Team-JSK: MBZIRC Progress Report

Team JSK[†]
JSK Lab, Graduate School of Information Science and Technology, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan 113-8656.

I. Introduction

This document provides a report of Team JSK's progress in preparing for the Mohamed Bin Zayed International Robotics Challenge (MBZIRC). The team consists of members from the JSK Laboratory at the University of Tokyo. The JSK Lab, founded in early 1980s, has a long history of robotics research with focus on areas including humanoids, drones, robotics manipulation, and perception, and the lab has experience in participating in robotics challenges including the DARPA Robotic Challenge and the Amazon Picking Challenge.

A. Project Personnel

Team JSK is made of eleven members: Prof. Masayuki Inaba, Prof. Kei Okada, Dr. Yohei Kakiuchi, Dr. Wesley Chan, Bakui Chou, Xiangyu Chen, Krishneel Chaudhary, Kohei Kimura, Yuki Furuta, and Hiroto Mizohana. The team is roughly divided into three groups corresponding to each task with groups having overlapping personnel.

II. Challenge 1: Landing UAV on a Moving Vehicle

A. Hardwares

We developed the uav with hex rotors as shown in Fig.1. As descrbied in Fig.2, this aerial robot consists of onboard sensors such as IMU, barometer, laser sensor, GPS for basis hovering flight control, as well as the original flight controller and high level processor. The monocular camera is installed for the further egomotion estimation. The total weight of the uav is 4.3Kg, while the flight time can reach 20min with heavy vision processing on the onboard processor. We have achieved the outdoor flight with autonomous altitude hold mode using our original sensor fusion algorithm(Fig.3).

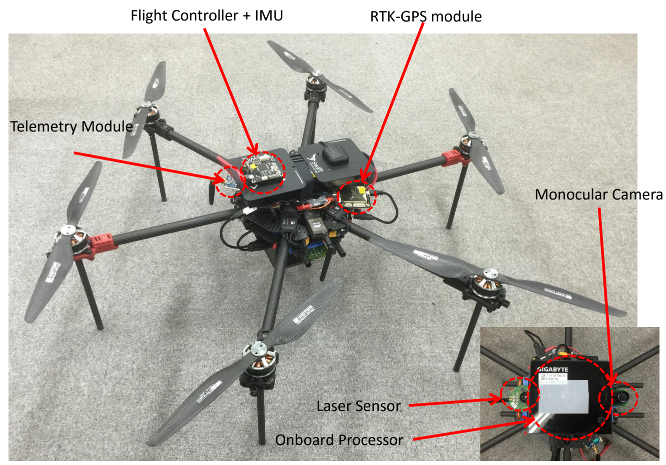


Fig. 1: Image of task1 UAV(Hawk)

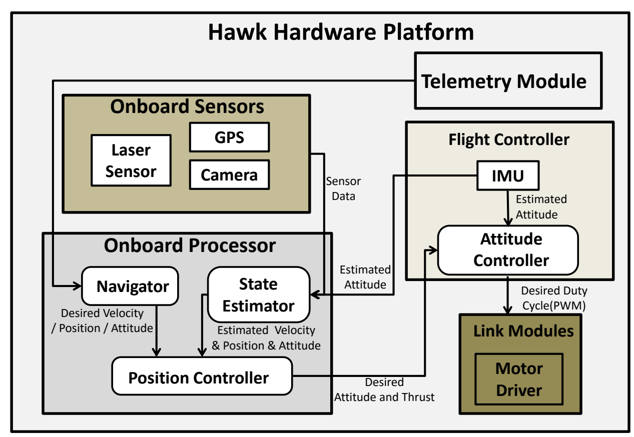


Fig. 2: Hardware platform of "Hawk"

B. Software

The software, including motion planning, visual perception and virtual simulation, are developed on the ROS robot operating system, and we use Gazebo for performing simulations [1]. We use the Gazebo simulator for testing and planning our strategy and for customizing our hardware and software. The visual perception component carries out target (heliport) localization of the moving vehicle, and we plan the efficient approaching and landing strategy based on the motion of both the UAV and the vehicle. Since we use Nvidia TX1 embedded processor for fast computations on GPU, our algorithms for *task 1* and *task 3* are developed in CUDA-C, C/C++ and Python.

