RESEARCH ON THE DRONE TECHNOLOGY FOR THE ISS APPLICATION

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INTRODUCTION

It is amazing to see the rapid expansion of the usage of drones and UAVs, and also to know the practical applications of them devised in various fields of business in recent years. Basically, most important thing is how much the drone can adjust its function according to the objectives. By considering the operational needs for crew, I think the drone technology could be useful for the space activities as well.

As one of the examples of drone application on earth, I would like you to imagine a disaster watch. The advantage of drone is that it can fly anywhere. By identifying the objects found at the destination and gathering information such as images, position, and time, it can replace a human job especially in a dangerous work or a patient investigation.

I will place this character of drones at the base of my drone research hereafter.

PROPOSAL OF SPACE DRONE

As the most useful applcation of drones in space, I propose an inventory management on the International Space Station. In this application, the face detection technology of a commercial camera will play a main role. This detection function is not limited to the human face only. If you let the detection system learn the items in advance, it can identify various items with high accuracy. In other words, if you input the information needed to identify items such as notebook PCs and camera lenses, which are likely to be onboard the ISS, the drone flying around the cabin can easily map the location of them.

On the other hand, development of drones suitable for space use is an issue here. It is necessary to use nonflammable and soft materials to build a fuselage. An autonomous avoidance function is indispensable to prevent a collision with the facilities. The wireless communication should not influence the electrical system of the ISS . Autonomous maintenance (battery charge) capability is also desirable so as not to increase a crew job.

ADVANTAGE OF DRONES ON EARTH

- Proxy of human in a dangerous environment (e.g. measurement of radioactivity, alpine accident search)
- Inspection of large infrastructures (e.g. solar panels, dam wall, conveyer, pipeline, power line)
- Facile air capability (e.g. crop-dust, small area mapping)
- Swift arrival to the scene (e.g. traffic accidents, disaster watch)
- High maneuverability (e.g. shooting athletic performance)
- Etc.

