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Real Environment Testing of Quadruped Robot Mobile Manipulator in Oil and Gas Facilities

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***Abstract*—This paper outlines a testing of quadruped robot mobile manipulation using robotic arm in oil and gas facilities to explore the opportunities and challenges of a full unmanned operation. Robotic arm replicates the agility of human hand, wrist, and fingers with an ability to perform hazardous tasks in inaccessible area. Four manipulation activities of panel door opening, valve opening, buttons and switches on/off and liquid sample collection are performed. A mission workflow for the arm manipulation performance is identified and each task is evaluated in term of accuracy, time to completion, and precision.**

***Index Terms*—robotic arm, hazardous area, quadruped robot, real environment testing, mobile manipulation**

I. Introduction

In recent years, robotic solution and utilization in the industry has been expanded due to the capability of undertaking tasks that are either impossible or undesirable for humans. Various operating condition in hazardous or aggressive environments are now accessible and repetitive task can be performed efficiently and uniformly. The are various type of robots which are commonly discussed which include wheeled robot, kobuki or home cleaning robot, unmanned aerial vehicle (UAV) and quadruped robot. In these studies, wheel robot has been tested in indoor for mapping and navigation, autonomous operation as well as outdoor on terrain for pesticide spraying in agriculture [1]. As the wheel performance is greatly influence by the surfaces, discrepancies in measurement is observed on a different platform of concrete, plastic, cardboard, wood and iron [2]. Kobuki robot on the other hand performs greatly in indoor environment for cleaning, mopping purposes. However, the horizontal field of 60 degrees depth camera view is limited to be matched with the 360 degrees LiDAR sensor info [3]. The observed challenge is addressed by using two or three robots to obtain an accurate mapping and localization during the mission. UAV also widely gained a huge attention in robotic industry, but the utilization is still limited to a low payload mission such as photogrammetry [4], scanning and mapping . Hence, the robotic industry has emerged by focusing on quadruped robot where it offers six or more degree of freedom in performing given tasks. The advantages of quadruped robot include (1) Discrete foothold to avoid obstacles and pits for workspace optimization (2) Good stability, economical and practical form (3) Omnidirectional motion capability without the lateral constraints (4) Good vibration isolation in a rugged terrain due to the decoupling of feet and torso (5) Flexibility with a various manipulator such as robotic arms which can perform large-range dexterous operation [5].

With the introduction of mobile manipulator, quadruped robots is able to perform various operation instead of only walking and surveillance. Therefore the mobile manipulation is the current direction in quadruped robots and addressed in using UniTree robot to learn the unified policy of deep whole-body control for manipulation and locomotion [6]. The unified movement of legs, body and arms are able to be coordinated in the study. Nevertheless, the mounted camera utilization for the object detection is still not studied and proposed for the future work. Similarly, ETH's quadruped robot, ANYmal is extensively studied for this unified movement in manipulation and locomotion using Model Predictive Controller (MPC) [7]. The MPC work is further utilized for a coordinated components self-collision avoidance in later work [8]. Nevertheless, the aforementioned studies have been conducted on a pedestal, grass, indoor office, laboratories or a highly structured environment only. Limited studies of the robotic arm on a quadruped robot deployment on an actual environment are discussed [9], [10].

Robots face a significant challenge of malfunction due to the major dependency of highly structured environment. It hindered any modification during the deployment. Therefore, the adaptability issue is addressed using teleoperation approach. It involves humans in maneuvering and remotely controlling an operation. However, the high dependency on the user interface during the environment manipulation limits the feedback information of the exerted force by the robotic arm. This scenario is more challenging in a rough and uncertain environment such as oil and gas facilities which is highlighted in this paper. Hence, the testing of robotic arms as the mobile manipulation of the quadruped robot to explore the unlimited opportunities and challenges in a real oil and gas facilities is presented. In the first part, the robot system setup, robotic arms specification and mission workflow are outlined. Then, the system capability to perform four tasks are discussed and last part provides the conclusion and recommendation for the study.

II. Materials and Methods

In this section, the robot system setup with the robotic arms specification are presented. Then, a mission workflow for the investigated activities is outlined.

