

# Launch of Robotic Fish to the Space: Development of Autonomous Cleaning Robot in the International Space Station

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**Abstract:** This paper describes development of autonomous robot to clean dust in the International Space Station. Clean robot having an autonomous flight control and navigation in Japanese Experiment Module named "KIBO". And, it has function to collect dust which can't be recovered by ISS air conditioning. In this study, the authors chose to fish shapes for cleaning robot. Elastic oscillation fin was realized to have high controllability and soft behavior of creatures. Robotic fish takes evasive action by detecting the astronauts, walls, and obstacles. Then, cleaning work continues safe in cabin. The purpose of robotic fish is to reduce the cleaning workload of astronauts. And, the basic technology contributes to establish autonomous flight control and navigation in zero gravity.

*Keywords:* Spacecraft autonomy, Robotic fish, Elastic oscillation fin, Safe, control, CAD / CAM

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## 1. INTRODUCTION

Environmental Control and Life Support System (ECLSS) is controlled for temperature and humidity, oxygen and carbon dioxide concentration, air-pressure, fire extinguishing, and etc. (Robert, Dale 2005) In the International Space Station cabin. In addition, dust is a problem in closed cabin environment. Dust in the cabin is adsorbed in the air conditioning filter, but is not perfect. Astronauts using vacuum cleaner to clean dust that cannot be absorbed by air conditioning (Fig. 1). (JAXA 2013) Reducing the load of astronaut cleaning is a challenge. Method for behalf of cleaning work is required for increasing efficiency of astronauts' mission. This paper describes development of autonomous robot to clean dust in the International Space Station.

In this study, the authors chose to fish shapes for cleaning robot. A creature suitable for movement under water has the characteristics streamlined body and fin for propulsion and attitude control. Fish shape is excellent to transfer efficiency and maneuverability of three-dimensional. Elastic oscillation fin was realized to have high controllability and soft behavior of creatures. Robotic fish is safe, because outside of robot is not equipped rotary parts, such as propellers. Our design objective is to lower the risk to astronauts and damage to the cabin. This paper introduces trial product robotics fish which is manufactured by "3D printer ". Robotic fish takes evasive action by detecting the astronauts, walls, and obstacles. Authors will verify the autonomous navigation algorithm assumes the cleaning work in Japanese Experiment Module named "KIBO". And, the basic technology contributes to

establish autonomous flight control and navigation in zero gravity.



Fig. 1. Cleaning Work (Vacuum Cleaner). (C) JAXA.

## 2. ROBOTICS FISH

### 2.1 Overview of Robotics Fish

This paper describes development of autonomous robot to clean dust in the International Space Station. Forms of creature have evolved by adapting to surrounding environment. A creature suitable for movement under water has the characteristics streamlined body and fin for propulsion and attitude control. Therefore, fish shape is excellent to

transfer efficiency and maneuverability of three-dimensional. In this study, the authors choose to fish shapes for cleaning robot (Fig. 2), such as fin to move freely. Elastic oscillation fin was realized to have high controllability and soft behavior of creatures. Air bladder is not required for movement in zero gravity. There are many precision instruments in International Space Station cabin. Therefore, to detect a collision and to avoid is required autonomous control system and maneuverability. Also, robotics fish do not harm is required of astronauts. Even if collision, robot must be a safe shape. Robotic fish is safe. Because the robot is not equipped by external rotary parts.

Robotic fish takes evasive action by detecting the astronauts, walls, and obstacles. Clean robot having an autonomous flight control and navigation in Japanese Experiment Module named "KIBO". And, it has function to collect dust which can't be recovered by ISS air conditioning. Robotic fish start to the autonomous navigation after a few seconds to turn on the power. Then, autonomous navigation avoid to astronauts and wall until to turn on the power. To recover dust from robotic fish is cleaned for vacuum cleaner by astronauts.