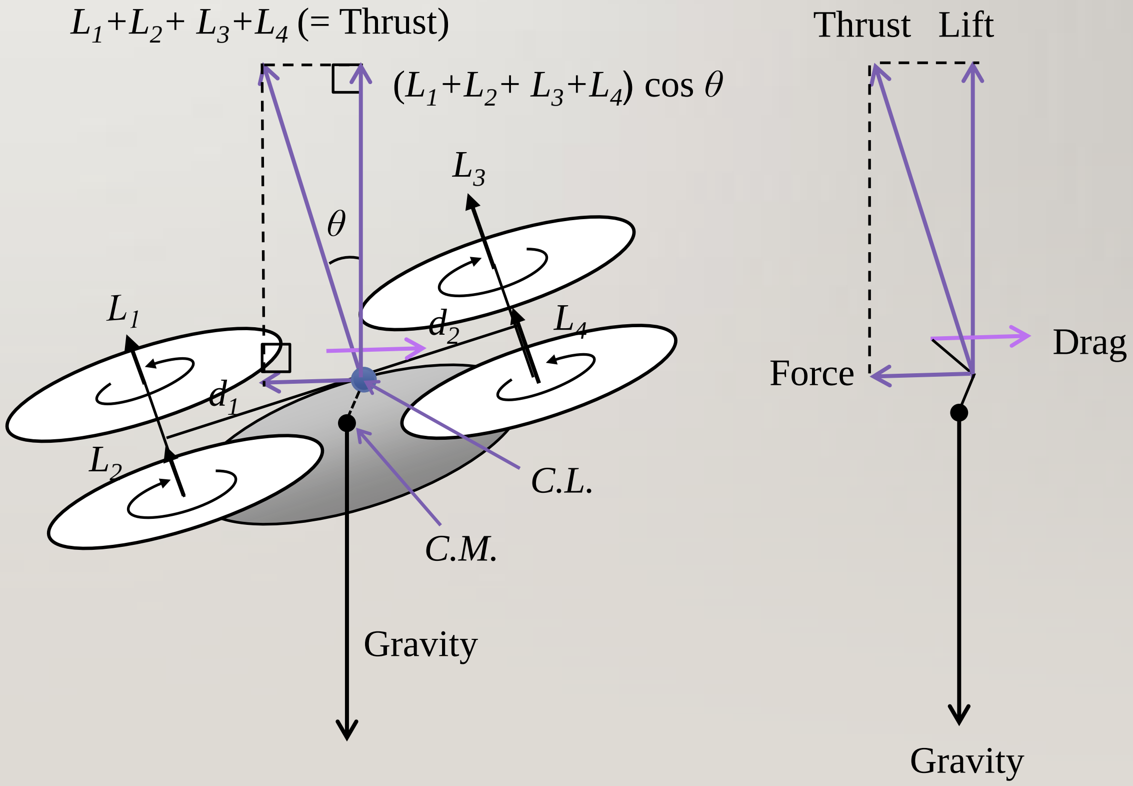

DYNAMICS OF DRONES UNDER THE GRAVITY

- This figure shows the forces work on the quadrotor drone on earth (under gravity) when it moves toward left. Here, the following equations is applied for the equilibria.

$(L_1+L_2) \times d_1 = (L_3+L_4) \times d_2$

$(L_1+L_2+L_3+L_4)\cos\theta = G$

The moment at the center of mass is balanced by the combination of torques (Thrust, Drag and Gravity). Translational force is generated by inclining direction of thrust from the perpendicular line.



QUADROTOR DRONE

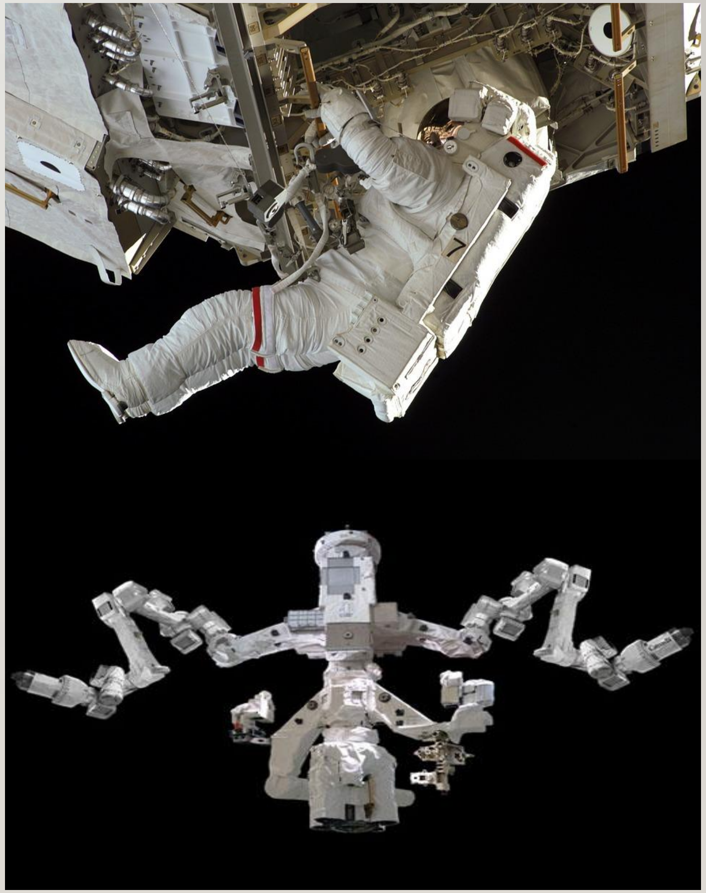
As an example of the drones used on earth, a quadrotor is shown here. The quadrotor has the most simple configuration equipped with four orthogonal rotors. At the same time, it has the most suitable shape for maneuvering under the Earth's gravity.

The adjacent rotors of the drone are made of reversed screw each other and they rotate in the opposite direction when the drone move toward. If all the rotors turn round in the same direction, the drone just rotates at the same place.

Thrust lifts the quadrotor up and down to a desired vertical position, while Roll, Pitch and Yaw control the attitude of the quadrotor.

