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Single Device that Can Measure Gravity, Magnetism & Data for Inertial Navigation System and Also Provide Propulsion to Satellites for Prolonged Missions in Space

Muhammad Amjad Ali*

Post Office Karam Pur, Ahmed Pur, Tehsil Mailsi, District Vehari, Pakistan
Email: muhammadamjadali_83@yahoo.com

Abstract

The paper proposes workable ideas for development of a single device that can measure values of Gravity, Magnetic Fields and changes in Angular and Linear velocity of a vehicle to be used for inertial navigation system. Moreover, the same device can also be used as in-space propulsion system for satellites that can sustain operations indefinitely; thus paving way for miniaturization of satellites in order to achieve cost effectiveness and prolonged life time of satellites in space, by eliminating the need of propulsion fuels. The system will be powered by onboard solar panels. This will enable not only missions around earth, moon or nearby planets but also deep space missions around solar system as long as power source remains viable. The device utilizes magnetic levitation achieved through combination of permanent and electromagnets whereby momentum of a ball magnetically suspended inside a spherical electromagnet is transferred to satellite due to its acceleration under magnetic forces to provide propulsion. The linear and angular displacements of the inner suspended ball provide data for inertial navigation and measurement of gravity and magnetic fields.

Keywords: In-space propulsion; Gravity; Magnetic Fields; Inertial Navigation System; deep space missions; magnetic levitation.

1. Introduction

Race to Space is an expensive undertaking and has largely been attributed to developed nations due to heavy costs. With the inception of modern technologies, the size & weight of satellites has shrunk manifold.

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* Corresponding author.

Now-a-days, countries around the world are focusing more on developing micro-satellites due to obvious reasons of cost effectiveness in terms of fuel consumption and need for development of constellations of satellites for specific purposes. In fact, numerous micro-satellites have already been sent [1] to space for applications like research, earth observation and communications etc. In nutshell large satellites are out of fashion. In this regard, viable and cost effective solutions for navigation and propulsion along with miniaturizing the size of satellites for prolonged missions in space are the only way forward for mankind. In order to achieve the goal set above, following topics are discussed in this paper:-

- Inertial Navigation System
- Measurement of Magnetic Fields and Force of Gravity in Space
- Propulsion of Satellites in Space
- Constructing a single device that can measure gravity, magnetism and data for inertial navigation system and also provide propulsion to satellites for prolonged missions in Space

The device proposed in this paper utilizes magnetic levitation achieved through combination of permanent and electromagnets whereby momentum of a ball magnetically suspended inside a spherical electromagnet is transferred to satellite due to its acceleration under magnetic forces to provide propulsion. The linear and angular displacements of the inner suspended ball provide data for inertial navigation and measurement of gravity and magnetic fields. The ideas of free power generation through permanent magnets and magnetic levitation are viral now-a-days.

1.1. Inertial Navigation System (INS)

An inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references [2] like Global Navigation Satellite Systems including GPS (USA), GLONASS (Russia), BIEDOU (China) and Galileo (EU). Other terms used to refer to inertial navigation systems or closely related devices include inertial guidance system, inertial instrument, inertial measurement units (IMU) and many other variations. Many types of inertial navigation systems are being used in aircrafts, ships, submarines, guided missiles, space crafts as well as daily uses like cell phones, cars and industrial applications. Various types of Gyros like Gimbaled Gyros, Laser Gyros and Fiber Optic Gyros etc are being used in Inertial Navigation Systems. Modern Accelerometers and Gyroscopes being commercially used are based on MEMS (Micro Electromechanical Systems) technology. These are very compact but each one has advantages and disadvantages. The device proposed in this paper integrates the functions of gyroscopes and accelerometers into one device.

1.2. Measurement of Magnetic Fields and Force of Gravity in Space

Normally, a magnetometer is used to determine strength and direction of magnetic field in space. A Magnetometer is also suitable for use as part of a coarse attitude determination system (or simply INS) on LEO (Low earth Orbit) missions [3]. A 3-axis fluxgate magnetometer measures the magnetic field and provides readings from 3 sensors arranged in orthogonal axes. It can be used in combination with a satellite position fix and International geomagnetic reference field (IGRF) model to determine satellite attitude. Magnetometers are used in satellites for autonomous navigation basing on the fact that Earth's Magnetic Field is fairly well modelled whose intensity and direction are functions of position. The yearly variations can be accounted for with reasonable accuracy [4]. Measurement of value of g (gravity) is normally done with the help of a gravimeter. The proposed device integrates measurement of gravity along with measurement of magnetic field and data for INS.

1.3. Propulsion of Satellites in Space

Numerous innovative propulsion systems are being used/ developed/ tested for station keeping, orbital maneuvering and deep space propulsion. These include electric propulsion, MEMS based fuel cells, steam based propulsion, Hydrazine/ Xenon based propulsion system, magneto torquers, reaction wheels, fusion drive, warp drive and EM drive etc. Although fuel free propulsion/ attitude control systems are being developed and tested around the world, yet thrust generated by the systems is low along with other issues.