A. Robot System Setup

The robot system for this research is ANYmal-D, a quadrupedal robot designed for autonomous operation in various hazardous environments. The operation includes mission control and robot behavior, diagnostic and data logging, localization and mapping, path planning and motion control and inspection intelligence. It runs on a 2 × 8th Gen Intel Core i7 (6-core) CPU with 2 × 8GB Memory (RAM) and installed Ubuntu 20.04, ROS Noetic. The robot typical payloads are compromise of zoom camera, thermal camera, ultrasonic microphone and spotlight. The robot is attached with the Adroit Small Arm System with a gripper as illustrated in Fig. 1 and utilizes the perceptive sensor of depth camera for a locomotion and manipulation.

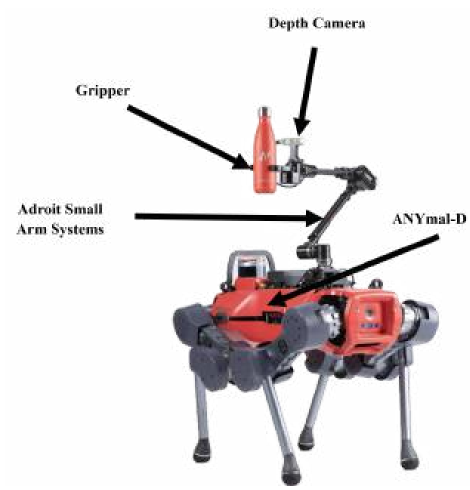


Fig. 1. Anymal-D with addition of arms system illustrations

B. Robotic Arm Specification

ANYmal D is equipped with Adroit Small Arm System, a torque-controllable 6- Degree-of-Freedom robotic arm as illustrated in Fig. 2. The lifting capability is specified at 8lbs for gripper, 11lbs for joint 1 and 8lbs at joint 2. Each joint drives with 24Nm and 48Nm pneumatic actuator torque respectively. The modular system of bases, joints, connectors and end effectors are customizable. The joint wiring with slip rings ensures a continuous rotation of the arm and eight signal lines reserved for accessories up to 100W (24V at 4A) are available. It is capable of a full HD images and videos with a night and depth visions from the mounted RGB depth camera at the gripper.

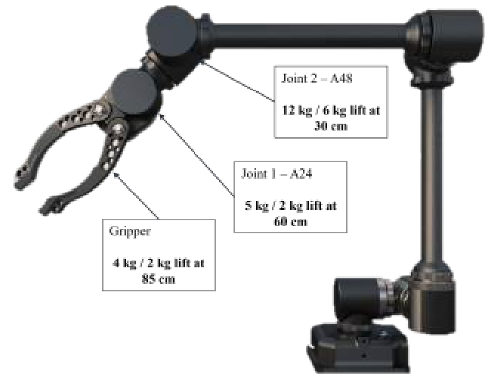


Fig. 2. Adroit Small Arm illustration with lifting capacity for gripper and joints

C. Mission Workflow

The ultimate objective for utilizing the mobile manipulator is to achieve autonomous manipulation. Hence, a one-time and manual operation setup of the mission workflow is outlined in Fig. 3. First, oil and gas facilities environment is mapped in 3D using LiDAR. Then, manipulation checkpoints for object localization on the map is recorded. Following step involves with the waypoints configuration for motion planning of the arm during object manipulation. In this step, MoveIt package with Pilz Industrial Motion Planner for point-to-point (PTP) planning is utilized. Once the manual setup is completed, repetitive operations which include navigating to checkpoints, autonomous manipulation, missions report generation, and system self-charging are performed autonomously. Finally, the robotic arms capability in performing the manipulation of panel door opening and closing, valves turning, button pressing and switches on/off turning are evaluated and discussed in the next section. It is essential to note that this paper primarily focuses on the definition and testing of waypoints.

III. Result and Discussion

A. Panel Door

The first manipulation task is the opening and closing of a door panel equipped with electrical buttons and gauges for wellhead control and monitoring. The setup is depicted in Fig. 4 with a parallel side-to-side distance of the robot and panel. The dimensions of the panel are 170cm in height and 55cm in width and the door panel knob is at 85 cm from the ground. Side-to-side distance was set to be greater than the door's width for the collision prevention during manipulation. The robot's leg opening length also considered in the process to avoid collisions with equipment on the opposite side considering the narrow workspace in the platform. During the investigation, it is observed that the arm gripper's tip is made of rubber which tends to slipping during attempts to grab and pull the door's knob. Therefore, sandpaper was rubbed to the gripping area of the knob, enhancing friction and preventing slippage as the gripper rotated and pulled the knob.

