(19)

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie

(11) N° de publication : **LU503146**

(12) **BREVET D'INVENTION** **B1**

(21) N° de dépôt: LU503146

(51) Int. Cl.:
B64G 7/00, G09B 9/08

(22) Date de dépôt: 07/12/2022

(30) Priorité:

(43) Date de mise à disposition du public: 07/06/2024

(47) Date de délivrance: 07/06/2024

(73) Titulaire(s):
UNIVERSITE DU LUXEMBOURG – 4365 ESCH-SUR-ALZETTE (Luxembourg)

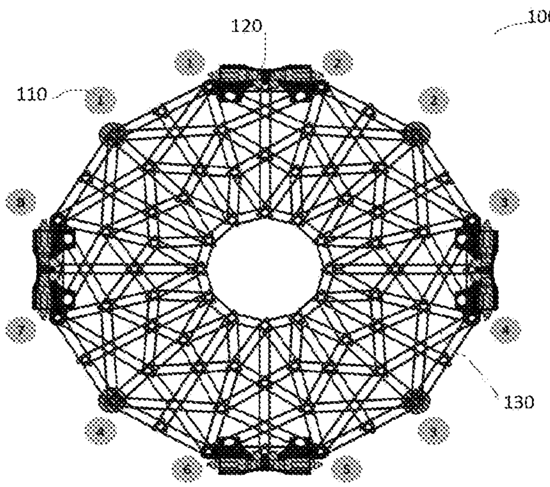
(72) Inventeur(s):
MARTINEZ Carol – Luxembourg, BOKAL Zhanna – Luxembourg, YALCIN Baris Can – Luxembourg, OLIVARES-MENDEZ Miguel Angel – Luxembourg, COLOMA Sofia – Luxembourg, SKRZYPCZYK Ernest – Luxembourg

(74) Mandataire(s):
ARONOVA S.A. – L-4004 ESCH-SUR-ALZETTE (Luxembourg)

(54) **PNEUMATIC FLOATING SYSTEMS FOR PERFORMING ZERO-GRAVITY EXPERIMENTS.**

(57) An aspect of the present invention relates to an arrangement for performing experiments with objects while mimicking zero-gravity conditions, comprising: (i) a support and (ii) one or more platform, comprising (a) a first set of pneumatic components arranged for blowing a pressurized fluid (air) to said support enabling the platform to detach from said support; (b) a second set of pneumatic components, different (in terms of performance) from said first set of pneumatic components, enabling the platform to move in one or more degrees of freedom; (c) one or more means for mounting objects to said platform and (d) one or more means for storage of said pressurized fluid.

Fig. 1



DESCRIPTION

PNEUMATIC FLOATING SYSTEMS FOR PERFORMING ZERO-GRAVITY EXPERIMENTS

FIELD OF THE INVENTION

The invention relates to arrangements, also denoted labs, for performing experiments with objects while mimicking zero-gravity conditions (meaning no or very low friction in 2D), such that movements of objects do cause effects on other objects (as observed in space). The invention also relates to systems, here denoted platforms, being part of such arrangements. The invention further relates to computer implemented methods supporting the use or operation of said arrangements and/or platforms.

BACKGROUND OF THE INVENTION

Earth orbits have crucial space debris pollution problem caused by millions of non-functional human-made objects left in space with varying geometry and weight, such as spacecrafts, construction materials from ISS (International Space Station), collision fragments, part of rockets, non-functional satellites etc. Most of the debris is concentrated in the near-Earth space region, becoming a hazard for current operational and future space missions. The Kessler Syndrome states that the number of space debris and active satellites are exponentially increasing, and eventually, there will not be a chance for a spacecraft to be placed in an earth orbit. This problem opens massive opportunities for R&D on low-cost servicing missions that provides ADR (Active Space Debris Removal) capabilities. However, the problem is; how to test, verify and validate ADR systems with on-ground testing conditions? One of the most challenging and risky tasks for an ADR mission is to realize the interaction scenarios of separate spacecrafts, such as rendezvous, docking, capture etc. Parabolic flight tests for validation and verification for ADR systems are inconvenient and time consuming. To avoid any failure, institutions and companies have to be confident about the validity of their products before setting a commercial or research mission to space. To tackle this problem, mission verification and validation experiments need to be simulated and tested in a laboratory environment before facing the reality of frictionless space condition. Ground based testing, verification and validation of the interaction model of two different spacecrafts is troublesome work since realizing both Guidance, Navigation and Control (GNC) and contact dynamics scenarios of two different spacecrafts with zero-gravity condition require the usage of high-tech laboratory equipment.

It is a troublesome task to conduct verification, validation and testing of the space related engineering system, since we cannot escape from the gravity on Earth. However, we can create pseudo non-gravitation scenarios using floating platforms. Space debris mock-ups can be mounted on top of the floating platform and simulate any space-related scenario. In the academia and industry, floating platforms have been developed and frequently used by many institutions to mimic space-related scenarios (NASA, ESA, DLR, York University from Canada) but have severe shortcomings...

Floating platforms existing in the literature do not have appropriate control structures, they are being controlled in a very primitive way, mostly by a simple Radio Control (RC) receiver with an open-loop structure. However more advanced control structures are needed to realize space interaction scenarios of ADR systems, such as capturing phase between the chaser and target satellites.

The studies in the literature have been conducted using simple RC receiver controlled by an operator.

AIM OF THE INVENTION

Design of floating platforms suited for the field of verification, validation and testing of the space related engineering systems is challenging. The invention provides the arrangements and systems or platforms being part of that arrangement and related computer implemented methods like a planner that are suited for such purpose.

SUMMARY OF THE INVENTION

The invention provides an advanced mechatronic system, namely floating platform, to successfully deal with this issue. Floating platform is based on or has pneumatic components that blow high pressurized air towards super-flat epoxy floor to cut off the mechanical contact between the pneumatic components mounted beneath the floating platform and the epoxy floor. In other words, the floating platform can informally be named as space-drone. Mock-up of space debris or ADR system can be mounted on top of floating platform. Therefore, with two floating platforms, one carrying ADR system and the other carrying space debris mock-up, can be used to verify and validate ADR system's performance on 2D frictionless plane. Moreover, through actuation of the nozzles of the floating platform, we can drive the floating platform in plane as if we have the ability to move an object in 2D space.

Said pneumatic components are preferably “air-bearings”.

Alternatively said the invention provides an arrangement (lab) for performing experiments with objects while mimicking zero-gravity conditions (no friction in 2D), comprising: (i) a (super-flat) (epoxy) support (floor) and (ii) one or more (floating) platform, comprising (a) a first set of pneumatic components arranged for blowing a pressurized fluid (air) to said support enabling the platform to detach from said support (*and positioned to compensate the weight distribution of the platform in a homogeneous way*); (b) a second set of pneumatic components (nozzles) (two per degree of freedom), different (in terms of performance) from said first set of pneumatic components, enabling the platform to move in one or more (translational and/or rotational) degrees of freedom (above and parallel to said support); (c) one or more means for mounting objects to said platform and (d) one or more (carbon-fiber) means for storage of said pressurized fluid (air).

In an embodiment of the invention said first set of pneumatic components being (aerostatic) air-bearings.

An embodiment of the invention is arranged for (feed-back) closed-loop position control of said second set of pneumatic components to enable ADR (Active Space Debris Removal) capability testing and further being arranged for open-loop control of said first set of pneumatic components).

In an embodiment of the invention said first and/or second pneumatic components are fed by (solenoid) valves and wherein said valves operated in a first pressure range and said one or more means for storage of pressurized fluid operating in a substantially different second pressure range (higher than said first pressure range); and said platform further being provided with means for pressure reduction, preferably in two steps, said means for pressure reduction receiving pressure sensor information (e.g. provided by a pressure sensor arranged on said one or more means for storage of said pressurized fluid).

In an embodiment of the invention the control of said first (and/or second pneumatic components) is arranged to minimize oscillations (caused by the mechanical dynamics of the valves) by providing for one or more (preferably all) components at least two supplies of pressurized fluid (and hence two valves). Note that hence the invention is about a dedicated selection of pneumatic components that offer the capability of accepting two (or even more) fluid (air) inputs for such purpose.