It was designed to round whale shark which order to calm down for astronauts. Small fish and plankton are swallowed by Whale shark's wide open mouth. Likewise, dust is sucked by robotics fish's wide open mouth. Body size is a limit of legislature of less than 200mm for transport by rocket. Therefore, it is required very compact movement and control mechanism. Size of the robotics fish is 199 (mm) × 135 (mm) × 71 (mm), total weight is about 0.2 (kg).

## 2.2 3D Printer

Outer shell of robotic fish is built by 3D printer. Material of outer shell is ABS resin. Technical information about free desktop 3D printer is published from Rep Rap project. Available to open source software can lower costs of 3D printer. 3D printer "Blade-1" price is about \$ 1,500-, and it can make 3-dimensional modelling to 100 (mm) cube or under. (Hotproceed 2013) 3D printer can manufacture quickly of parts that are designed in 3D CAD.

Fig.3 represents 3D printer work. STL data convert form modelling data that is designed by 3D CAD. Next, 3D printer is controlled by number control of G-code that is generated from STL data. G code send to 3D printer control soft, and make ABS parts by layered manufacturing. Layered manufacturing is method for making parts that is piled layer by cross-sectional shape. "Blade-1" is excreted to heated ABS resin from nozzle of the φ0.5 (mm). And, cross-sectional shape of Layered manufacturing is made with a single stroke of brush. Fig.4 represents parts are made by 3D printer.

"Blade-1" is making in about 20 minutes to 20 (mm) cube parts. Desktop 3D printer is valuable in parts development, and production running cost is low. ABS resin material: 1 (kg), φ1.75 (mm) is sale about \$ 40-.

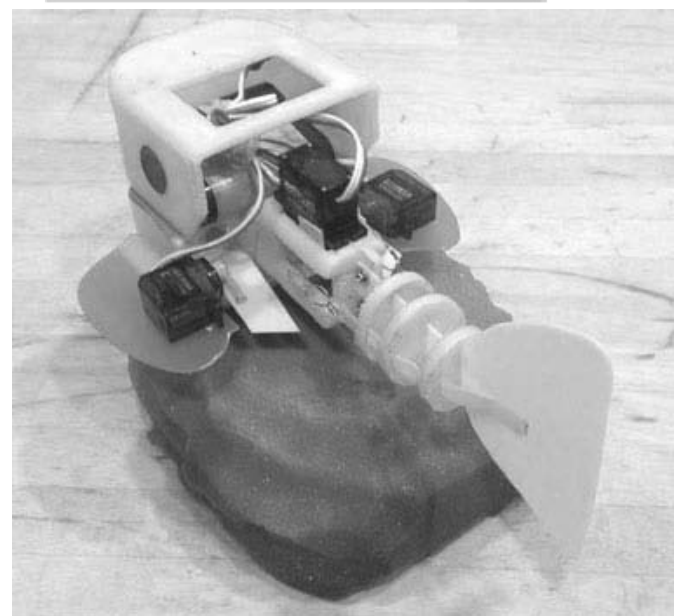
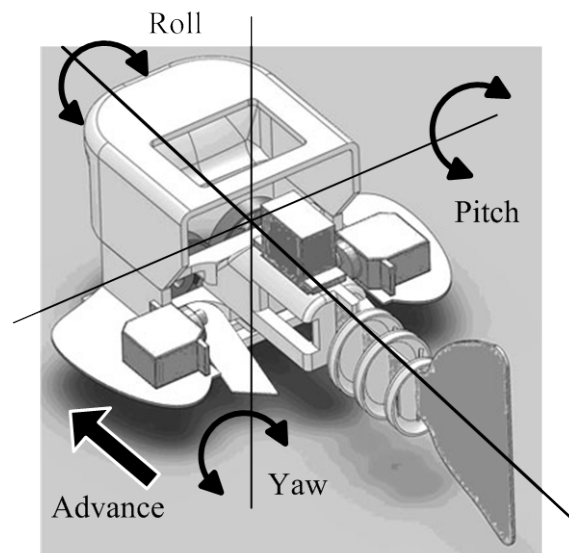


Fig. 2. Trial Type Robotic Fish (3D CAD Model and Photo).