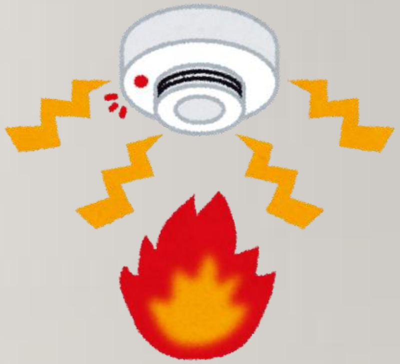
MISSION ANALYSIS FOR THE ISS APPLICATION

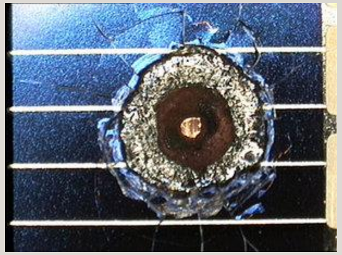
1. General Requirements
   - To provide services to the astronauts
   - To replace astronauts in repeatedly performing works
   - To replace astronauts in dangerous works
2. Technical Feasibility
   - To realize necessary technologies to achieve required functions
   - To accommodate resources for the operation
3. Restrictions
   - Safety concerns
   - Reliability management



POSSIBLE DRONE MISSIONS IN SPACE

1. Crisis control (Supplemental functions to the astronauts)
   - Find dangerous phenomena such as high temperature and unexpected protrusions
   - Emits an alarm signal and fix the problems
2. Inventory management (Replace astronauts in repeatedly performing works)
   - Identify and register scattered items in the cabin
   - Revise a stock list of the items with their location
3. Inspection of the ISS external structures (Replace astronauts in dangerous works)
   - Find damaged structures and parts
   - Repair or replace the damaged structures and parts

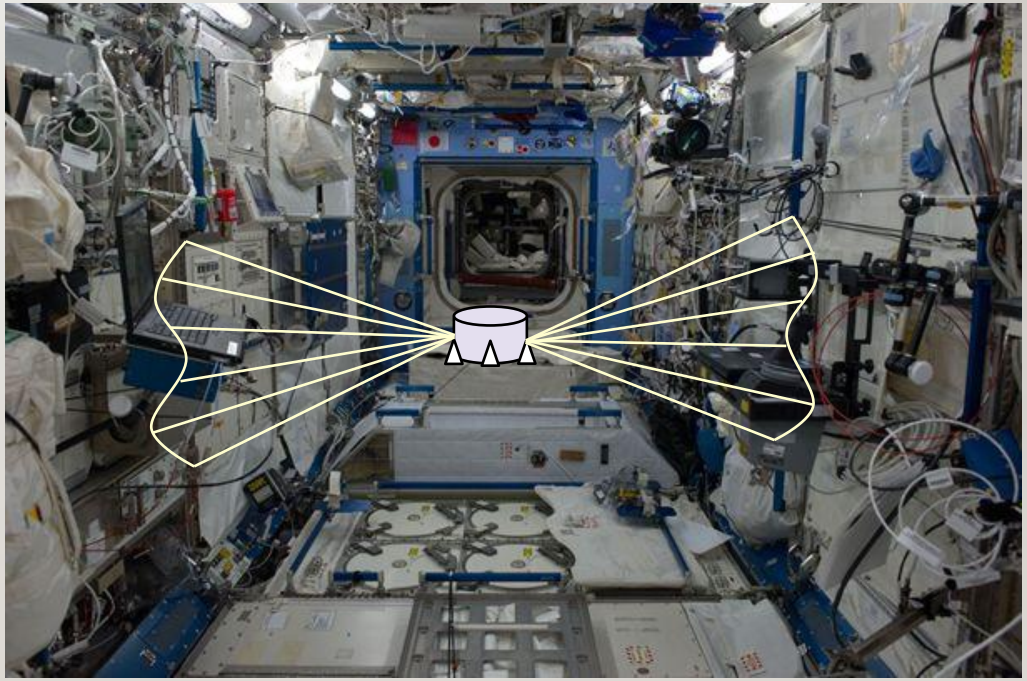




INVENTORY MANAGEMENT IN THE ISS USING DRONE

It happens so often in the ISS that equipment such as a camera lens and hand tools cannot be found when they are needed. The inside of the ISS is somewhat messy and it is not always easy to know the location of equipment.

In order to cope with such a situation, I propose to fly a drone through the cabin periodically and to record the name and the place of scattered items.