C. General Approach

We use the heliport model to train a linear classifier for detection of the landing region. Since heliport model is known, it is used as an a priori for learning. Once the heliport is detected, a visual object tracker running in real time onboard is autonomously initialized to start tracking the target

* [†]http://www.jsk.t.u-tokyo.ac.jp
[1]https://github.com/start-jsk/jsk_mbzirc

Fig. 3: Image of outdoor flight

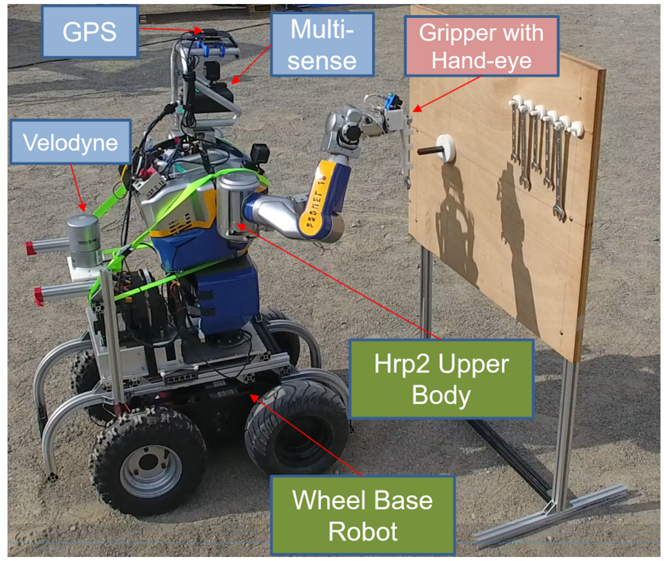


Fig. 4: HRP2 robot platform for task2

region. We use a robust tracking algorithm with efficient drift compensation algorithm to avoid lost of target when the UAV is in motion. Our visual tracking algorithm is also able to recover the target even if it went completely out of view. Once the target is localized, the UAV uses pose information from the visual tracker to navigate towards the target.

D. Future Plans

The future work on hardware platform for task 1 includes the design of landing gear which enables to attach to a moving heliport. The sturdy and light protector of UAV is another issue to avoid the crash while hitting to the truck. The future work on software for task 1 involves testing the completed software on the customized UAV which is currently under development. This involves fine tuning the current simulator version of our software. Considering the challenges in outdoor environment such as abrupt changes in image space, winds speeds etc. the landing strategy might vary significantly from the simulator version. One very important aspect of autonomous systems which we like to implement is the ability of the UAV to recover from erroneous decision, false positives that might result in highly cluttered and unstructured scene. To achieve this we plan to generate a map of the environment at the beginning for efficiently localizing the vehicle and for trajectory mapping. The idea is that, the UAV can use the constructed map, to eliminate regions that produces false positives. However, the current limitation is the time required for generating the map which we aim to reduce using the idea of task oriented solution.

III. CHALLENGE 2: OPERATING A VALVE STEM

A. Hardware

Our robot consists of an upper body humanoid(hrp2) on a high-power mobile base as shown in Fig.4. The robot is equipped with a stereo camera, a long range laser sensor, a global positioning system (GPS), and a custom made gripper. The gripper consists of a magnet embedded link actuated by a servo motor as shown in Fig.5. The wrist is also equipped with a six axis force torque sensor.

The hrp2 is our lab's main robot, it is relatively mature and we have created a lot of software packages for this robot, like the lisp based program language euslisp. We bought a mobile wheel base robot platform to replace the legs of the humanoid robot and designed both the control hardware circuits and the ROS control interface for the moving base.