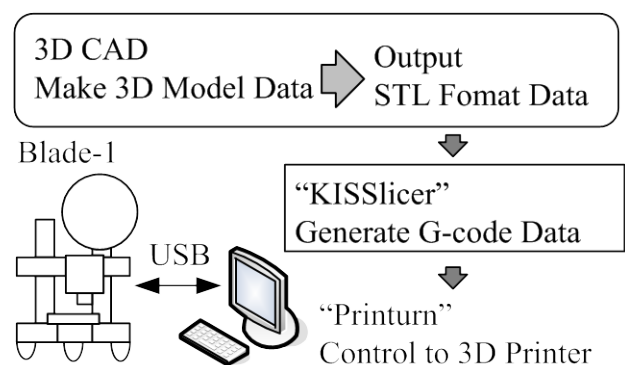


Fig. 3. 3D Printer Work.

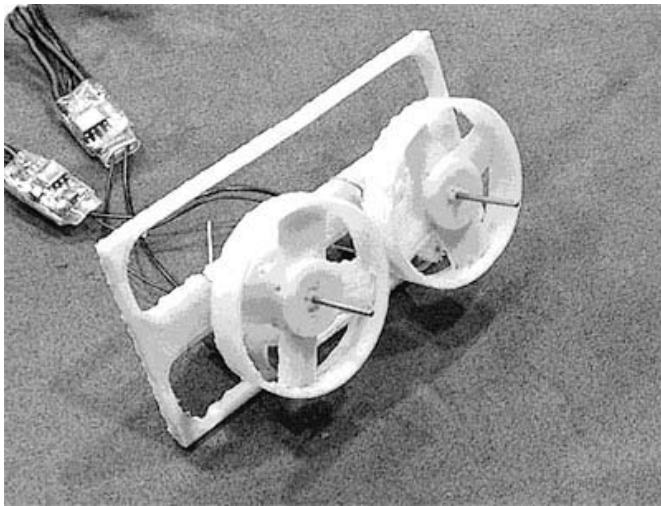


Fig. 4. Made by 3D Printer Parts (Propellers).

### 2.3 Thrust and clean dust mechanism

Fig.5 represents front view of robotics fish. Main thrust is generated in two propellers to turn clockwise and counter clockwise. Rotations of propellers are countervailing to rotation moment each other. Air is aspirated by from the large opening of robotics fish front, and breathes out to steering mechanism the rear. Dust clean filter is equipped with in front of the propellers. While cleaning performing inertial navigation, feeble negative pressure generated in the large opening of robotics fish front. Therefore, propeller to thrust is performing to collect dust. Dust clean filter is applied to absorb dust coating.

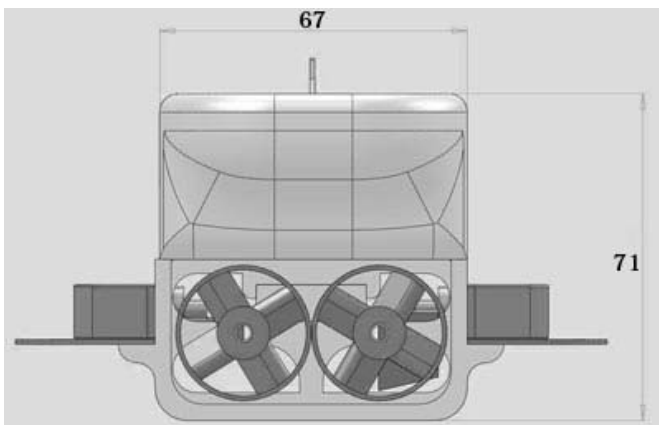


Fig. 5. Front View of Robotics Fish.

### 2.4 Steering Mechanism

Attitude control is using the air to breathe out for robotics fish rear, and bilateral pectoral fins and caudal fin. Attitude control for the roll, pitch and yaw axis is possible by steering mechanism. It is efficient method, breathe out of air is exposed to steering mechanism directly. Elastic oscillation fin is possible large curvature, it is achieved to quick yaw axis change. (Ikuro Yamamoto, 1993) Elastic oscillation fin is generated a small thrust from fin vibration. Fin action is

advancing like a fish shaking the body, and is effective in search of obstacle. To stop robotics fish is turning 180 degrees in yaw axis by elastic vibration fin, and used thrust of propeller.