The visualization of panel's door manipulation in RViz is illustrated in Fig. 5. The configuration of waypoints for the

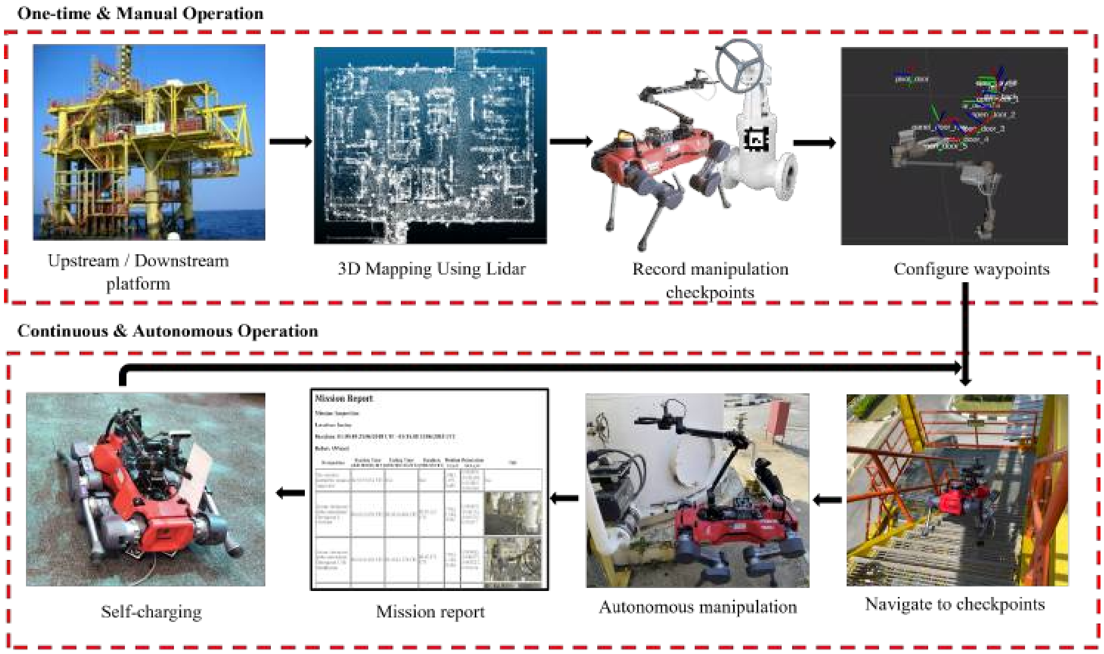


Fig. 3. Mission workflow

Fig. 4. Manipulation on panel's door

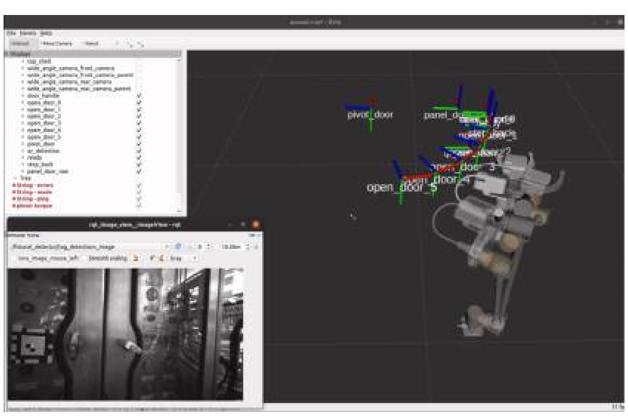


Fig. 5. Visualization in RViz

arm to open or close is determined based on the distance from the pivot door and the knob. Circular waypoints, labeled `open_door_0` to `open_door_5`, have been established using this distance. A unique QR tag from the 41h12 family was placed near the door's knob, facilitating the gripper's motion towards the knob with minimal error to enhance the precision. The bottom-left window demonstrates the QR tag detection capability, where the visible number on the QR tag will indicates a successful detection by the depth camera.

Tab. I summarizes the arm's performance in opening and closing the panel's door. The average accuracy was computed by comparing the actual movement of the robot with the measured distance between the QR Tag midpoint to the knob midpoint. The average accuracy is obtained satisfactorily at 2 cm and successfully repeated for four times.