TECHNICAL FEASIBILITY

1. Necessary technology to realize the inventory management
   - Automatic surveillance technology including image detection
   - High maneuverability in 6 degrees of freedom
   - Real-time communication
   - Precise guidance and control
2. Available resources
   - Electricity for battery charge
   - Wi-Fi network
   - Laptop computer
   - Air (ambient atmosphere)

RESTRICTIONS IN THE ISS

1. Safety (Hazard)
   - Materials : toxicity, flammability
   - Battery : explosion, leakage (contamination)
   - Rotating device : entanglement, damage to crew
   - Sharp edge : damage to crew
   - Radio interference : malfunction of electric devices
   - Collision : damage to crew and to the system
2. Reliability
   - Data : accuracy
   - Dependability : continuous collection
   - Maintainability : replaceability, reset recovery

COMPARISON OF DRONE DYNAMICS IN MICROGRAVITY WITH 1G ENVIRONMENT

1G (under gravity)

- The gravity can be used for attitude stabilization and translational movement.
- High thrust power is needed to lift the body.
- The wind influences the motion and stability significantly.

Microgravity

- An control device such as the momentum wheel is necessary to keep attitude stability.
- High thrust power is not necessary.
- The inertial force is significant in the dynamics of motion.

DESIRABLE DRONE FOR THE ISS

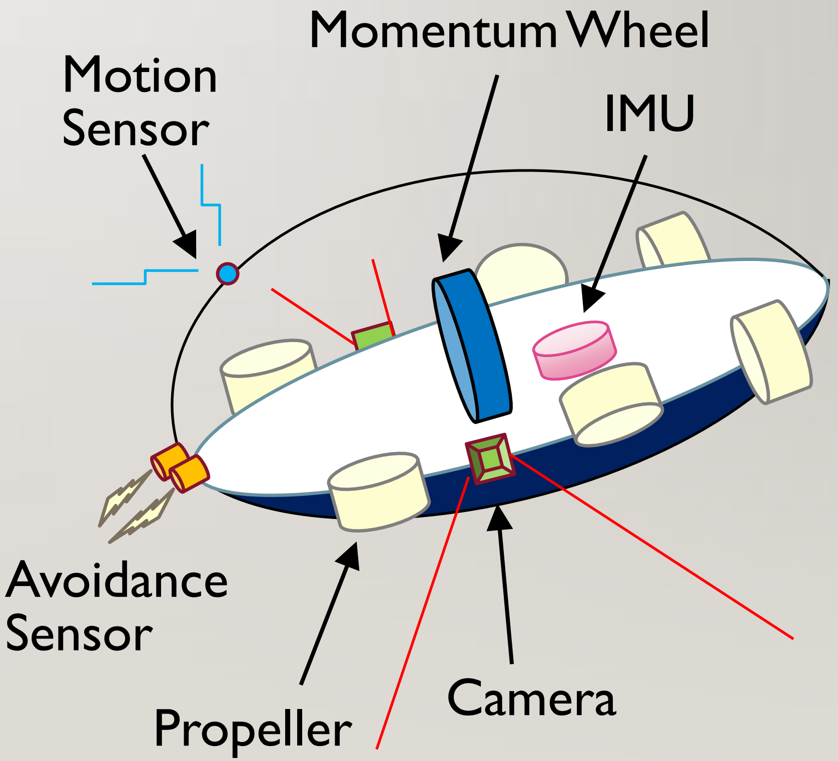
The drone in space does not need a high thrust to heave but requires precise control of attitude and position. It also requires a function to avoid collision.

Then, the desirable space drone is assumed to be presented like a figure on the right.

It consists of small rotors for maneuvering and a momentum wheel for stabilization. For the guidance and control, IMU (gyroscope and accelerometers) is used as the core sensors.