### 2.5 Control system

In the International Space Station inside, LR6 batteries can use as power supply of robotics fish. Control system of robotics fish is needed to compact and low power microcomputer. Therefore, microcomputer of robotics fish chose to "Arduino Pro Mini 328" (size: 33mm × 18mm × 3mm, Vcc: 3.3V).

Fig.6 represents control system of robotics fish. Start and stop of Robotics fish is obeyed by power switch. Flight speed of Robotics fish is controlled by volume controller. Flight speed can be set to 100 (mm/sec) or less. Obstacle is detected by four infrared sensors, and to perform evasive action. These sensors arrangement is detected the direction and distance of the obstacle with respect to travelling direction. Obstacle direction is detected by infrared sensor, and to move according to the autonomous navigation algorithm.

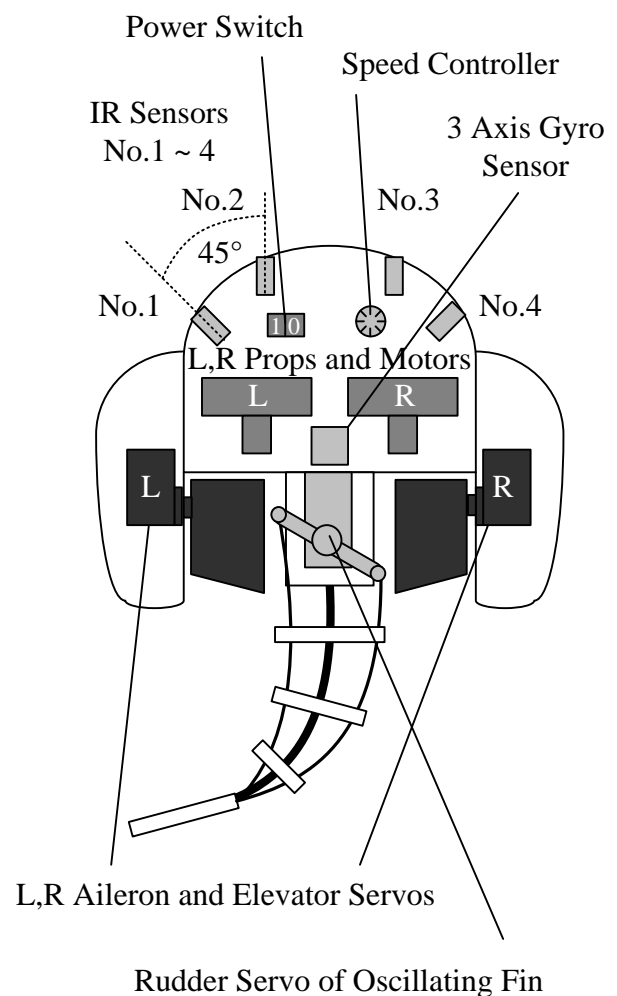


Fig. 6. Control System of Robotics Fish.

When robotics fish is collision to astronauts and obstacles, so it is became to spin state. Therefore, 3-axis gyro sensor is detected the angular acceleration. Robotics fish is recover from the spin state by fins, and back to the autonomous navigation. Spin recovery operation is the highest priority in autonomous navigation.