In an embodiment of the invention said platform is designed as a grid-like, string-like structure with (additive manufacturing) (carbon) fiber material.

In an embodiment of the invention said platform is further comprising first electronic components for providing (computed) control signals to one or more of said components (and said platform further comprising energy storage means (power bank) to said first electronic components).

In an embodiment of the invention said platform is further comprising second electronic components (camera, sensors) for sensing one or more of said components and/or third electro-mechanical components (robotic arms) for providing actuation capability (and said platform further comprising energy storage means (power bank) to said second electronic components and/or third electro-mechanical components).

In an embodiment of the invention said platform is comprising one or more (removably fixed) geometrically identical regular shaped (additive manufactured) plates (e.g. dodecagon (12-sided polygon), which are mechanically connected (and on which the other components are mounted).

In an embodiment of the invention each of said plates being provided with a different identification signage (e.g. color); and the arrangement further comprising: identification means (OptiTrack Motion Capture System) capable of identifying each of said plates based on said identification signage (said identification means being able to derive position information directly and compute velocity and accelerating information of said platform therefrom).

In an embodiment of the invention one of said plates being provided with said first and second set of pneumatic components (and at least one of said first electronic components) and one or more of the other plates with further first electronic components, second electronic components (preferably with accelerometer capabilities preferably at the geometric centre, pressure measurements) and third electro-mechanical components.

In an embodiment of said invention said first electronic components include means for driving said valves.

Finally the invention also disclosed a variety of computer implemented methods (executed on one or more computing platforms) in relation to use of the one or more of said platforms.

Note that the various embodiments of the invention can be and are preferably combined.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig 1. Lower plate geometry.

Fig 2. Middle and upper plate perspective geometry.

Fig 3. Air-bearings's levitation force-levitation gap relation curve.

Fig 4. Functional diagram.

Fig 5. Nozzle force and pressure regulation relation.

Fig 6. **a)** MPU6050 and 3d printed assembly part, **b)** MPU6050 assembled on the floating platform.

Fig 7. The lower plate with the equipment.

Fig 8. The floating platform CAD drawing.

DETAILED DESCRIPTION OF THE INVENTION

GENERAL TECHNICAL CONSIDERATIONS

The invention is about technical considerations to be made in relation to the number and type of components, like air-bearings and nozzles and their associated weight versus the control capabilities of certain methods in relation to the different (severe) control requirements dictated by the selected set-up and the experimental requirements respectively.

It is worth noting that for a realistic stable detaching of said platform from said support at least **three,** preferably four actuators (pneumatic components) are required but obviously only directed in one direction (generating a a pressurized fluid (air) against gravity).

It is further worth noting that for other translational degrees of freedom (in a plane orthogonal to the gravity direction) that it is sufficient per degree of freedom direction to have one actuator. As a translational degree of freedom requires two directions, hence a total of **two** actuators per degree of freedom is obtained. Note that stability issues (e.g. caused by misalignment could get corrected by using the control on the other degree of freedom).

It is further worth noting that for the rotational degree of freedom (in a plane orthogonal to the gravity direction) that it is sufficient per degree of freedom direction to have **two** actuators. Due to the nature of a rotational degree of freedom 1 direction (clock-wise or counter clock-wise) is sufficient, hence a total of **two** actuators per degree of freedom is obtained. In an alternative embodiment one may choose two directions also.

For control purposes, one has in theory the choice between open-loop control, which requires **one** actuator, or closed-loop control, which requires one actuator and one sensor, hence **two** weight carrying components.

Despite the severe control requirements in that the levitation gap (between platform and support) is extremely small (in a particular embodiment levitation gap is smaller than 35 microns, preferably 30 microns during the operation, in a further exemplary embodiment the air-gap between the floating platform and epoxy surface is even 5 micron), given the impact on weight as elaborated above (factor 3, preferably 4 for the detaching versus two of the other degrees of freedom), within the invented platform the choice is made to opt for open-loop control for the detaching and closed-loop control for the other degrees of freedom.

It is worth emphasizing that oscillations (in fluid pressure) may cause control issues (in view of the severe control requirements) mentioned above, therefore, despite the impact on weight (doubling of components) a dual input method is applied, not only for the closed-loop controlled degrees of freedom but preferably also for the open-loop one.

Given the requirement of detaching by use of blowing a pressurized fluid (air), the total weight of each of the platforms is important. It is a contribution of the invention to elect carbon-fiber as material choice for parts of the platform. The total weight however is determined by the material choice but also the amount and type of components, which in turn depend on the total weight, hence in theory a solution might not even be feasible. It is a contribution of the invention to provide a dedicated platform set-up by selecting an extremely small levitation gap (in the sense that this does require additional control considerations) in combination with reasonable fluid storage and fluid pressures for enabling experiment for a practical time duration. In particular the control concern in relation to oscillations (in view of the extremely small gap) requires a 2 input mechanism, leading to additional components. Furthermore the choice of a relative high pressure for storage of the fluid viewed in relation to the required force to be generates requires an extra pressure regulation component, preferably two, hence additional components.

In essence in the invention the option was taken to reduce the basic weight of the platforms by the material choice but also electing (pneumatic) components of which the performance versus extra weight ratio leads to a solution, more over a practical solution, meaning having some margin to add additional components for control required for the necessary experiments for this field. LU503146

DESCRIPTION OF AN EXAMPLARY EMBODIMENT OF THE INVENTION

The invented floating platform is an advanced mechatronic device, uses pneumatic components called "air-bearing" that blow high pressurized air towards the Zero- G lab's floor to cut the mechanical contact between the air-bearing (mounted beneath the floating platform) and the floor. The floating platform has also capability to move in 3 degree-of-freedom via its nozzles. Space debris mock-ups can be mounted on top of the floating platform and simulate any space-related scenario

Nevertheless, the design procedures of this engineering system have crucial difficulties, such that;

- The more weight the floating platform has, the more difficult to make it fly. To fly the floating platform, high pressure air is needed, and it is very hard to obtain it in a proper way since the pressurized air has non-linear nature. To achieve this task, the whole mechanical structure needs to be light-weight.
- All the mechatronic components of the floating platform are properly chosen and located on the floating platform. It is not that easy to have lots of electric and pneumatic components and have them integrated with each other.
- The originality of the invention comes from the lightweight and compact structure of the mechanical design. To make the floating platform work, all the components have to be chosen carefully and integrated with each other precisely.

The exemplary design discussed here and the generalization thereof as discussed in the claims satisfies the above-given matters in an appropriate way and brings a novel solution for the floating platform design aspects.

The floating platforms use pressurized air to "fly" as the air-bearings repulse pressurized air to cut off the mechanical contact between the floating platform and epoxy floor. Which means that; the more weight the floating platform has, the more air it consumes. To find a novel solution for this problem, the floating platform that has been designed by SpaceR includes "ultra light-weight" carbon-fiber material which reduces the overall weight considerably to lower levels. Therefore, the floating platform can endure more with same amount of air compared to the equivalent ones. Another advantage that has been brought by the carbon-fiber structure, as given in Fig. 1 and Fig. 2, is the

easiness of assembling more equipment on the floating platform (camera, sensors, robotic arms *etc.*). LU503146
The grid-like structure of the carbon-fiber material allows to locate any equipment in a compact form.

The invented novel floating platform design is made of additive manufacturing based ultra light-weight carbon-fiber material. The weight of the floating platform is a very important factor since it determines the endurance of the floating platform, thus the endurance of the experiments. If the floating platform's weight increases, air-bearings consume more air to compensate the increased weight. Another novelty presented in this paper is the closed-loop position control capability of the floating platform. Floating platforms existing in the literature do not have closed-loop control structures, they are being controlled in a very primitive way, mostly by a simple Radio Control (RC) receiver with an open-loop structure. However, closed-loop structure, especially position-feedback control, is needed to realize space interaction scenarios of ADR systems, such as capturing phase between the chaser and target satellites. The floating platform as shown here has an ARM based processor, 1.5GHz 64-bit quad-core ARM Cortex-A72 CPU integrated with Ubuntu OS, which can be used for drone-like application, such as obstacle avoidance, trajectory tracking, path planning and any other GNC application as integrated with several sensors. Due to the floating platform has its own IP address, on-board sensors can be used for many network applications, such as cloud/edge computing, sensor fusion, Software-in-the-loop (SIL) and Hardware-in-the-loop (HIL) etc.