However, the device proposed here in this paper *can provide propulsion indefinitely due to the fact that it does not involve loss of any mass in propulsion and also promises sufficient thrust with comparatively lesser disadvantages*. Most of existing propulsion systems need to carry along additional mass (gas, steam or solid fuel cells) for sake of propulsion in space. The problem of carrying this additional mass for propulsion not only makes the satellite heavier but also limits the operational life due to continuous consumption.

The proposed propulsion system will be powered by onboard solar panels and will not lose any mass in space. Thus no additional mass will be carried for propulsion. ***The much debated problem of propulsion systems based on ejection of some mass in the form of gases or ions to achieve propulsion is eradicated***.

2. Materials and Methods

2.1. Basic Construction of Proposed Device

The device consists of a permanent Ball Magnet suspended inside cavity of sphere with the help of electro-magnets. The upper half of outer sphere is north pole whereas lower half is south pole. Opposite poles of both the magnets will attract each other thus suspending the inner magnet inside cavity of the outer magnet. The design of proposed device is given in figure 1.

It may be noted that there is only one possible orientation of the inner magnet while suspended inside the outer magnet due to attraction between the opposite poles of both the magnets. The inner Ball Magnet will always tend to orient itself at the centre of space inside the outer magnet with South Pole pointing upwards. Whenever there is any change in orientation of the outer magnet with respect to inner Ball Magnet, the inner magnet will try to re-orient itself at the centre of the cavity. It is important to cancel out the ambient magnetic field to allow accurate calculations. This can be accomplished by enclosing the device in a magnetic shielding material.

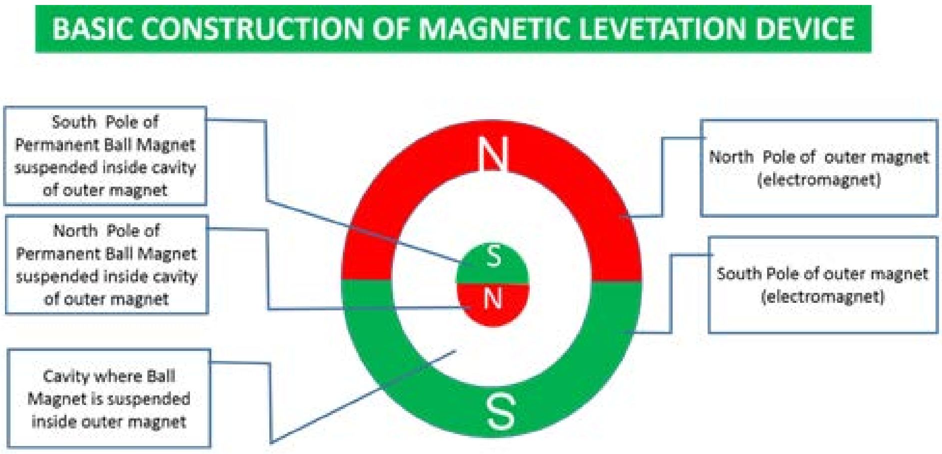

Figure 1

2.2. 3D Construction of Device

3D construction of the device based on principal described in basic construction is given in figure 2. Outer Ring or Sphere consists of coil magnets plugged along the periphery. Each coil can be individually switched on/ off and polarity can also be reversed in order to orient the inner ball in desired direction.

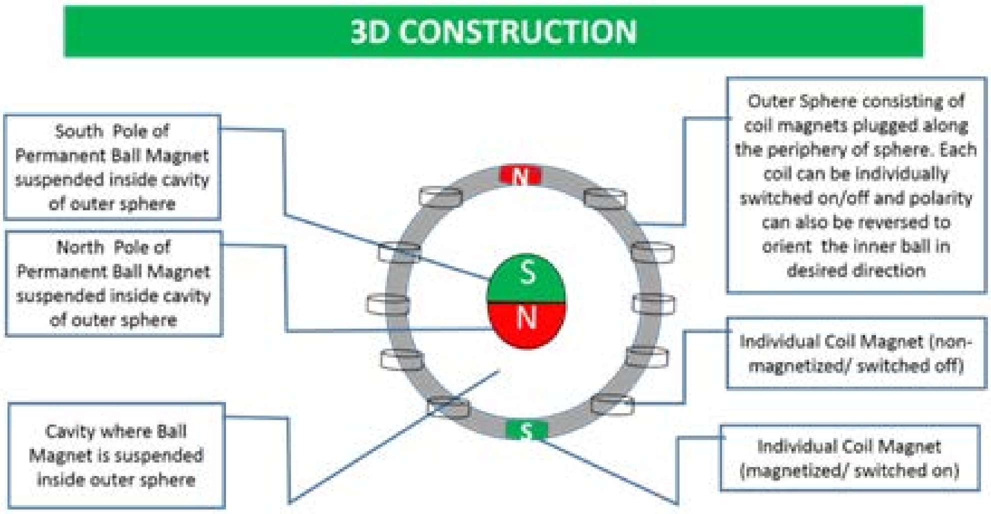

Figure 2: Cross Section view of outer sphere containing multiple coil magnets

Examples of construction involving multiple coils along the periphery of device are given in Figure 3 [5] & Figure 4 [6]. Moreover, the inner ball magnet may be replaced with a simple ball of Ferro-magnetic material.