### 3. AUTONOMOUS NAVIGATION ALGORITHM

#### 3.1 Japanese Experiment Module named "KIBO".

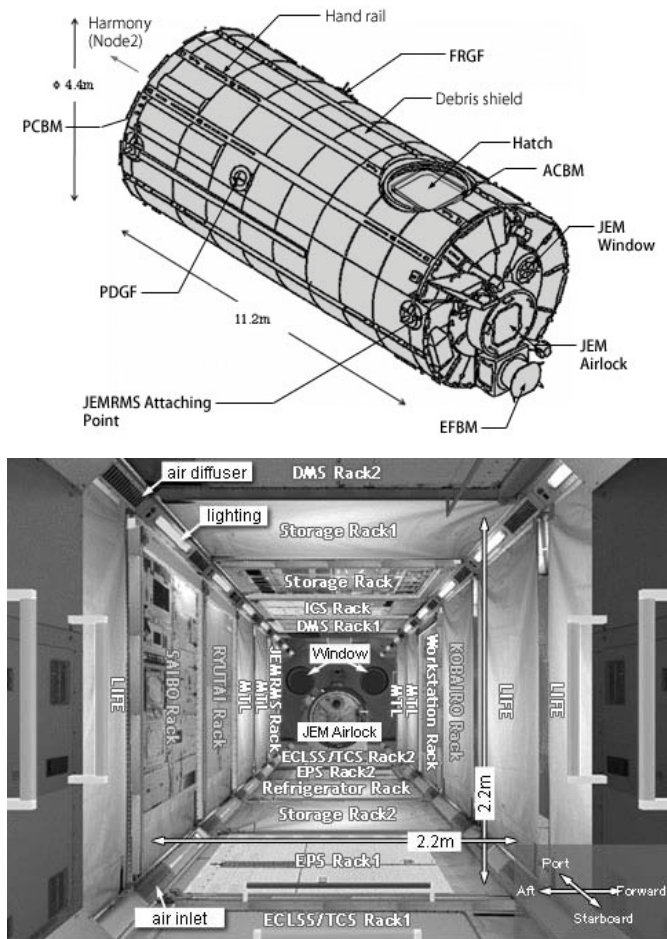


Fig. 7. Japanese Experiment Module named "KIBO".  
(C) JAXA.

Japanese Experiment Module naming "KIBO" (Fig. 7) has the cabin size of 2.2 (m) × 2.2 (m) × 11.2 (m). There are many precision instruments in "KIBO" cabin. Therefore, to detect a collision and to avoid is required autonomous control system and maneuverability.

Our design objective is to lower the risk to astronauts and damage to the ship. Robotic fish takes evasive action by detecting the astronauts, walls, and obstacles. Development objective is construction algorithm for cleaning dust in the cabin. Therefore, it is required efficiently autonomous navigation in all over cabin. Air conditioning (Environmental Control and Life Support System (ECLSS)) by the life support system is working in cabin. But, the air flows assume there is no hindrance to the navigation of the robotics fish.

Disregarded : Roll Axis Change

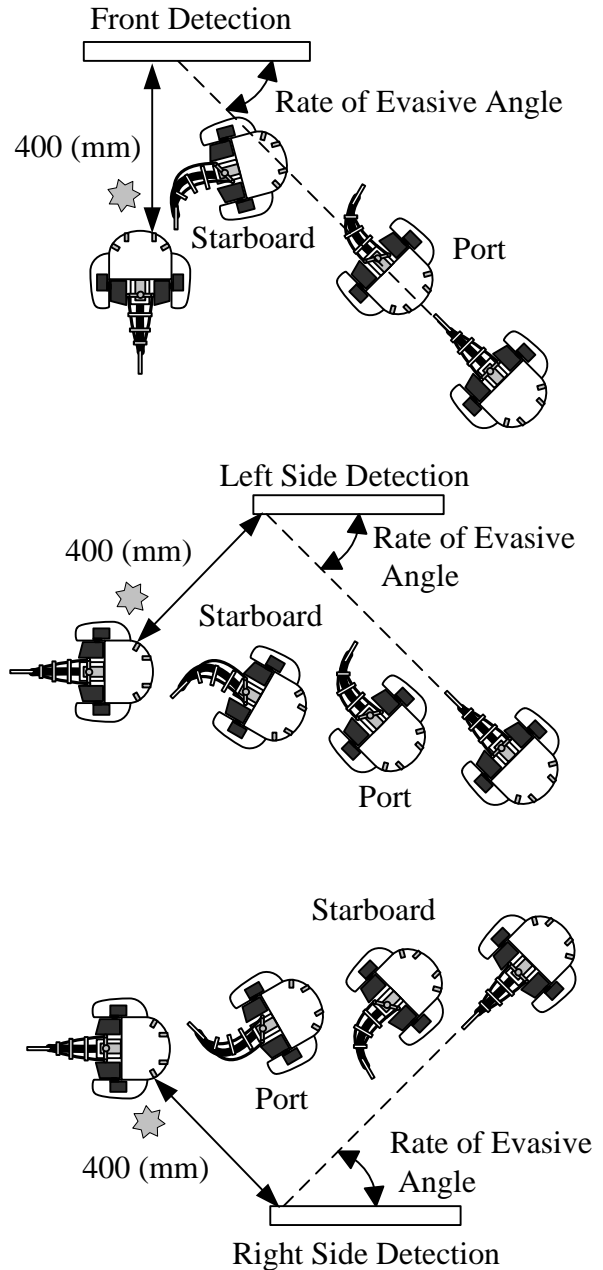
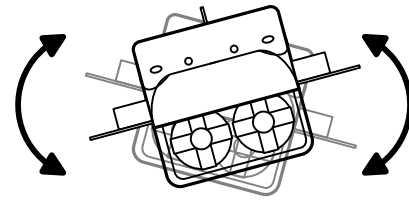