B. Software

For task 2, the softwares are also implemented on ROS environment with utilization of multithreading for fast computation. Euslisp programming language from JSK lab was used for kinematics simulation and robot control. OpenCV and in-house developed algorithms [2] are used for recognition and perception.

C. General Approach

Navigation: Our approach is to use the long range laser sensor and the GPS positioning for searching and navigating to the panel when the robot is at a far distance and the panel is out of range of stereo sensors. As the panel becomes closer than the minimum range of the laser sensor, the robot will then switch over to use the stereo camera. Our high-powered mobile base can reach up to 4m/s and can drive through various outdoor terrains.

Wrench and valve stem detection: We experimented and compared infrared camera with stereo camera, and we have decided to use stereo camera for close range perception, since infrared cameras tend to fail in outdoor environments subjected to UAV lightings, and cannot sense objects that are too close to the robot.

We detect the wrench by using Edge detection, Hough transform and K-means. Firstly, we select a region circumscribing the 6 wrenches on the camera image as shown in

[2] `https://github.com/jsk-ros-pkg/jsk_recognition`

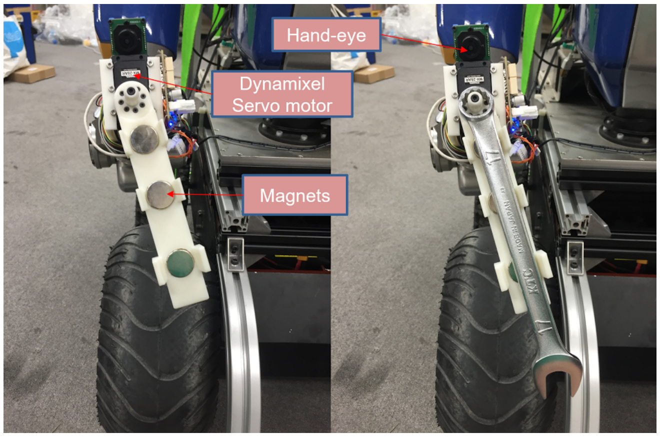


Fig. 5: Custom made magnetic gripper.

Fig.6A. We apply hough line transform to the edge image of selected region and extract lines which have large slopes, then apply K-means (K is 6) to extracted lines. The size of wrenches can be estimated from classified lines, but the position of wrenches estimated from lines is not correct as illustrated in Fig.6B. Therefore we use Hough circle transform to detect the hanger (circular part of the wrench) on image (Fig.6C) and get depth from point cloud (Fig.6D). Hence, we can detect the size and position of wrenches. We also select the region on the camera image to detect the valve stem (Fig.6A). We estimate the plane from the point cloud in the selected region and extract the points in front of the plane (Fig.6E. The centoroid of the extracted points is considered as the position of the valve stem (Fig.6F).

Picking the wrench: Our robot picks up the wrench by aligning the gripper with the wrench, moving the gripper toward the wrench, and letting the magnets pull the wrench into the gripper. The gripper is designed so that the wrench is grasps firmly, but with some movement possible for passive compliance.

Wrench fitting and turning: To fit the wrench head onto the valve stem, we use force feedback from the wrist to gauge the tool contact state. The robot first moves its gripper above the detected position of the valve stem. Due to error in detection or calibration, the wrench head could be directly above the valve stem or it can be slightly misaligned as shown in Fig.7A, B. The robot moves its gripper down, until a force in the vertical direction is detected, indicating that the wrench has come in contact with the valve stem. Once it detects contact with the valve stem, the wrench can be in one of the contacts states as shown in Figure 1 The robot then moves its gripper in the horizontal direction in a widening zigzag pattern. Depending on the forces it detects, the robot then begins to turn the wrench, or adjusts its gripper position and retries to fit the wrench (Fig.7).