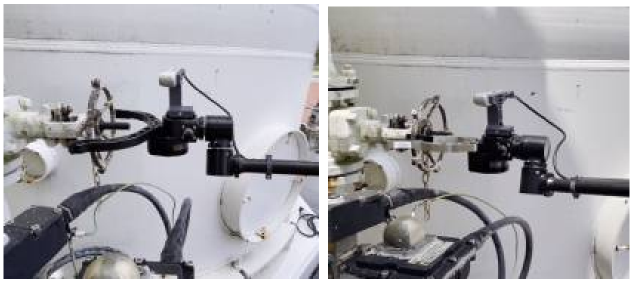
TABLE I
PERFORMANCE IN MANIPULATING DOOR PANEL

Evaluation	Results
Average accuracy	2 cm
Time response	52 s
Minimum side to side distance	70 cm
Maximum side to side distance	85 cm
Successful repetition	4 times

B. Valves

1) Gate Valve: The subsequent activity involved manipulation of a gate valve located at the instrument air header which regulates the airflow from a large white tank to the user, as shown in Fig. 6. Two different approaches were tested:

grabbing from outside of the valve's ring as shown in Fig. 6(a), and gripping directly on the valve's ring with extended tip as shown in Fig. 6(b). It is observed during the testing that the gripper design, particularly at the tip, requires further enhancement to avoid slipping during rotation. Hence, number of rotations executed by the arm are guaranteed.



(a) Approach 1: Grab from outside (b) Approach 2: Grip on the ring

Fig. 6. Failed manipulation of gate valve

Tab. II summarizes the parameters and results obtained during the manipulation task using both approaches on the gate valve. Notably, the second approach offers no limitation on the valve diameter since it is independent of the maximum gripper's opening. In terms of the duration to rotate the valve, the first approach is faster than the second due to the absence of unnecessary gripper movements to traverse backward and forward for one full rotation. Additionally, the first approach allows full utilization of the end effector's drive torque as the center aligned with the valve's center. This alignment makes it easier for the gripper to rotate the valve, even under challenging conditions such as rusty environments.

TABLE II
MANIPULATION ON GATE VALVE

Evaluation	Results	
	Approach 1	**Approach 2**
Maximum valve's diameter	19 cm	Unlimited
Number of rotations	Unlimited	Unlimited
Time response	39 s	2 m 47 s
Robot head to mid valve height	60 cm	60 cm
Robot to mid valve distance	67 cm	67 cm
Successful repetition	3 times	3 times

2) Block Valve: The arm's performance in opening and closing a block valve was also investigated and the corresponding drive number and inital length is illustrated in Fig. 7.

The torque value of each arm's driver is depicted In Fig. 8. it is observed that drives number 2 and reached the maximum torque value of 60 Nm, leading to the unsuccessful execution of the manipulation task.

Despite attempting approaches from above and the front, the valve resisted movement in the pushing direction. To address the torque issue, the initial length of the valve was extended by 20 cm, resulting in a total length of 50 cm. This extension effectively resolved the torque problem, particularly for drives 2 and 3, as illustrated in Fig. 9. Consequently, the

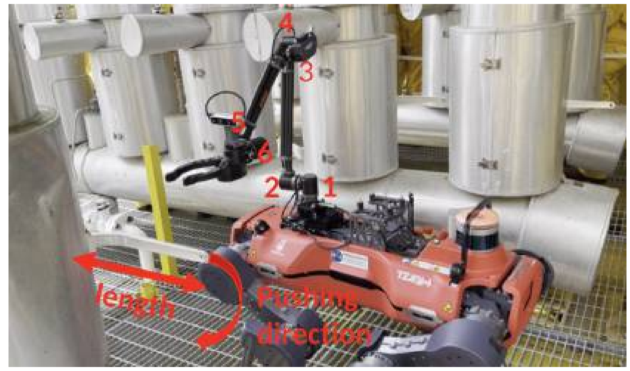


Fig. 7. Corresponding drive number of the arm and initial length of the valve

arm successfully performed and repeated the manipulation task twice.

