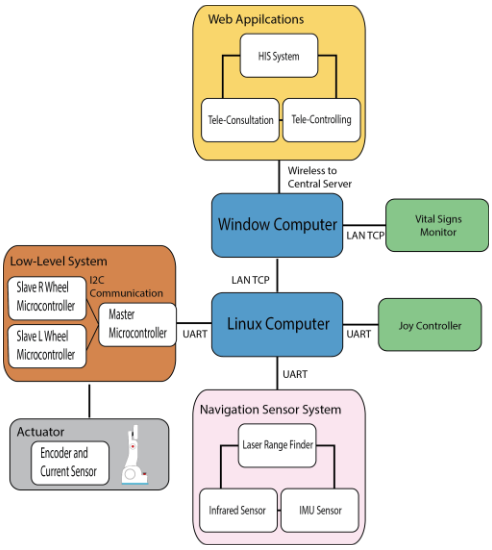


Figure 6. Robot processing architecture.

E. Navigation and Robot Control Software

Robot navigation system was developed based on ROS. ROS is an opensource that provides tools to manage sensing data of robot in team of node and message. In addition, node is a processing unit for one or more tasks of robot. The communications between nodes are provided by publicher and subscerber to public and recieve messages.

Hector is a reserach group, who is working on mapping and navigation system in rescue robot. Hectorslam use laser rangefindder data to create and localize robot. Therefore, the robot odometry is update depend on processing speed of scanmatching system [14,15]. In order to increse calculation speed and reduce processing units acllocation, we adapted HectorSLAM algorithm by integrating scan-matching data together with odometry from imu as in Fig.7 [16].

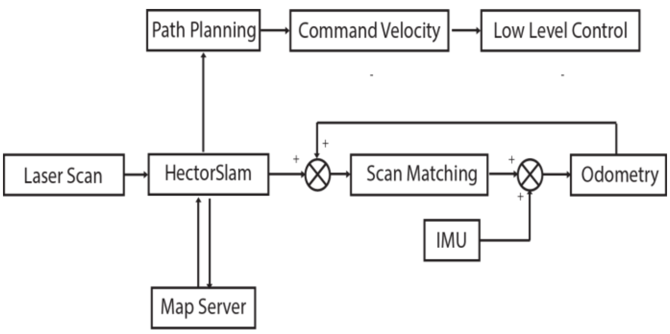


Figure 7. Robot navigation and mapping archetecture in ROS

Additionally, HectorSLAM are used to create map and generate pathway in navigation system. The odometry of robot is based on data from IMU. Mapping system created by runing exploration function. Robot generates random goals in unknow map to explore experiment room. Map is created by input of data from laser scanner and odometry of IMU. Map data is saved to mapsever in YAML file as in Fig. 8.

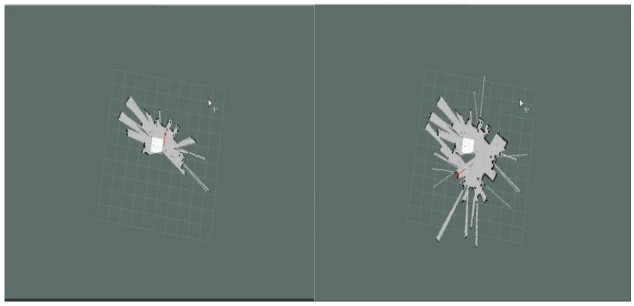


Figure 8. Example of mapping system in Tele-med robot, The black line represents obstrucles, and gray is observed area.

Navigation system used goal point coordinate on map to generate pathway. Navigation system is provided by map integrated with laser range finder data to create local and global costmap. Local costmap is an obstucle from laser rangefindder data, so it makes local costmap is able to update realtime during robot operation. Global costmap is static map system for example wall and object area which created in map sever. Both costmap was used to generate robot pathway from current position to goal position as in Fig. 9. The pathway message is calculated into command velocity, which consisted of translation in x axis and rotation in z axis.