2.1. Principle of Calculation of Orientation and Fixation

Proposed device can serve the purpose of both Accelerometer as well as Gyroscope. Now consider figure 2 above. Let's say that outer sphere containing coil magnets is fixed on the aircraft with Ball Magnet suspended inside its cavity. The aircraft moves in eastern direction. Thus outer magnet will also move in the same direction. However, suspended Ball Magnet will initially lag behind due to inertia and subsequently tend to position itself at the centre of the cavity inside outer magnet due to forces of attraction between opposing magnetic poles.

Figure 3

Figure 4

If we install a sensor (covered later) which can measure the displacement of the inner Ball Magnet, we can measure the linear acceleration of the satellite on all three axes (X, Y & Z axes). Similarly, whenever the satellite undergoes any change in Yaw, Pitch or Roll, the Inner Ball Magnet will also tend to re-orient itself with South Pole facing upwards against North Pole of outer magnet.

In nutshell, by tracking both the current angular velocity and the current linear acceleration of the suspended Ball Magnet relative to the moving system, it is possible to determine the linear acceleration and orientation of the satellite [7].

2.2. Sensing the Linear and Angular Displacement

Construction given at Figure 5 may be used to sense the linear and angular displacement of the Inner Ball Magnet with respect to Outer Magnet and vice versa. Light emitted from the source forms an image of Ball Magnet on Photo Sensor on the right.

The size of the image will alter with any change in distance of the Ball Magnet from Light source or Photo Sensor; thus the displacement of the ball in any direction (3D) can be accurately measured.

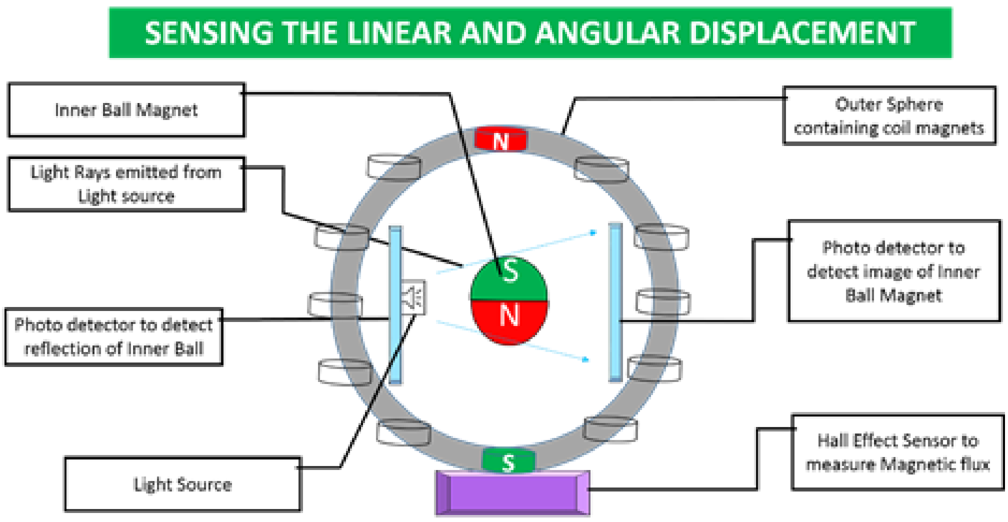

Figure 5

The Ball Magnet may be marked on its outer surface in order to allow for visual measurement of angular displacement through change in reflection of the Ball Magnet as seen from Photo sensor on the left. Moreover, Hall Effect sensor will also allow to measure change in Magnetic Flux.

According to Faraday's Law of electromagnetic induction (see example in Figure 6 [8]), if the inner ball magnet moves near the coil of outer magnet, an emf (electromotive force) gets induced in the coil. The magnitude of induced emf can be calculated from the emf equation [9] of DC Generator. The direction of induced current is given by Fleming's Right Hand Rule. When the inner ball magnet is moved one way (say, towards the coil), current is produced in one direction; when the magnet is moved the other way (say, away from the coil), current will be produced in opposite direction. Not only can a moving magnet cause a current to flow in the coil, the direction of the current depends on how the magnet is moved. As the outer electromagnet has been distributed into multiple coil magnets (figure 5) along the periphery of the outer cylinder; thus by measuring the magnitude and direction of current induced in each coil by the inner ball magnet, we can detect the movement of the inner ball magnet. This will eradicate the requirement of additional sensors for measuring the displacement of the inner ball.