Structure of the Floating Platform

a) Plates

The floating platform consists of three geometrically identical dodecagon (12-sided polygon) plates that made of string-like carbon-fiber material. This string-like design approach provides super light-weight property with economical usage of the volume and mechanical strength at the same time due to the physical properties of the carbon-fiber based additive manufacturing method. The lower plate is full black, whereas the middle and upper plates have four different colors, grey, blue, red and white as shown in Fig. 1 and Fig. 2. The reason of colorful configuration is to identify the orientation of the floating platform using OptiTrack Motion Capture System (MCS). From Fig. 1, it can also be seen that the lower plate integrated with nozzles and air-bearings, nozzle numbers are shown with orange color and air-bearing numbers are shown with blue color. The floating platform is modular, which means the middle and upper plates can easily be disassembled. To increase the endurance of the floating platform, decreasing the overall weight is an advantage. The middle and upper plates are necessary to gain more volume for equipment, such as ADR system, space debris mock-up, more computation boards, sensors etc.

b) Air-bearings

The identical plate scheme and the locations of the air-bearings can be seen from Fig. 1. For the configuration of the air-bearings, the square approach has been used to compensate the weight distribution of the floating platform in a homogeneous way. In the floating platform configuration, Newway S104001 – 40 mm diameter flat round air-bearing is used. This air-bearing model's force-levitation gap relation for 5,5 bar pressure is given in Fig. 3. The total weight of the floating platform is 6 kg, since four air-bearing are used, each air-bearing needs to lift 1,5 kg. Therefore, it is estimated from Fig. 3 that the floating platform has 30-35 microns levitation gap during the operation. Since the air-bearings are controlled in a passive manner (no closed-loop actuation), no sensor to measure this levitation gap is integrated. In the market, there are some sensor options that can be used for this purpose, such as laser gap sensors. However, any further hardware implementation will bring more energy consumption and complexity. Moreover, the floating platform floats very smoothly in its current shape, so that this laser gap sensor option is not considered for the floating platform design.

c) Nozzles

The floating platform has eight nozzles to ensure 3-DoF movement. Actuating the nozzles with a specific configuration gives the opportunity to drive the floating platform along two translational axes, X and Y, and around one rotational axis Z (yaw axis movement). The nozzle locations are given in Fig. 1. The configuration of the nozzles for each specific movement can be seen from Table 1. As nozzle, FESTO LPZ-SD high thrust air-jet nozzle is used in the floating platform setup.

Table 1. Nozzle Configuration.

Nozzle#/Motion	X^+	X^-	Y^+	Y^-	Z^+	Z^-
Nozzle#1	ON	OFF	OFF	OFF	ON	OFF
Nozzle#2	OFF	ON	OFF	OFF	OFF	ON
Nozzle#3	OFF	OFF	OFF	ON	ON	OFF
Nozzle#4	OFF	OFF	ON	OFF	OFF	ON
Nozzle#5	OFF	ON	OFF	OFF	ON	OFF
Nozzle#6	ON	OFF	OFF	OFF	OFF	ON
Nozzle#7	OFF	OFF	ON	OFF	ON	OFF
Nozzle#8	OFF	OFF	OFF	ON	OFF	ON

d) Solenoid valves

Air-bearings and nozzles need to be fed by solenoid valves. In this study, FESTO VUVG-B10-T32C-MZT-F-4P3-N102 is used as solenoid valve and energized by a 5 V DC signal, and FESTO VTUG-572230-N102 is used as solenoid valve manifold. The stability of pressure parameter for air-bearings is vital due to air-bearing works to cut the contact between the floating platform and epoxy surface, especially taking into account that the air-gap between the floating platform and epoxy surface is 5 micron under 5.5 bar air-bearing working pressure. One can imagine that how vulnerable 5 micron air-gap parameter is and how hard to protect it, any possible oscillation around this 5.5 bar value may create a contact between the air-bearing and epoxy surface, thus, the oscillation of the pressure parameter has to be minimized. To achieve this goal, two way pressure input method has been used.

In an embodiment of the invention two pressure inputs are supplied to the air-bearings associated valves to minimizes the oscillations of the pressure parameters.

In an alternative embodiment of the invention two pressure inputs are supplied to both air-bearings and nozzles. Pilot air input for both air-bearings and nozzles is used as additional air source, so that supplying air to air-bearings and nozzles from two sources minimizes the oscillations of the pressure parameters. The solenoid valve configuration is given in Fig. 4. Pilot air feeds to the solenoid valves that supply air to air-bearings and nozzle. Four air-bearings are parallelly connected to the solenoid valve-9, and each nozzle is connected to a single solenoid valve, the sequence is Nozzle\#n is connected to solenoid valve\#n. Solenoid valve\#10 is idle since FESTO VTUG-572230-N102 solenoid valve manifold has ten solenoid valves as standard. The parts shown with red color in Fig. 4 are acoustic silencers.

e) Driver for solenoid valves

Solenoid valves have simple DC voltage inputs. To energize solenoid valves in a controlled way, a driver board is needed, since the energy that can be harvested from a single General-Purpose Input/Output (GPIO) pin of Raspberry Pi-4 is very limited. The power to drive a single FESTO VUVG-B10-T32C-MZT-F-4P3-N102 solenoid valve is around 0.3 W. However, GPIO pin of RaspberryPi-4 is able to give maximum 16 mA at 3.3 V. To tackle this task, a relay board in Fig. 4 is used as driver board. GPIO pins of Raspberry Pi-4 simply sends low-energy trigger signals to relay board to actuate the solenoid valves. The relay board is parallelly connected to 5 V energy supply of the power bank. When it receives a low-energy trigger signal from GPIO pins of Raspberry Pi-4, it draws the necessary energy from the power bank to actuate the solenoid valves.

f) Pressure source

As compressed air source, X-Fiber S3, a 3 liter carbon-fiber air-cylinder is assembled on the floating platform. The choice of carbon-fiber as material of the air-cylinder is to minimize the weight that the floating platform carries. The more weight the floating platform carries, the more air it needs to consume. Compared to similar products in the market, such as aluminium air-cylinders, a 3 liter empty carbon-fiber cylinder is around 2 kg. whereas a 3 liter empty aluminium cylinder is around 6 kg. This carbon-fiber air-cylinder can be pressurized up to 300 bar and supplies necessary air to the solenoid valve manifold.

g) Pressure regulation

Pressure regulation is an important process since 300 bar pressure inside the air-cylinder needs to be reduced before the air gets inside the solenoid valve manifold. In the market, off-the-shelf solenoid valve products that can be appropriately used on the floating platform, in terms of weight, geometry etc. work mostly between 0-10 bar pressure. Furthermore, the working pressure of the air-bearings for 5 micron is 5.5 bar, where the working pressure of FESTO LPZ-SD nozzle is 0-10 bar, depending on the thrust force to be generated. In this study, two step pressure regulation is applied. The first step is to reduce the pressure at the output of the air-cylinder to 10 bar. To achieve this, San-O-Sub 300 bar to 10 bar pressure regulator is used. As second step regulator, a specific FESTO MS2-LR-QS6-D6-AR-BAR-B pressure regulator is assigned to both air-bearings and nozzles, this pressure regulator regulates the pressure values between 0-10 bar for air-bearings and nozzles. The numeric relation between the nozzle force and second step pressure regulator is acquired using a primitive system identification approach and shown in Fig. 5. The maximum force that can be obtained from a single FESTO LPZ-SD nozzle is 2 N when the output pressure of second step pressure regulator is adjusted to 10 bar. The values in Fig. 5 are obtained using MPU6050 onboard sensor that gives acceleration data.