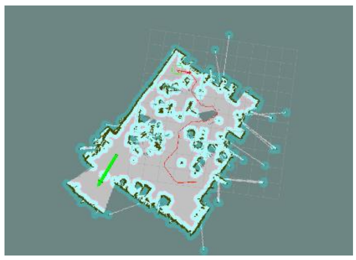


Figure 9. Example of navigation system (black line is static map, bule area is costmap, red arrow is odometry and position of robot, and red line is robot pathway).

In order to calculate velocity commands of 2 drive wheels, drive wheels locate in center line of platform with symmetric casters as in Fig 10. Therefore, velocity is calculated without effect from casters by differential wheeled equation 3-5.

$$V_t = \frac{v_l + v_r}{2} \tag{3}$$

$$\omega\left(R + \frac{l}{2}\right) = v_r \ and \ \omega\left(R - \frac{l}{2}\right) = v_l \tag{4}$$

$$R = \frac{l(v_l + v_r)}{2(v_l - v_r)} \tag{5}$$

$$\omega = \frac{v_r - v_l}{l} \tag{6}$$

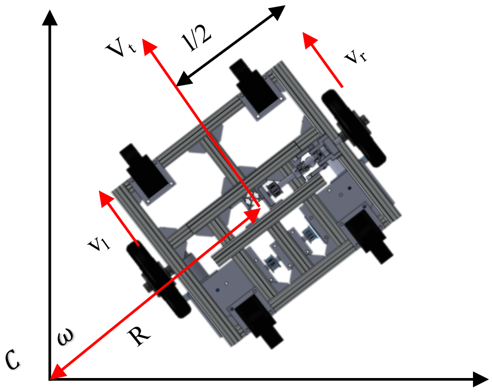


Figure 10. 2 Differentail wheeled robot kinematic, C is Center of Curvature, R is distance from C to center of robot, V_t represents robot velocity, v_r and v_l are velocity of robot wheels, and l represents distance between 2 wheels

According to equation (3) and (6), the inputs of velocity equation are translation and rotation. The velocities of left and right wheels (v_r and v_l) are calculated by using liner velocity and angular velocity (V_t and ω). The commands of both wheels are transferred to low-level system for control robot movement. Robot is able to control by handhold joystick. The commands from joy are translated into command velocity in x axis and rotation in z axis before calculate command into speed of wheels.

III. Experiment and Results

A. Experiment

We designed and created robot cover to protect mechanical part as in Fig. 11. We tested concept of robot before use in real environment. An experiment room was simulated for testing suspension system by control robot via joy stick command and navigation command. Experiment took place at BART LAB in Mahidol Engineering Building. The connection between robot and station provided by ADSL Wifi. Robot was set to 2 condition, first is with suspension sytem and without suspension system by fixing movement of 4 bar linkages. IMU was intergated in middle position of robot platform.

Figure 11. Tele-med robot

B. Result of Suspension System Design

Suspension system was tested by tele-operation mode via joy stick in both toward and backward direction across steps height 0.0 cm to 3.0 cm. Tele-operation was tested 10 times per each height as in Fig.12. Criterion of passing was set more than 9 of 10 times in each height. We recorded Euler angles from IMU in robot to evaluate system between with suspension and without suspension system are list in table 2 and Fig.13.

Figure 12. Experiment moving through doorsill high 2 cm in tele-operation mode.