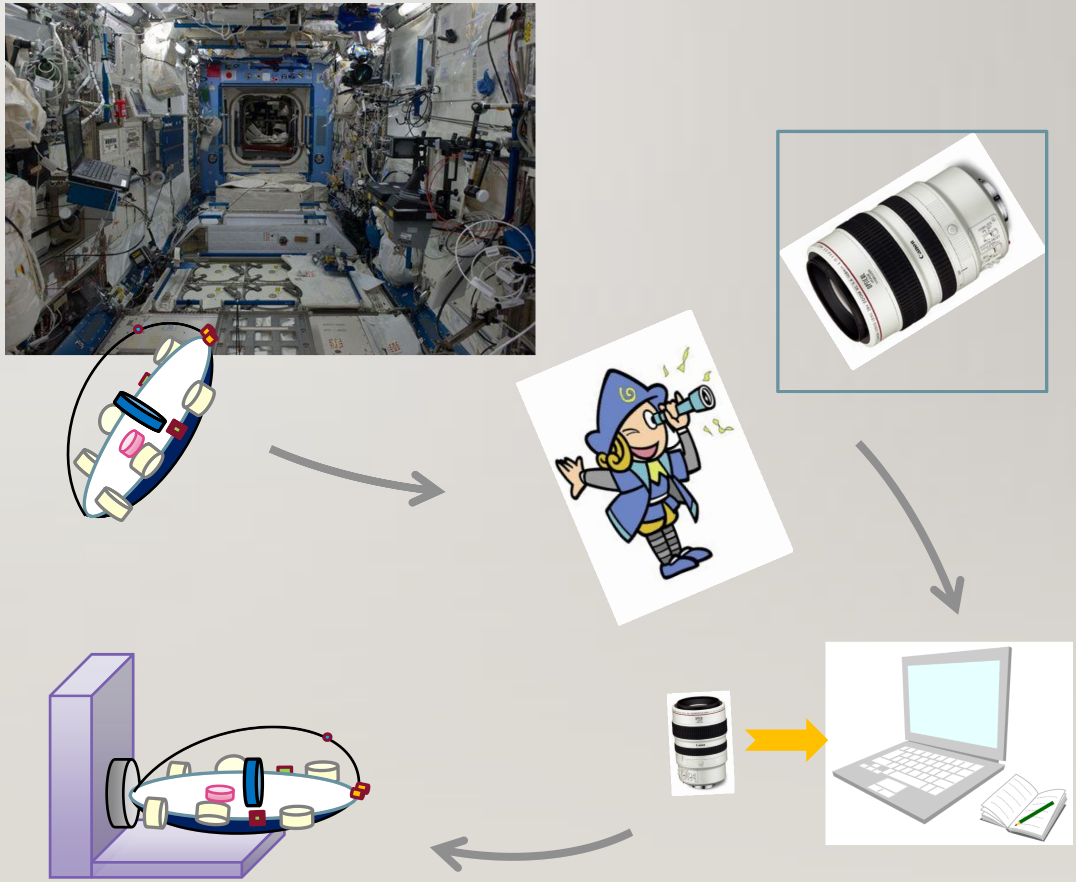
Image detection cameras, a motion sensor, and collision avoidance sensors should be equipped for the purposes of mission accomplishment and safety.

The body of drone must be made of a non-toxic and fire-resistive materials for the reasons of safety and weight saving.