h) Power source and voltage regulation

As power source, 5 V power bank with 26800 mAh and 45 W power properties is used. LiPo battery can be used as an alternative when the computation load/energy consumption of the processor or of any peripheral device is more than expected. A voltage regulator is integrated at the output of the power source to regulate the voltage in case of any voltage peak occurs. Furthermore, any other power source which gives more than 5 V voltage, for instance standard 6S LiPo that gives 22.2 V, can be easily be replaced with power bank. Since the output of the voltage regulator is adjusted to give constant 5 V, there will be no difference in terms of constant voltage supply to the electronic components of the floating platform.

i) On-board computer

As on-board computer, the floating platform has Raspberry Pi-4 that has quad-core Cortex-A72 (ARM v8) 64-bit 1.5GHz processor with 8GB LPDDR4-3200 SDRAM. Ubuntu 20.04 is setup as operation system and integrated with ROS libraries. Assigned IP allows to realize any remote access scenario. To drive the solenoid valves, GPIO pins of Raspberry Pi-4 are used. The digital signals generated from GPIO pins are sent to the relay, so that the relay open and close the solenoid valves.

j) On-board sensors

MPU6050 low-cost accelerometer and gyroscope, as known as Inertial Measurement Units (IMU), is located at the geometric center of the second plate of the floating platform. Since the air-gap between the air-bearings and the epoxy floor is 5 micron, the floating platform does not perform roll and pitch movements, so that gyroscope property of MPU6050 is not used. On the other hand, MPU6050 gives two translational acceleration data, translational acceleration parameters along X and Y axes, and rotational acceleration parameter around Z axis. Therefore, these data can be used to construct force-feedback structure for future studies. In Fig. 6, the location of MPU6050 on the floating platform can be seen, it is assembled with a 3d printed structure that has 120 degrees difference between its legs. The sampling frequency of MPU6050 is 1 kHz. Another sensor located on the floating platform is TP3 (TP3.400.R4) pressure transducer, which measures the pressure value inside the air cylinder. It is located between the air cylinder and San-O-Sub pressure regulator. Since the pressure value inside the air cylinder is the function of the air mass quantity inside the air cylinder, TP3 pressure transducer provides the data about how long the floating platform can operate. The output of TP3 is an analog signal, however, Raspberry Pi-4 has only digital input. To tackle this issue, Analog-Digital Converter (ADC) is needed. As ADC, Microchip-MCP3008 10-Bit ADC is integrated between TP3's analog output and Raspberry Pi-4's digital input ports.

k) OptiTrack motion capture system

OptiTrack MCS consists of camera and marker. The marker is located at the center of the third plate of the floating platform, whereas the camera is located on a specific place in the laboratory. Therefore, the position of the floating platform can be tracked by the camera, and is being processed as position feedback data by the on-board computer. For the position data, the sampling frequency is 240 Hz. The velocity and acceleration data can be derived using the position data as well. However, this procedure requires filter design steps. Additionally, the sampling frequency of velocity and acceleration data would be depending on the filter dynamics.

The equipment located on the lower plate is given in Fig. 7, and Computer Aided Design (CAD) drawing of the floating platform is shown in Fig. 8.

Finally the invention has successfully been tested several times on the surface of the zero-g lab and has achieved State-of-the-Art objectives given as follows;

- A novel floating platform architecture made of additive manufacturing based ultra light-weight carbon-fiber material. Thus, increasing the experiment time for different scenarios.
- Closed-loop position feed-back control approach integrated with the floating platform to realize ADR scenarios. During the capturing phase, ADR system needs to apply a trajectory profile to ensure the capturing process of space debris. In the literature, there is no closed-loop feedback study conducted for floating platforms. Therefore, this study aims to be the pioneer for this field.

A path-planner is created considering the floating platform dynamics and its interaction with the epoxy floor.

In a particular embodiment the weight of one platform is less than 5 kg.
In another particular embodiment, the pressure in the fluid storage is higher than 200 bar, preferably higher than 300 bar.
In a particular embodiment said air-bearings operate at 5 bar while said nozzles operate at 10 bar.
In a particular embodiment said platforms allow for experiments with a duration longer than 15 minutes, preferably longer than 20 minutes.

The invention further pertains to a ROS package, which provides basic functionality for the floating platform using the Robot Operating System framework as a communications and control middleware. The software functionality consists of direct hardware control and interfaces to other frameworks via ROS such as MATLAB for example. The interfaces use basic ROS mechanisms such as topics and services in order to control the floating platform.

The invention further discloses a digital twin model based on designed CAD (Computer Aided Design) models in STL format, which has been integrated to Gazebo environment with its specific dimension and weight. In the Gazebo simulation environment the model is fed sensory and actuation data generated during the operation of the floating platform in Zero-G Lab. There is no control algorithm integration, users can integrate any control algorithm they wish. The digital twin model in Gazebo synchronizes with the movements of the floating platform in Zero-G Lab. Additionally the floating platform of Zero-G Lab has SIL (Software In the Loop) and HIL (Hardware In the Loop) capabilities, that can be further integrated into the digital twin, whereas the floating platforms existing in the literature do not have SIL and HIL capabilities and are being controlled in a very simple and direct way, mostly by a simple radio control with an open-loop structure. However, SIL and HIL architectures that can be modelled in a digital twin environment are needed to realize space interaction scenarios of ADR (Active Space Debris Removal) systems. Any additional hardware can also be implemented to SIL and HIL architectures to test, verify and validate product's performance. Nozzle and air-bearing actuation of the floating platform in real experiment is synchronized with the motion being generated in Gazebo environment. Hence the invention provides methods for generating a virtual representation (so-called digital twins) of one or more of said platforms based on a inputted CAD model, the use of such virtual representations or digital twins in either simulation environments and/or the control environment used to control the platforms during actual experiments.

MORE ELABORATED DESCRIPTION OF A FEW DRAWINGS

Figure 1 shows a platform (100), comprising (a) a first set of pneumatic components (110) arranged for blowing a pressurized fluid (air) to said support enabling the platform to detach from said support; (b) a second set of pneumatic components (120), different (in terms of performance) from said first set of pneumatic components, enabling the platform to move in one or more degrees of freedom, said platform being designed as a grid-like, string (130) -like structure with fiber material.

Figure 4 shows a means for storage of pressurized fluid or air cilinder (400), three means for pressure reduction or pressure regulators (410, (420), (430)), one shared for both air bearings and nozzles and two dedicated for either for the nozzles or the air bearings. The same figure illustrates that for the solenoid valves two air inputs are used, in particular one coming from the regulator (410) and a second one called pilot air, which is derived from the same regulator (not shown). Note that these regulator can be and preferably are adjustable such that adaptions can be done depending on the type of experiment.

Figure 3 and 5 shows ways of expression the performance of a pneumatic component.

Figure 7 shows (solenoid) valves (700), a means for storage of pressurized fluid or air cilinder (710), two means for pressure reduction or pressure regulators (720) , energy storage means (power bank) or power supply (730) and a first electronic components for providing control signals (740).

Figure 9 shows graphical solving of the equation Total Weight as a sum of a basic weight and a sum of all components, whereby their weight depends on the Total Weight itself. Graph (900) illustrates a situation wherein no such solution exist. Graph (910) shows the enforcing of solutions by one of the contributions (990) in that the basic weight is reduced by used of (carbon-) fiber. Graph (920) shows the enforcing of solutions by one of the contributions (980) in that the derivative (read dependency) of the component weight is reduced (e.g. by electing for the set-up a small air gap which substantially influences the air cylinder size required). The invention also describes embodiments where both contributions are used. Moreover these contributions are used beyond just enforcing a solution but also to create some design freedom for adding additional components enabling for instance better control.