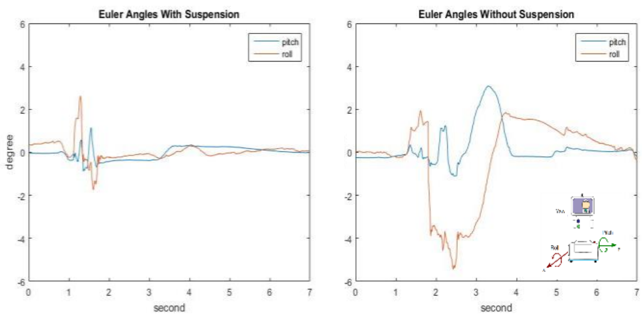
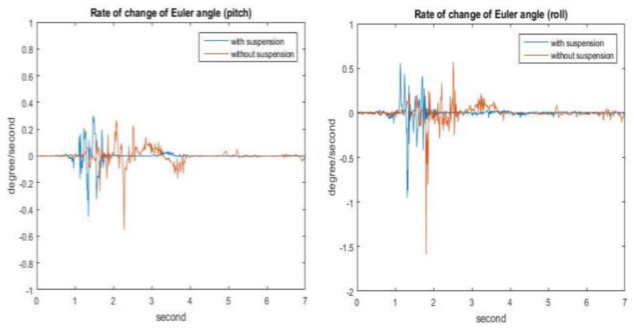


Figure 13. Pitch and roll angles of climbing steps high 2 cm in forward and backward direction.

TABLE II. Maximum and minimum Roll and Pitch of robot while climb steps (N=10) with and with suspension system (WS = With Suspension system, WOS = without suspension system)

Step height (cm)	Roll (degree)				Pitch (degree)			
	Min WOS	Max WOS	Min WS	Max WS	Min WOS	Max WOS	Min WS	Max WS
0.0	0.23	0.45	-1.77	1.10	-0.12	0.13	-0.25	0.06
1.0	-5.35	7.8	-4.35	4.68	-2.6	3.5	-2.12	4.26
2.0	-8.26	7.9	-4.10	4.23	-3.15	6.28	-2.07	4.24
3.0	Unable to Pass	Unable to pass	-5.12	4.35	Unable to pass	Unable to pass	-3.86	6.61

Results display reduction of maximum and minimum Euler angles when moving through steps and rough terrain. We calculated rate of change of Euler angles in pitch and roll directions to display the reation of sypension system to shock force as in Fig. 14. The result shows that rate of change of Euler is reduced 0.0664 degree/second in pitch direction and 0.6454 degree/second in roll direction.



a. b.

Figure 14. Angular velocity of robot when move through rough terrain. a) Changing rate of pitch angle b) Changing rate of roll angle (blue line is with suspension and orange line is without suspension)

C. *Navigation System*

Rough terrains were added in experiment room. Robot was command to explore unknow area to create map by tele-operation mode. Experiment shown that robot was able to create map in experiment area which simulated non-smooth terrain and step field in environment without slipping of localization. Robot generated random goals in experiment room as in Fig 15. Random goals generated pathway according to position of robot. Robot was able to move following pathway through rough terrain without getting stuck or slipping.

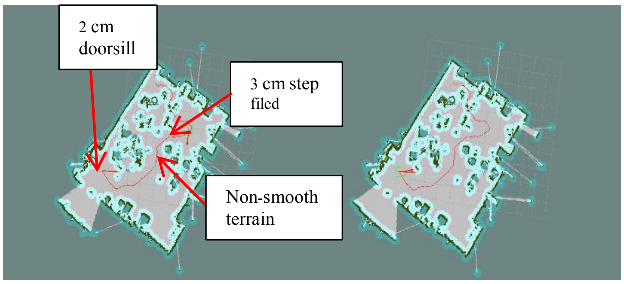


Figure 15. Map of experiment room and navigation system

IV. Conclusions and Future Work

In this paper presented an adaptaion of suspension system design for differential drive system. The stability of robot is incresing when compare between non suspension and suspension system. Platform design can move robot through rough terrian, step filed in experiment room. However, the suspension system in drive wheel increses Euler angles in non-rough terrain because center of gravity is changed when robot move.

Next step, robot will be tested all function in real rural hospital environment to get feedback for robot design in real situation. We aim to develop 3D mapping system via depth camera for help obstrucle avoidance and in next iteration.

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