The parameters and results during the manipulation task on the block valve is summarized in Tab. III. Since the task is performed in a narrow path, the first challenge is the collision prevention between the robots and the surrounded manifold line on the platform. Hence, the side-to-side distance determination is crucial to ensure that the gripper has a sufficient space to push and pull the valve without colliding with its leg. Second identified challenge was the arm's tendency to re-plan the grabbing orientation while pushing the valve. For instance, the depth camera faced upward at the start of pushing the lever but downward at the end of the pushing direction. This behavior may be attributed to the use of discrete waypoints, as shown in Fig. 5, instead of constructing a continuous waypoints.

TABLE III
PERFORMANCE IN MANIPULATING BLOCK VALVE

Evaluation	Results
Initial valve's length	30 cm
Extended valve's length	50 cm
Side to side distance	45 cm
Time response	48 s
Successful repetition	2 times

C. Buttons and Switches

The testing continued with the manipulation of electrical switches, where the challenge lay in achieving accuracy due to the small size of the buttons and switches. Despite having an accuracy target of 2 cm to reach the desired position, further tuning was necessary to ensure that the arm could accurately reach, grab, and push the switches.

The selector switch, as depicted in Fig. 10(a), proved to be the easiest to manipulate. It only requires a simple grab and turn by 45 degrees of the gripper. However, push button in Fig. 10(b) is more challenging as the gripper must accurately push the middle tip of the button with an error tolerance of 1 cm . The pushing force also had to be carefully tuned to trigger the button effectively while avoiding damage. In the