Fig. 8. Autonomous Navigation Algorithm.

### 3.2 Autonomous Navigation Algorithm.

System of robotics fish is referenced "Micromouse contest". (New Technology Foundation 2013) Because, it is a robot contest to advance mazes by detecting the wall. Robotics fish is avoided the complexity of the autonomous navigation algorithm, and target is a higher reliability. In this study, algorithm of autonomous navigation is selected a simple way to reference the behavior of insects. (Mandyam 2010, p. 413)

In the cabin is no distinction top and bottom for zero gravity. Therefore, robotics fish is disregarded roll axis change. Navigation stability control is performed to the pitch and yaw axis by gyro sensor. Obstacle is detected by four infrared sensors of front, and to perform evasive action. Basically evasive action is starboard.

Obstacle direction is detected by infrared sensor of front, and to move according to autonomous navigation algorithm (Fig. 8). Obstacle detection of the infrared sensor is two-dimensional. obstacles are detected in 400(mm) or less for front, right side, and left side, and robotics fish take evasive action. Evasive action is similar to insects that responded to sensory organs. So, autonomous navigation algorithm is written in small program code. Evasive action is correspond with rate of evasive angle, and to change track. Evasive angle is managed to Proportional Integral controller from value of infrared sensors and gyro sensor. Change the avoidance angle, to explore the cabin cleaning efficient.

### 3.3 Simulation of Evasive Angle

Navigation track is simulated rate of evasive angle 30 (°), 45 (°), and 60 (°), and "KIBO" cabin is estimated to two-dimensional (Fig. 9). Robotics fish is started from center of cabin, and to begin moving for airlock side. Condition of Each evasive angle simulation to the tracks is velocity: 0.1 (m / sec) and 10 (min). Cabin is assumed that there is no obstacle of wall other. Start point is indicated by double circles, and end point is indicated by circles. Bold line shows the "KIBO" cabin.

It was found that 45 (°) evasive angle is cruising the cabin almost equally. Evasive angle 45 ° is possible to reduce the correction amount from any intrusion angle. Autonomous navigation algorithm is two-dimensional. During navigation, three-dimensional moving is able to show prediction for roll changing of robotics fish.

Therefore, navigation track is simulated in three-dimensional space(Fig. 10), evasive angle 45 °, roll: CW 0.5 (° / sec), speed: 0.1 (m / sec). The navigation track is shown by X-Y and X-Z plane. Small roll changing is accorded to changing of Z-axis direction by the evasive action.

From the simulation results, the envisaged that 45 (°) evasive angle is cruising the cabin almost equally.