CLAIMS

1. An arrangement for performing experiments with objects while mimicking zero-gravity conditions, comprising: (i) a support and (ii) one or more platform, comprising (a) a first set of pneumatic components (100) arranged for blowing a pressurized fluid (air) to said support enabling the platform to detach from said support; (b) a second set of pneumatic components (110), different (in terms of performance) from said first set of pneumatic components, enabling the platform to move in one or more degrees of freedom; (c) one or more means for mounting objects to said platform and (d) one or more means for storage of said pressurized fluid.
2. The arrangement of claim 1, wherein said first set of pneumatic components being (aerostatic) air-bearings.
3. The arrangement of claim 1 or 2, being arranged for closed-loop position control of said second set of pneumatic components to enable ADR (Active Space Debris Removal) capability testing and further being arranged for open-loop control of said first set of pneumatic components).
4. The arrangement of claim 1, 2 or 3 wherein said first and/or second pneumatic components are fed by valves and wherein said valves operated in a first pressure range and said one or more means for storage of pressurized fluid operating in a substantially different second pressure range and said platform further being provided with means for pressure reduction, preferably in two steps, optionally said means for pressure reduction receiving pressure sensor information.
5. The arrangement of claim 1, 2, 3 or 4 wherein the control of at least said first pneumatic components is arranged to minimize oscillations (by providing for one or more (preferably all of said) components at least two supplies of pressurized fluid).
6. The arrangement of any of the previous claims, wherein said platform being designed as a grid-like, string-like structure with (carbon-) fiber material.
7. The arrangement of any of the previous claims, wherein said platform further comprising first electronic components for providing control signals to one or more of said components.
8. The arrangement of any of the previous claims, wherein said platform further comprising second electronic components for sensing one or more of said components and/or third electro-mechanical components for providing actuation capability.
9. The arrangement of any of the previous claims, wherein said platform comprising one or more geometrically identical regular shaped plates (stacked upon each other).

10. The arrangement of claim 9, wherein each of said plates being provided with a different identification signage and the arrangement further comprising: identification means capable of identifying each of said plates based on said identification signage.
11. The arrangement of claim 4, wherein said first electronic components include means for driving said valves.
12. A method for automated generating of the control signals for the one or more platforms of claim 1, comprising: (i) inputting the path or trajectory by a planner; (ii) inputting the platform dynamics and its interaction with the support means; and generating said control signals based on said inputs.
13. A method for performing low (gravity) experiments with objects with the one or more platforms of claim 1: (i) loading the control signals generated by the method of claim 12; and applying said loaded control signals to said platforms.
14. A method for generating a virtual representation of one or more of said platforms (suitable for use in any of the methods of claim 12 or 13), said method comprising: (i) providing a parametrized digital representation of said one or more platforms; (ii) loading measurements from operating said one or more platforms; and (iii) determining said parameters of said digital representation from said measurements.
15. A computer program product comprising computer-readable code, that when run on a computer system causes the computer system to execute the methods of any of the previous method claim 12, 13 and/or 14 and/or represents the virtual representation of claim 14.
16. A non-transitory machine-readable storage medium storing the computer program products of the previous claim 15.

REVENDICATIONS

LU503146

1. Un arrangement pour réaliser des expériences avec des objets en imitant des conditions en zero gravité, comprenant: (i) un support et (ii) une ou plusieurs plateformes, comprenant (a) un premier jeu de composants pneumatiques(100) arrangés pour souffler un fluide pressurisé (air) vers le support de telle façon à ce que la plateforme puisse se détacher dudit support; (b) un second jeu de composants pneumatiques (110), différent (en termes de performance) dudit premier jeu de composants pneumatiques, telle façon à ce que la plateforme puisse bouger selon un ou plusieurs degrés de liberté; (c) un ou plusieurs moyens pour attacher des objets à ladite plateforme et (d) un ou plusieurs moyens pour stocker ledit fluide pressurisé.
2. L'arrangement de la revendication 1, dans lequel ledit premier jeu de composants pneumatiques étant paliers à air (aérostatiques).
3. L'arrangement de la revendication 1 ou 2, étant arrange pour un contrôle de position en boucle fermée dudit second jeu de composants pneumatiques pour permettre un test ADR (« Active Space Debris Removal » en anglais) et étant en plus arrangé pour un contrôle de position en boucle ouverte pour ledit premier jeu de composants pneumatiques).
4. L'arrangement de la revendication 1, 2 ou 3 dans lequel lesdits premier et/ou second composants pneumatiques sont alimentés par des valves et dans lequel lesdites valves sont opérée dans un premier intervalle de pression et lesdits un ou plusieurs moyens pour stocker ledit fluide pressurisé opèrent dans un second, substantiellement différent, intervalle de pression et ladite plateforme étant en plus pourvue de moyens de réduction de pression, préférablement en deux étapes, optionnellement lesdits moyens de réduction de pression recevant des information de capteurs de pression.
5. L'arrangement de la revendication 1, 2, 3 ou 4 dans lequel le control d'au moins un desdits premier composants pneumatiques est arrangé pour minimiser des oscillations (par la mise à disposition pour les un ou plusieurs (préférablement tous) composants au moins deux apports de fluide pressurisé).
6. L'arrangement selon l'une des revendications précédentes, dans lequel la plateforme étant conçue comme une structure en grille ou fils avec un matériau en fibre (de carbone).
7. L'arrangement selon l'une des revendications précédentes, dans lequel ladite plateforme comprend en plus des premier composants électroniques pour mettre à disposition des signaux de contrôle à un ou plusieurs desdits composants.
8. L'arrangement selon l'une des revendications précédentes, dans lequel ladite plateforme comprend en plus des second composants électroniques pour capter un ou plusieurs desdits composants et/ou des troisième composants électroniques pour mettre à disposition des capacités d'actuation.

9. L'arrangement selon l'une des revendications précédentes, dans lequel ladite plateforme comprend un ou plusieurs plateaux géométriquement identiques et réguliers (empilés les uns sur les autres).
10. L'arrangement de la revendication 9, dans lequel chacun desdits plateaux ayant une signalisation d'identification différente et l'arrangement comprenant en plus des moyens d'identification capables d'identifier chacun desdits plateau sur base de la signalisation d'identification.
11. L'arrangement de la revendication 4, dans lequel lesdits premier composants électroniques incluent des moyens pour actionner lesdites valves.
12. Un procédé pour générer automatique des signaux de contrôle pour une ou plusieurs plateformes selon la revendication 1, comprenant (i) l'insertion d'un chemin ou la trajectoire par un planificateur ; (ii) la saisie d'une dynamique de la plate-forme et son interaction avec les moyens de support ; et générer lesdits signaux de commande sur la base desdites entrées.
13. Un procédé pour réaliser des expériences en basse (gravité) avec des objets avec une ou plusieurs plateforme selon la revendication 1: (i) la charge des signaux de contrôle générés par le procédé de la revendication 12; et l'application desdits signaux de contrôle chargé aux plateformes.
14. Un procédé pour générer une représentation virtuelle des une ou plusieurs plateformes (adapté pour utilisation dans l'un des procédés selon la revendication 12 ou 13), ledit procédé comprenant : (i) la mise à disposition d'une représentation numérique paramétrisée desdites une ou plusieurs plateformes; (ii) le chargement de mesures de l'opération des une ou plusieurs plateformes ; et (iii) la détermination des paramètres de ladite représentation numérique desdites mesures.
15. Un produit de programme d'ordinateur comprenant un code lisible par ordinateur, qui, quand exécuté par une système d'ordinateur, cause l'exécution par le système d'ordinateur du procédé d'une des revendications de procédé précédentes 12, 13 et/ou 14 et/ou représente la représentation virtuelle de la revendication 14.
16. Un support de stockage non transitoire lisible par ordinateur stockant le produit de programme d'ordinateur de la revendication précédente 15.