D. Results Achieved to Date

We have completed the prototypes of our mobile base and customized gripper. The entire robot has been assembled and all sensors are functional. The robot can be operated through tele-operation, and we have been able to successfully complete challenge 2 using full tele-operation indoors and outdoors. Recognition of the wrenches and the valve stem has also been implemented. Once we select the region to detect wrenches and valve stem, they will be detected autonomously. We experimented with wrench fitting and turning with different initial wrench alignments. Among twenty trials, we were able to achieve a 95% success rate with only one failed trial. We have also tested our system for performing the entire challenge 2 with partial autonomy in outdoor experiments. In our experiments, we used tele-operation to drive the robots mobile base, allowed the robot to detect the wrenches and valve stem with human supervision, and grasp, fit, and turn the wrench with full autonomy. In our fastest run, we were able to complete challenge 2 in less than ten minutes. This time can be easily shortened as many parts of our code had deliberate pauses for debugging and testing purposes.

E. Future Plans

Our future plans include speeding up our task completion time, enabling autonomous navigation of the mobile base, autonomous search of the panel, full autonomous wrench and valve stem detection, and failure detection when grasping, fitting, and turning the wrench. We will also consider and compare alternative wrench detection, and wrench fitting methods. Currently, the valve stem we have been operating has very little resistance. While we have successfully turned a valve stem with 5Nm resistance, our gripper prototype broke after turning a quarter turn. We have already strengthened our gripper design, and as future work, we will be testing with valve stems having higher torque resistance. Finally, we are also considering the potential use of another robot platform that is more lightweight and allows us to more easily transport it from Japan to the competition venue.

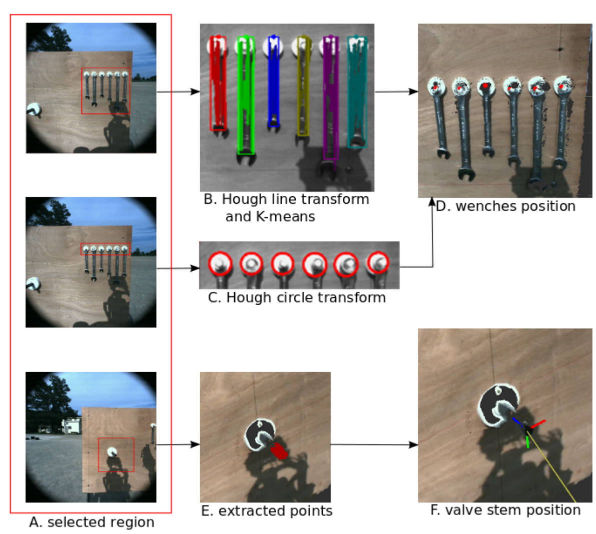


Fig. 6: Wrench and valve stem detection.