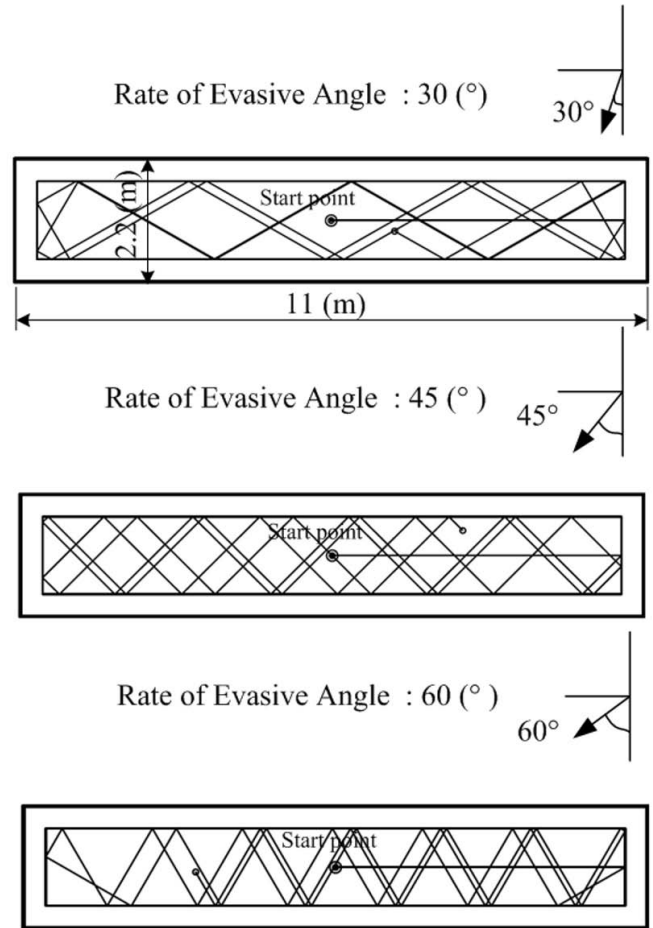


Fig. 9. Result of Each Evasive Angle Simulation to the Tracks.

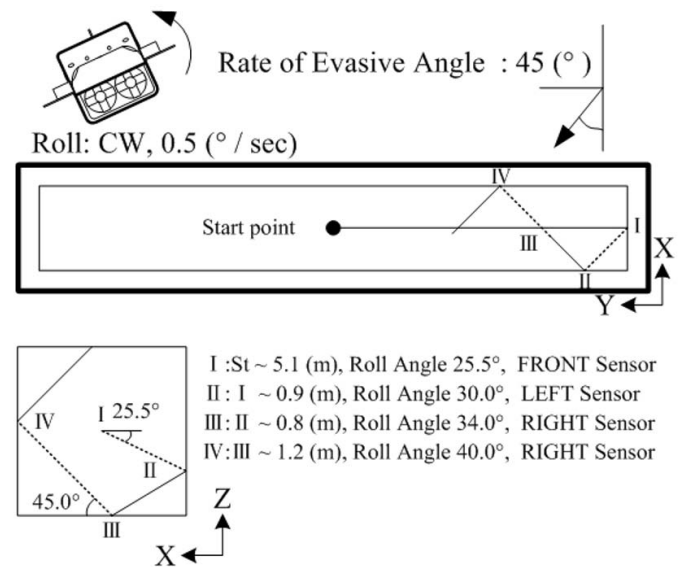


Fig. 10. Result of Simulation to Three-Dimensional Track.

#### 4. CONCLUSIONS

This paper has made a trial product of autonomous robotics fish to clean dust in the International Space Station. 3D printer can manufacture quickly of parts that are designed in 3D CAD. Elastic oscillation fin was realized to have high controllability and soft behavior of creatures. It was predicted that simple algorithm of autonomous navigation is cruising the cabin almost equally. The future, robotics fish is required to correspondence for Electro-Magnetic Compatibility Test, Vibration Test, Aging Test, Offgas Test.

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