Fig. 1

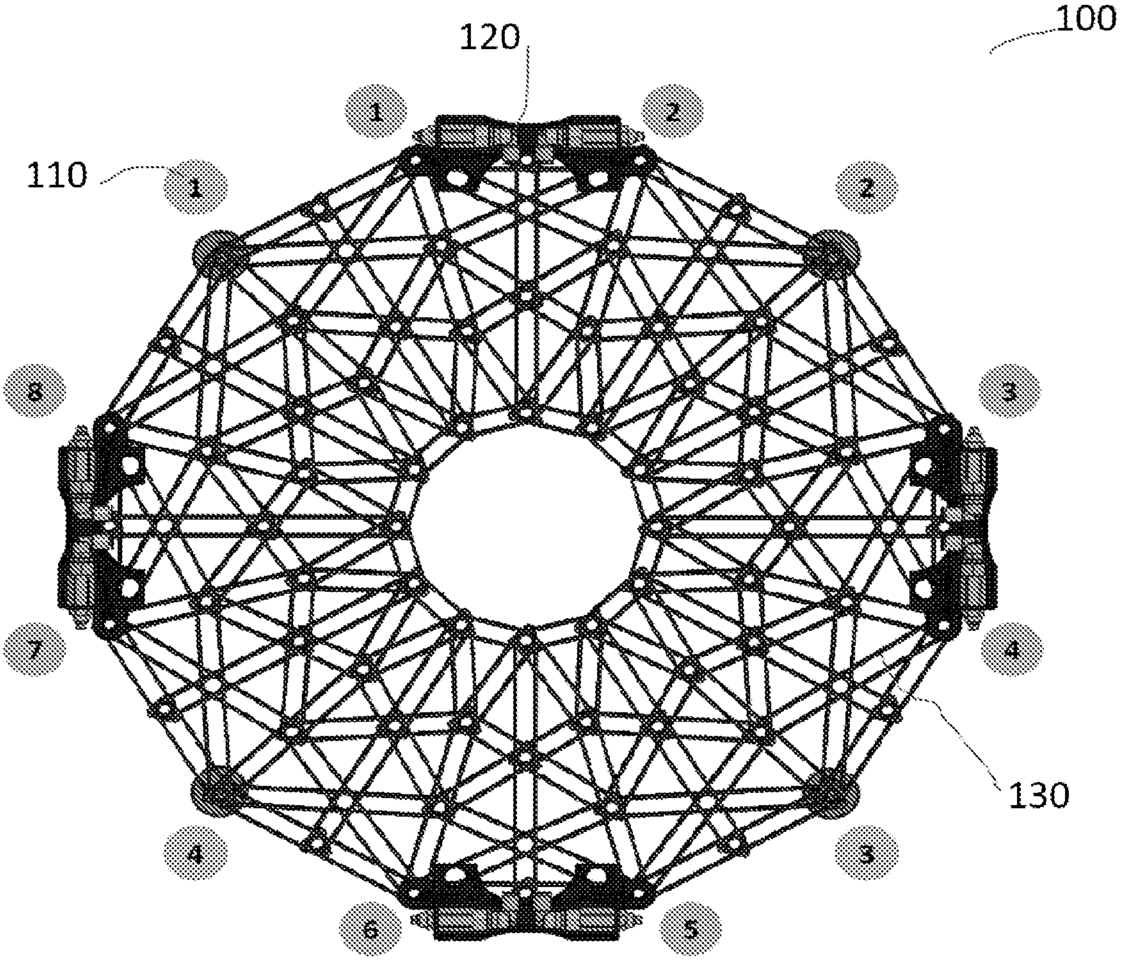


Fig. 2

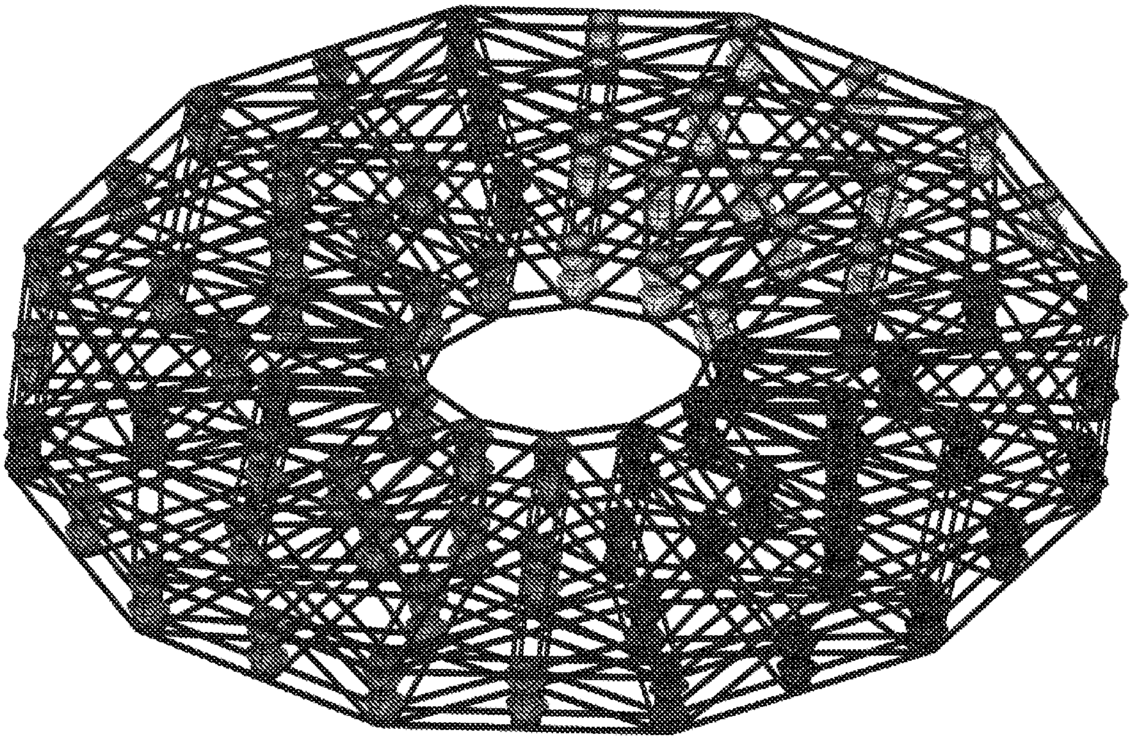
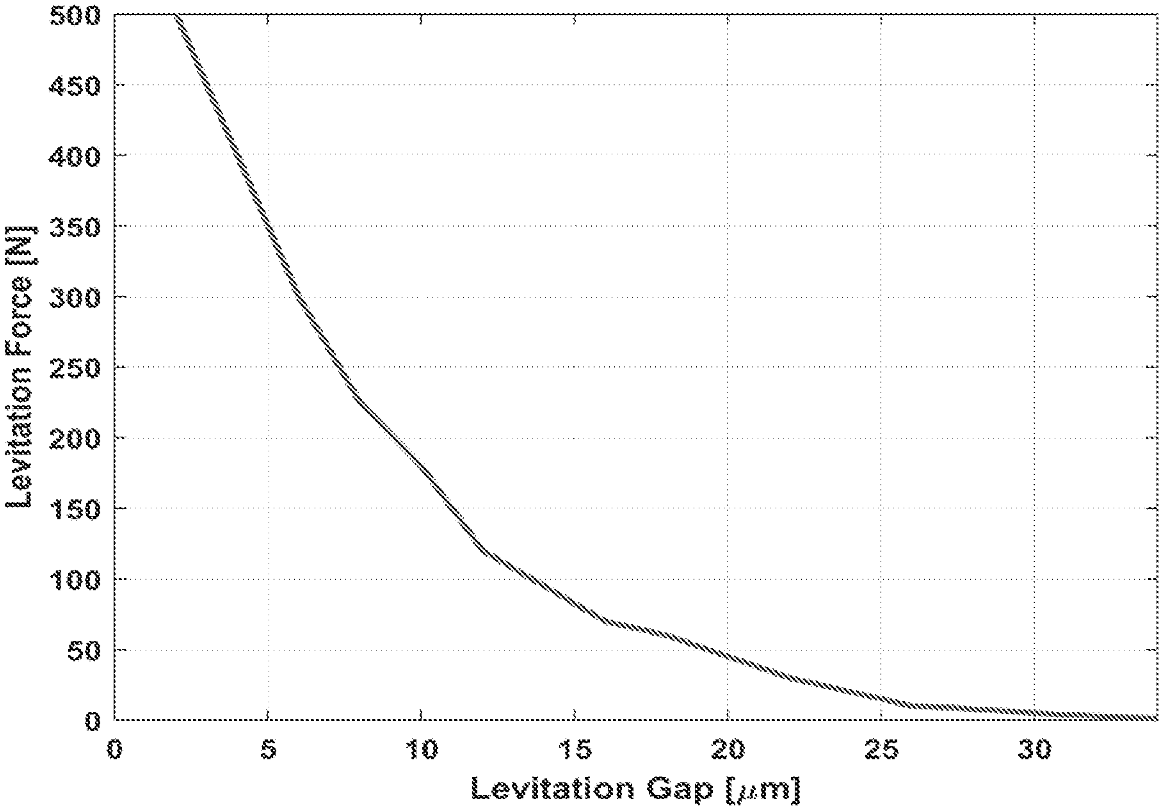