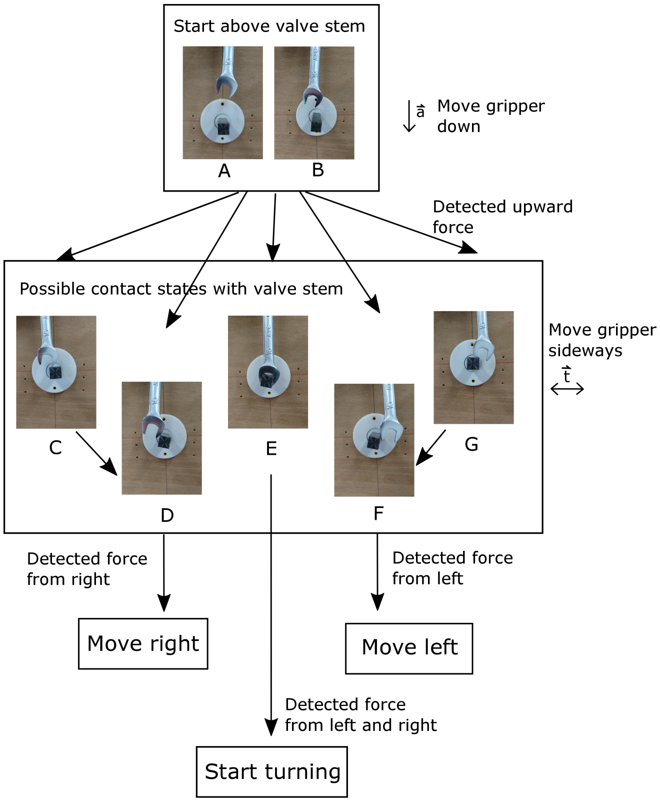


Fig. 7: Using force fitting for wrench fitting

IV. CHALLENGE 3: SEARCH, PICK AND PLACE

V. TASK3

A. Platforms

For task 3, we applied two kinds of UAVs to challenge the task. The general UAV called ”hawk” as shown in Fig.8, which is similar to the one used in task 1, and the transformable aerial robot with multilink which is called ”Hydrus”(Fig.9). As described in Fig.10,tThe hardware platform of ”Hydrus” envolves the controller for joints which enables the stable aerial transformation.

Although the flight control algorithms between ”Hawk” and ”Hydrus” are fundamentally different, we use the smae flight controller board which is build by ourselves. We additionally designed another PCB board for controlling the eletromagnet module which can generate the suction force up to 20[N]. We equipped 5 eletromagnet in the UAV and build the attachment with tactile sensors as shwon in Fig.8(c). The electro-magnet moudle control board is connected to the flight controller board unit through CAN bus.

For the transformable UAV, we introduce the prototype which contains four links and three servo joints. The modularization of the whole platform is achieved by distributing the power and control system to each link with excpect of flight controller and sensors. Therefore, it becomes easier to the change the amount of rotors, according to the application of the flight.