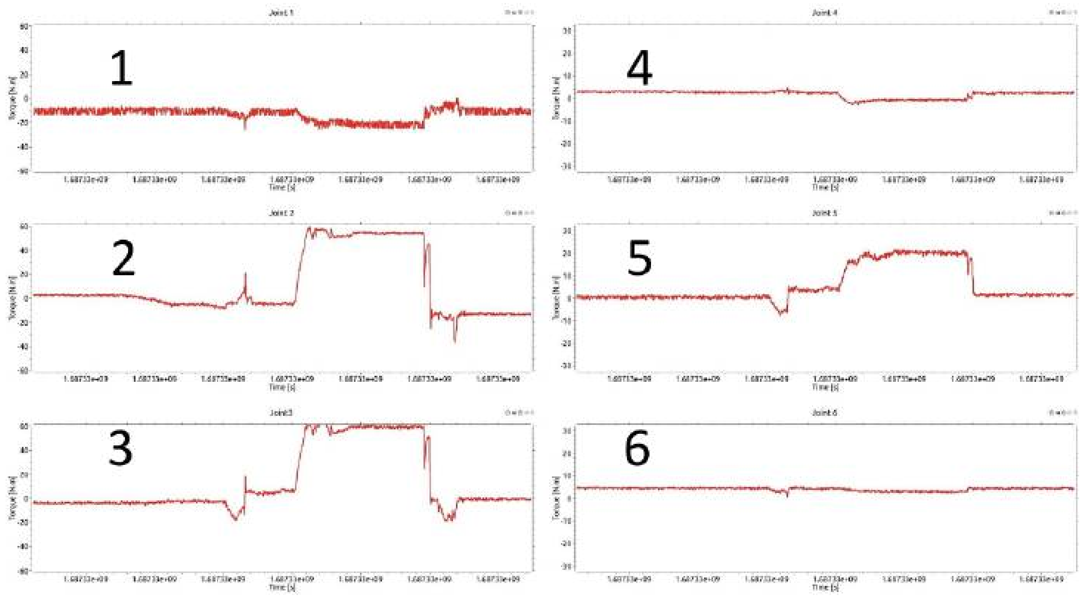


Fig. 8. Torque value of each arm's drive

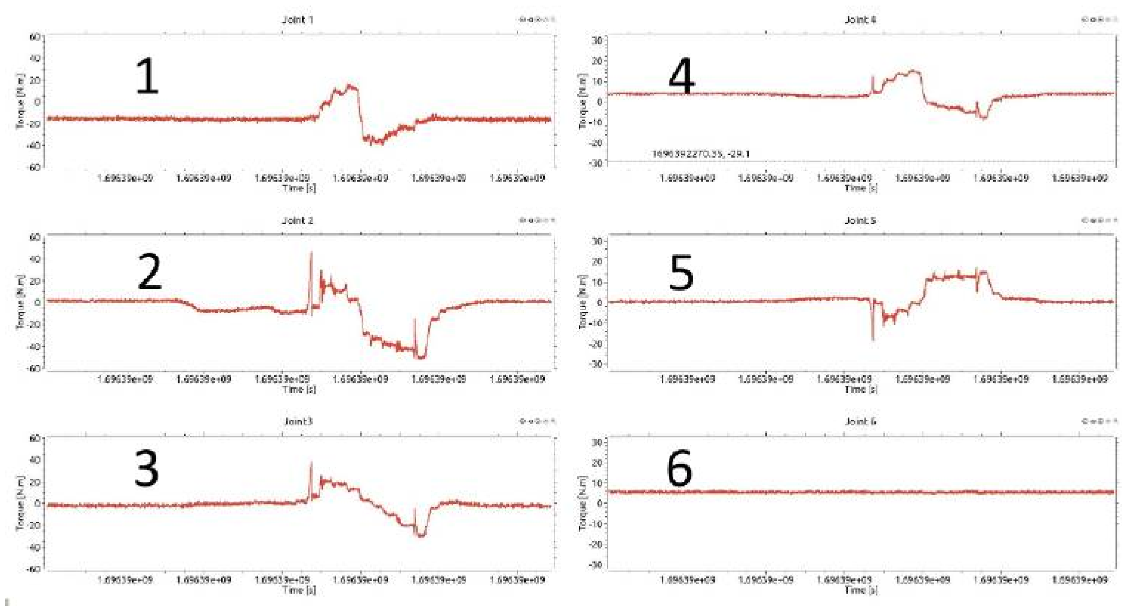


Fig. 9. Successful manipulation of the gate valve

case of an emergency switch button shown in Fig. 10(c), a simple modification was implemented since it could not be disengaged in the same manner as a human. Hence, a very small stick was attached to the middle of the switch, allowing the gripper to disengage the button by twisting the small stick. It's noteworthy that engaging the emergency switch button is facilitated when the gripper's tip is long and small enough to pass through the metal cover surrounding the button. As a result, the button was successfully pushed within 1 minute, and the emergency switch button was disengaged in approximately 35 seconds. This manipulation task was consistently repeated for two consecutive trials

D. Sample Taking

As liquid sampling is a common task in oil and gas platforms, this section presents the testing results of the mobile manipulator in performing the task. It involves multiple valves manipulations to allow the liquid to flow into the metal bottle. For simplicity, only one valve was manipulated during this activity, with a primary focus on configuring waypoints for retrieving the bottle from the liquid catchment area, as illustrated in Fig. 11. The results showed that the duration to extract the sample from the water catchment area was 1 minute

(a) Selector switch

(b) Push button

(c) Emergency switch button

Fig. 10. Manipulation on electrical switches

and 11 seconds. The operation was successfully repeated three times, showcasing the robot's capability to perform complex tasks in the oil and gas environment.

Fig. 11. Sample taking

Tab. IV provides a summary of the performance criteria established for each manipulation test. The table outlines three evaluation criteria for each test, with the majority of the target performances successfully attained. However, it is important to note that a specific target performance could not be achieved, attributable to limitations in the motion speed of the arm.

IV. Conclusion

This paper outlines the standardized workflow for all tasks where challenges and recommendation to counter it are properly discussed. As a conclusion, the mobile manipulator as an arm on the quadruped robot is successfully tested for four common task in oil and gas facilities. However, future enhancements may involve incorporating methods such as visual servoing to improve accuracy and consequently reduce tuning time.

TABLE IV
PERFORMANCE CRITERIA

Items	**Item Manipulation Target Performances**	**Is the target achieved?**
Panel Door	1. Perform opening/closing of door panels 2. Perform operation in a timely manner 3. Perform operation repetitively	1. Yes 2. No 3. Yes
Valves	1. Perform opening/closing of valves 2. Perform operation in a timely manner 3. Perform operation repetitively	1. Yes 2. No 3. Yes
Buttons and switches	1. Perform switching on/off of the switches 2. Perform operation in a timely manner 3. Perform operation repetitively	1. Yes 2. No 3. Yes
Collect Liquid Samples	1. Perform the sample taking 2. Perform operation in a timely manner 3. Perform operation repetitively	1. Yes 2. No 3. Yes

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