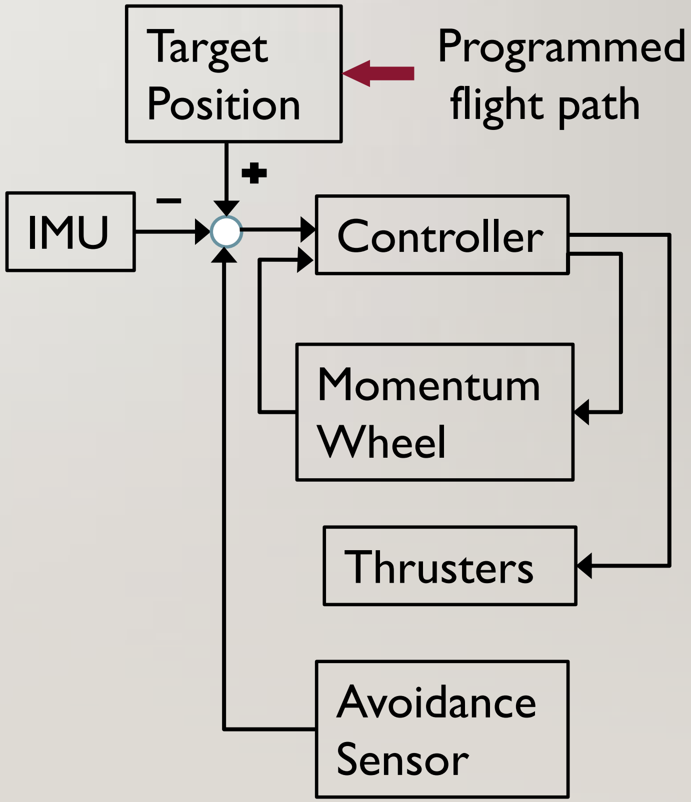
CONCEIVABLE OPERATION SCENARIO

1. Conduct periodical automatic research flights
2. Detect and register scattered items in the cabin
3. Revise a stock list of the onboard items with their location
4. Return to the energy station and self-charge battery



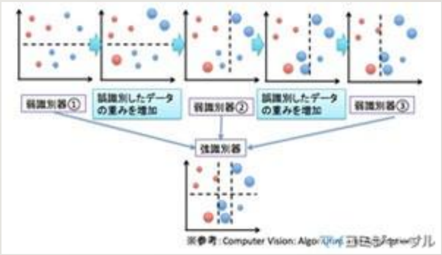
FLIGHT CONTROL OF THE DRONE IN SPACE

- Inertial navigation according to the programmed flight path
- Attitude dynamics control
- Thrust power adjustment
- Collision avoidance
- automatic return to the energy station

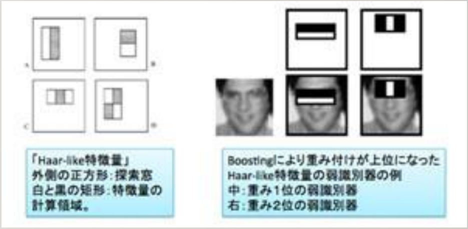


DETECTION OF THE SCATTERED ITEMS

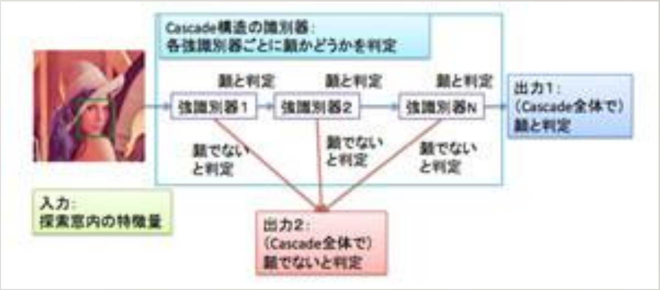
1. Making highly accurate classifiers using AdaBoost algorithm and Haar-like features
   - Combination of weak classifiers through learning of object items (before the operation)
2. Detection of the object items using Cascade classifier by Viola-Jones method
   - Rapid object detection by multiple accurate classifiers
3. Collation of the detected items with the inventory list
4. Update of the inventory list



AdaBoost algorithm



Haar-like features



Viola-Jones method

From "mynavi news"

TECHNICAL CHALLENGES

- Current technologies at hand
  - automatic works and recharge of battery are already realized by a vacuum cleaner "Roomba".
  - Advanced computer vision with obstacle sensors enables "Phantom 4" to avoid obstacles in its path.
  - Recent vision system provides high-speed detection of multiple workpieces.
- Technologies to be developed
  - To furnish the thrusters and attitude control system suitable for microgravity environment.
  - To establish safe radio communication between drone and control station including the inventory management computer.

From "iRobot"

From "DJI Phantom 4"

From OMRON

CONCLUSIONS

- It is without question that the drone technology on earth is applicable to the operations in outer space.
- We may rename a drone to a free-flying robot in the aspect of human support.
- There are lots of available technologies at hand which can enhance the benefit of drones to be used in space.
- International collaboration in development of space drones is easy to be realized because most of the technologies are common with the ground applications and they are easy to be obtained worldwide.
- If only we were given a chance to launch drones into the ISS, a new perspective of space activities will be opened through the collaboration of human and robots in outer space.

Thank you for your attention!