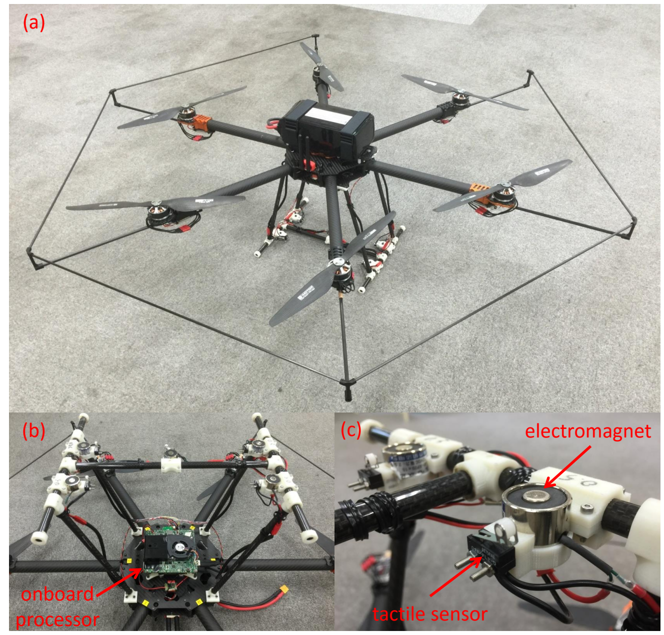


Fig. 8: Image of task3 Hawk

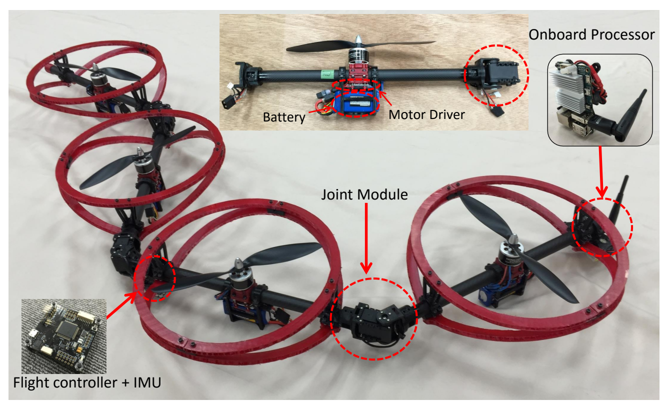


Fig. 9: Image of Hydrus

B. Aerial Manipulation Strategy

For each type of UAV, we develop different piccking method. For ”hawk” type UAV, we appy the magnetic force to absorb the ferrous object as shown in Fig.11. When the contact between the bottom of landing gear and object occurs, the tactile sensor provides certain signal, leading the actication of the eletromagnet module. We have achieve to the pick and carry the object inder indoor enviroment using motion capture system, which confirm the validty of the eletro-magnet based manipulation strategy. The cylinder type object is created according to the regulation description.

On the other hand, the object transporation based on the whole-body-manipulation strategy using ”Hydrus” is also acheived as shown in Fig.12. The grasping control is developped based on the torque feedback from each joint.