Fig. 3



500
450
400
350
300
250
200
150
100
50
0
Levitation Force [N]
0
5
10
15
20
25
30
Levitation Gap [μm]

LU503146

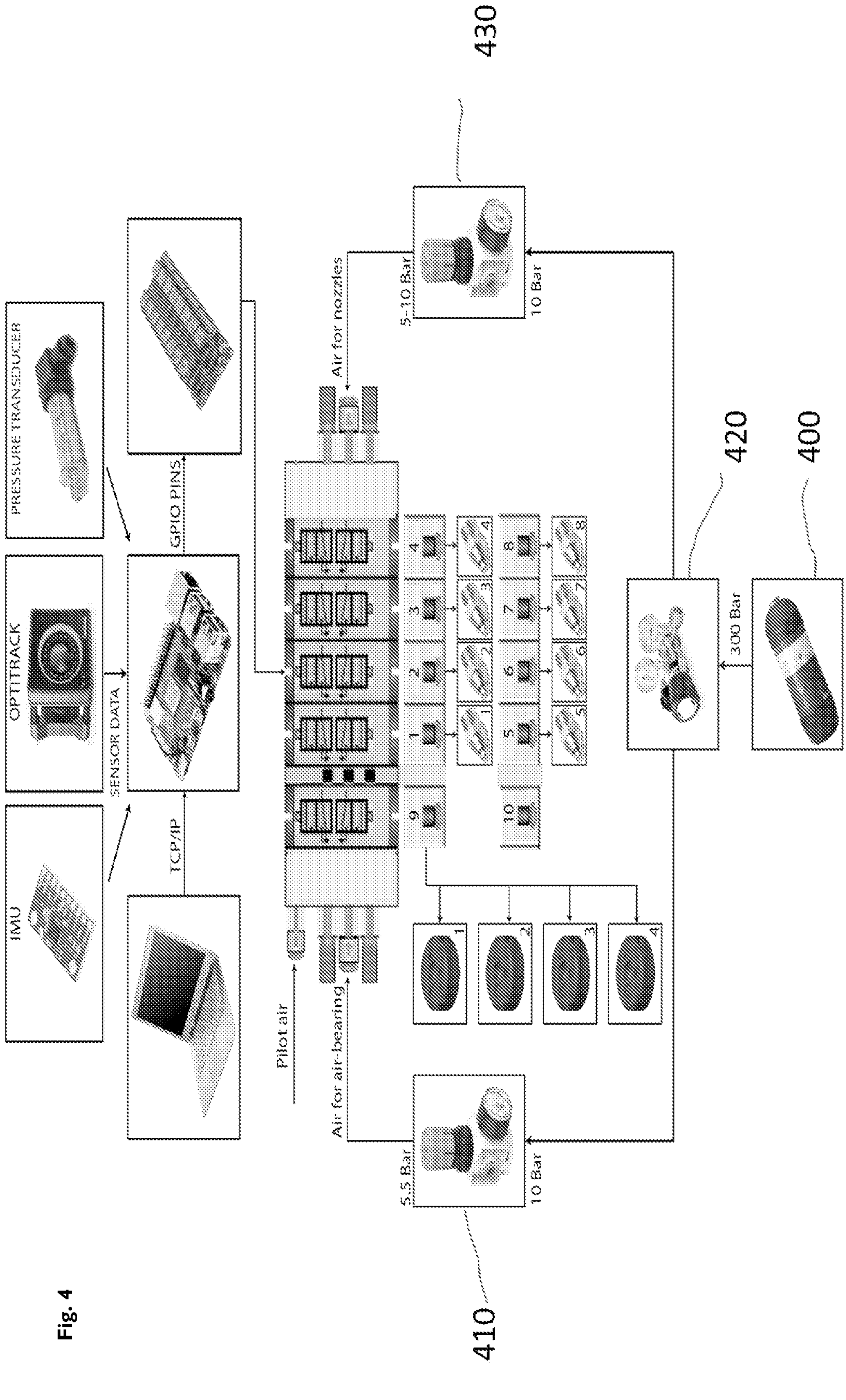


Fig. 4

Fig. 5

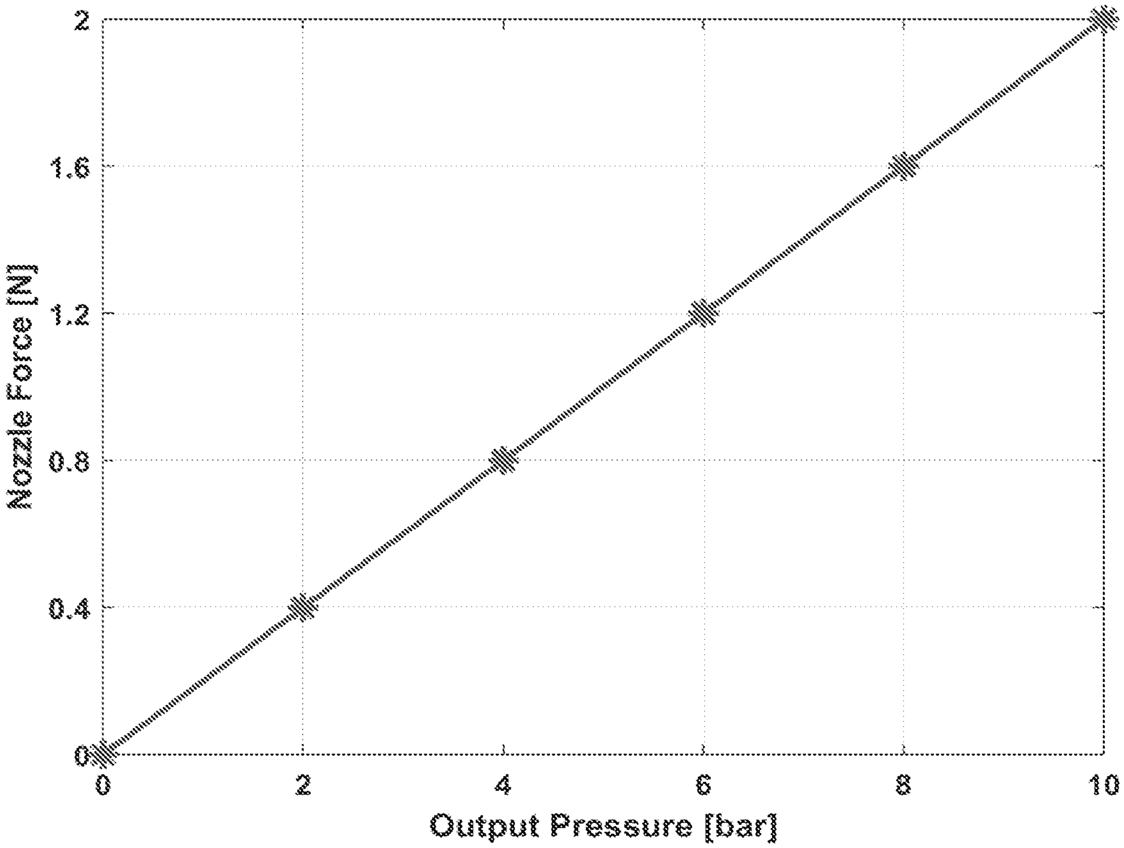

Nozzle Force [N]
Output Pressure [bar]
0
0.4
0.8
1.2
1.6
2
0
2
4
6
8
10

Fig. 6

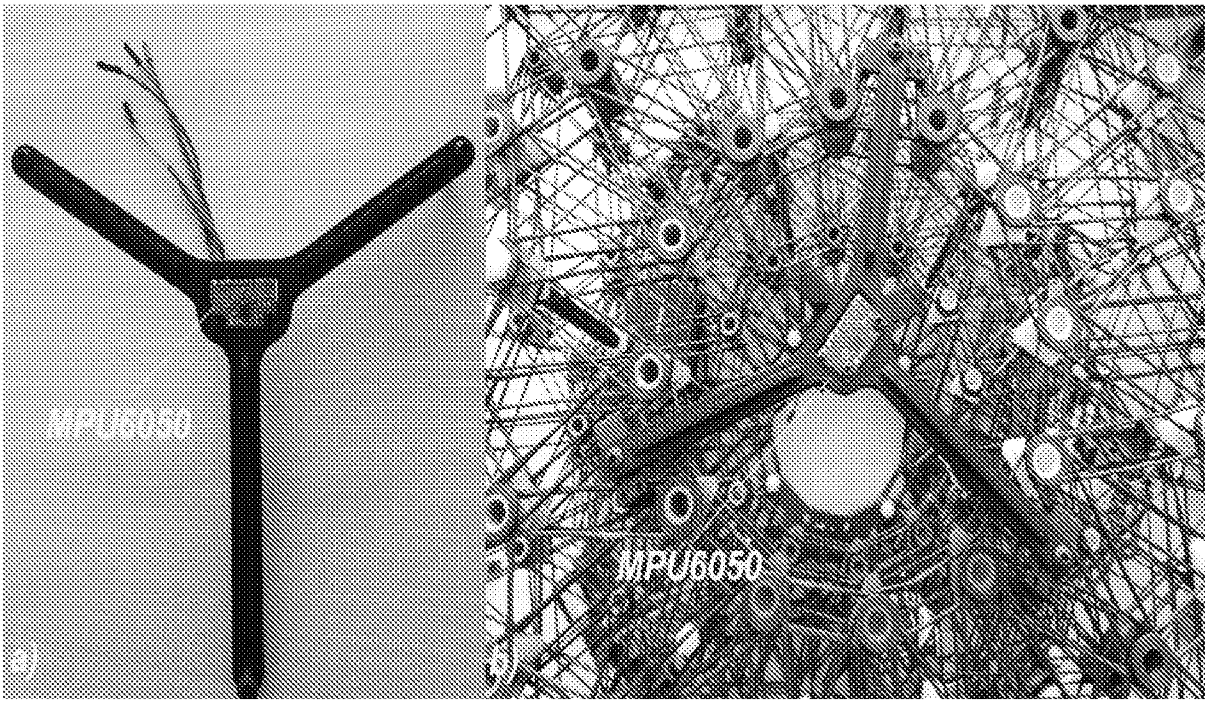

MPU6050