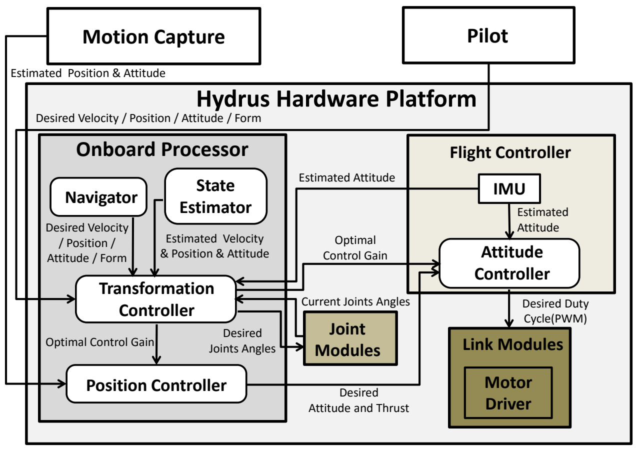


Fig. 10: Hardware platform of task3 Hawk

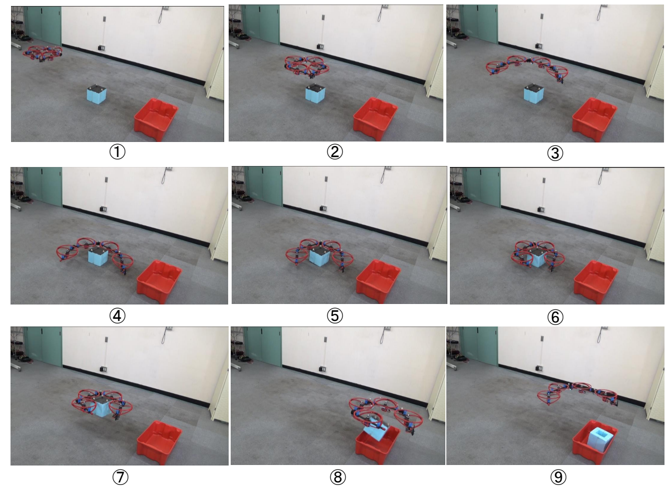


Fig. 12: Aerial manipulation method of Hydrus

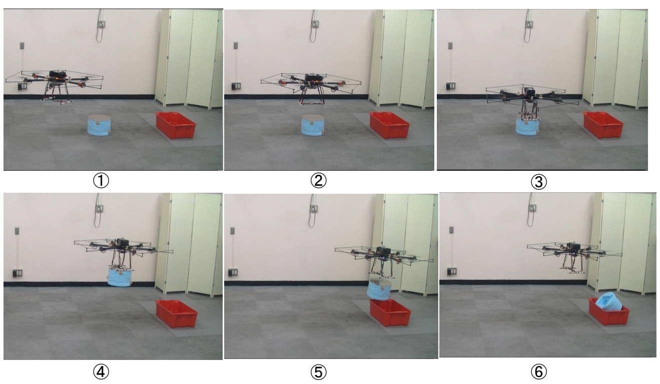


Fig. 11: Aerial manipulation method of Hawk

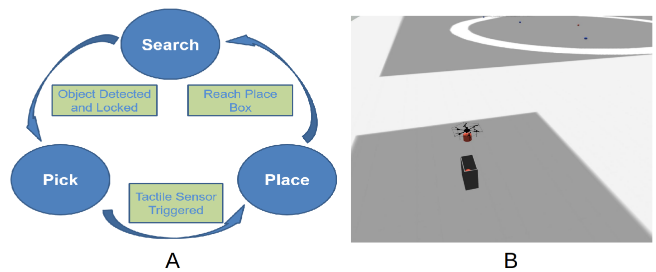


Fig. 13: Task 3 Demonstration

C. Software

Just like other tasks the softwares are build on ROS environment and some functionalities are shared from task 1. Point Cloud and OpenCV libraries are used for visual perception.

1) General Approach: Basically for task 3, we divide the task into three states: Search, Pick and Place. The UAVs are always within these three states and the states automatically transferred to the next one if the certain condition is satisfied as illustrated in Fig. 13A. In "Search" state, the drone will traverse to the center of the arena and randomly generate a search end-point, the treasure detector will work when the drone is searching, once the object is detected and locked, a pick motion will be generated in the "Pick" state, the UAV will open the Elec-Magnet and moving approach to the treasure. The transfer state signal depends on the trigger of the tactile sensor, once the Elec-Magnet catch the treasure, the UAV enters "Place" state, it will directly fly to the placing zone and find the box to place the treasure. After release the treasure upon the place box, the UAV re-enter the "Search" state and loops until task is completed.

2) Treasure Detection: As the treasures have distinct color features compared to the ground, we firstly used a simple detection method to localize the treasure. The inputs are 3D points p_i from the Stereo sensor and the RGB image projection to the ground by the projection matrix computed using the known camera parameters. HSI color filter is applied to obtain to 3D point candidates of treasure from the point cloud data. Next we apply Euclidean clustering to the filtered point cloud P_{hsi}. Euclidean clustering technique can organize points into clusters with respect to the distance feature in 3D space.

When we get all the clusters, we apply a simple tracker to every cluster center and as we continue to detect the same cluster over time space, the weight of the tracker is increased to boost the confidence of tracking. For clusters that are not always detected the confidence are slowly decreased and removed from the treasure candidates vector. The UAV will lock the cluster candidate when the weight is large enough and switch into the "Pick" mode to approach the treasure.

3) Simulation: We first perform full automatic simulation in gazebo environment as shown in Fig.13B. To fully simulate the real scene, we add noise and outliers to the detection. In simulation, the UAV takes almost $70 seconds$ to detect, pick and place a single object. In future we will use three UAVs in coordination to complete the task which will not only decrease the time but also can be used to transport larger treasures which a single UAV might not be able to lift. For real robot, we tested with tele-operation control, both Hawk and transformable UAV can grasp the treasure, pick and place into a specificed box. We are planing to perform more test on the real robot to justify the detection and motion planning algorithm in the simulation as part of the future work.

D. Future Plan

The future work on hardware platform for task 3 contains the improvement of the structural strength, as well as the enhancement of the modularization of link system by using CAN communication network. We will also continue to validate the performance of the eletromagnet module, and the collaboration between the eletromagnetic force and whole-body-manipulation will be developped for the "Hydrus."

The future work on software for task 3 involves the outdoor expeirment with acutal robot to test the performance of both eletromagnet module and whole-body-manipulation. Further more, we will focus on the collaborative motion for picking up the large object using two or three UAV simultaneously, as well as the swarm control strategy while searching object.

VI. GRAND CHALLENGE

A. Setup of TestBed

We have prepared our testbed where we will perform the outdoor testing in the real world is located in Hachioji, Tokyo, Japan as shown in Fig.14. As far we finish developing the robot system for each task in this testbed individually, as the ground challenge is based on all of the three tasks above, we plan to challenge the first three challenges.

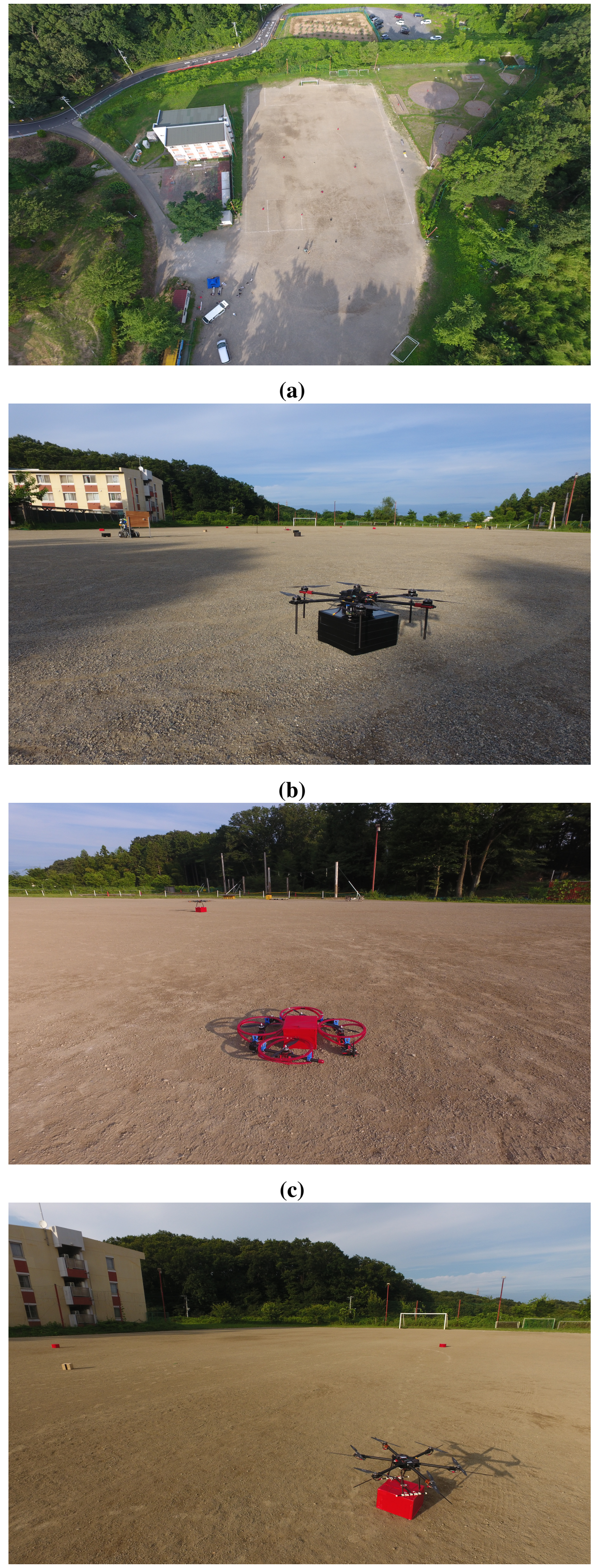
B. Future Work

Once we complete each of the three tasks above, for the grand challenge we will combine each of the 3 tasks above, however we plan to make some changes such as UAV to UAV and UAV to UGV communications such that all the robots are able to collaborate in completing the tasks.

VII. FUTURE PLAN

For now our team finished both design and make the hardware for all the tasks. Build the software architecture and implement the detection and motion algorithm for all the tasks in simulation and tele-operation. However, since the the hardware are new designed and we need more time to debug and adjust the stability of the hardware performance.

In the next step we will implement our detection and motion algorithm on our robot platform and try to make it full autonomous. For software algorithm design, we are trying to address the problem we faced in the simulation and come up with some novel ideas to solve that in real hardware platforms.



(a) **(b)** **(c)** **(d)**

Fig. 14: JSK–Team testbed setup at Hachioji, Tokyo, Japan