a)
MPU6050
b)

Fig. 7

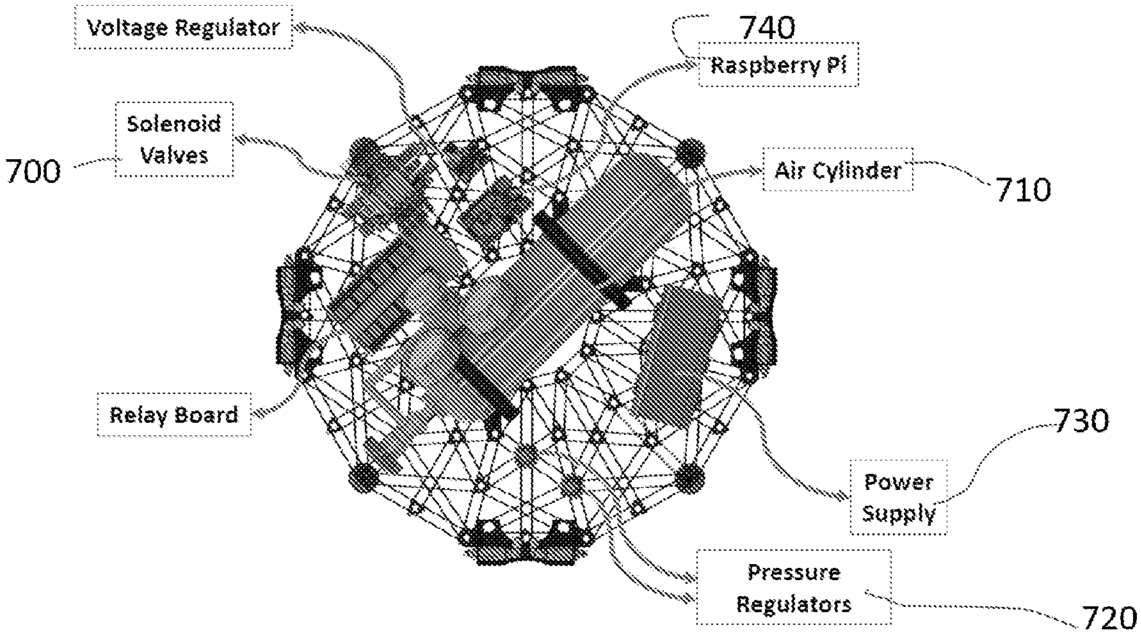

Voltage Regulator
740
Raspberry Pi
Solenoid Valves
700
Air Cylinder
710
Relay Board
730
Power Supply
Pressure Regulators
720

Fig. 8

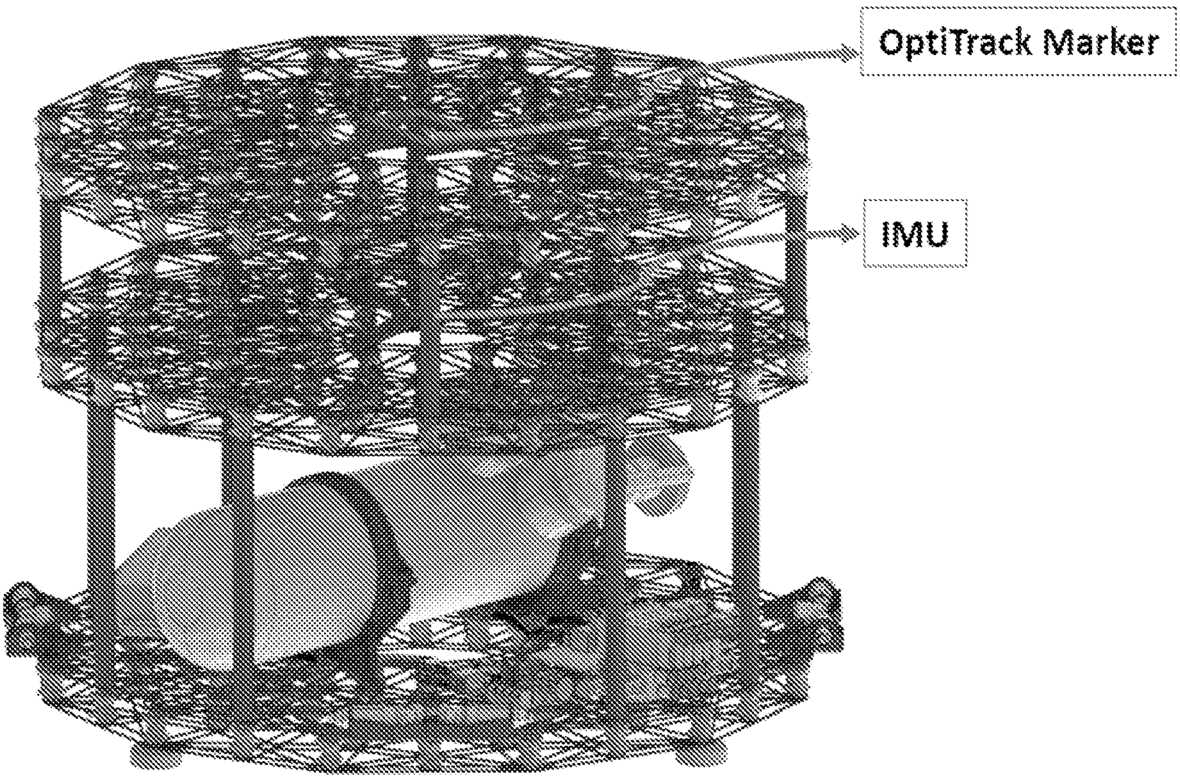

OptiTrack Marker
IMU

Fig. 9

Total weight = Basic Weight (e.g. plates) + Sum over components (Total Weight)