Figure 6: Faraday's Law of Induction

2.3. Measuring Value of Gravity on Earth and Space Missions

Consider Figure 2. As outer magnets are electro-magnets, we can conveniently measure the value of electric potential required to suspend the Ball Magnet at 1g when strength of magnetic field and acceleration of satellite are known. This value can then be compared to the electrical energy required to lift the ball at any given point; thus helping to determine value of ‘g’ at that point. In this scenario Hall Effect sensor may provide the value of ambient magnetic field with reasonable accuracy. Moreover, ambient magnetic field may also be computed with the help of current position of satellite as magnetic field is function of position around earth. Alternatively, the suspended ball can be allowed to fall freely and acceleration due to gravity at desired point can be determined with the help of sensors. This can also be used to determine gravity of a planet for deep space missions. In this scenario, it is important to cancel out the ambient magnetic field to allow free fall under gravity. This can be accomplished by enclosing the device in a magnetic shielding material.

2.4. Measuring the Value of Magnetic Field in Space

Since the Inner Ball Magnet is suspended with the help of magnetic forces; thus any change in magnetic field outside the device will also affect the amount of electrical energy required to suspend the Ball Magnet when value of gravity and acceleration of satellite are known. In this case value of ‘g’ can be taken as last measured value. Moreover, gravity can also be computed with the help of present position of the satellite with respect to earth or other heavenly bodies. Alternatively, when the magnetic field produced by outer electro-magnet is turned off, the inner magnet will orient itself in accordance with ambient magnetic field. The orientation and rate of movement of inner magnet can be used to determine the value of ambient magnetic field at a given point. Moreover, ambient magnetic field can also be measured by electric current induced in the coils of outer electro-magnets due to motion of satellite (along with coils) in prevailing magnetic field in space. While measuring ambient magnetic field, it is preferable to remove magnetic shield if the magnetic field is very small.

2.5. Propulsion of Satellites without Loss of any Mass

The propulsion here means functions like station keeping, orbital maneuvering and deep space propulsion, after the satellite has been placed in orbit. Calculations for factors like drag due thin atmosphere and micro-gravity etc as encountered in space, will be carried out as being done in existing satellite missions without any change. However, factors of gravity and magnetism have been discussed in relevant paragraphs where they affect functioning of the device. The system as described earlier can also be used for propulsion of satellites in space. The concept utilizes law of inertia as its baseline i.e. “The heavier the mass of an object, the more difficult it is to move it”. Consider construction and functioning as given below in figure 7 & 8. The diagrams are self-explanatory. For sake of simplicity, construction involving only two magnetized coils as described earlier in figure 2 have been considered. Suppose, the outer coil magnets are strapped/ fixed at the body of a satellite of 10 kg mass; whereas the inner ball magnet weighing 100 grams is suspended inside its cavity in gravity free space. When outer magnets are energized electrically, the inner ball magnet (being lighter in mass) will accelerate towards the heavier outer magnet on the right, ultimately hitting the right side wall of the satellite; thus transferring momentum to the satellite on impact. This process will cause the satellite move in direction of movement of inner ball magnet.

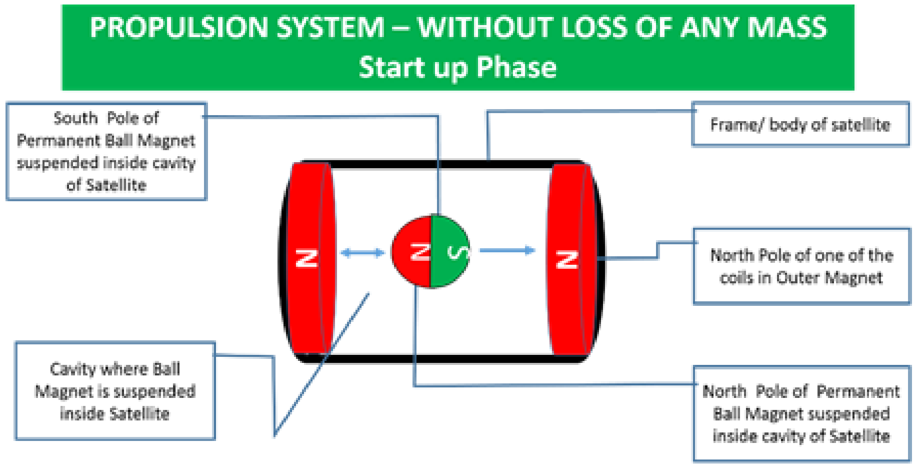

Figure 7

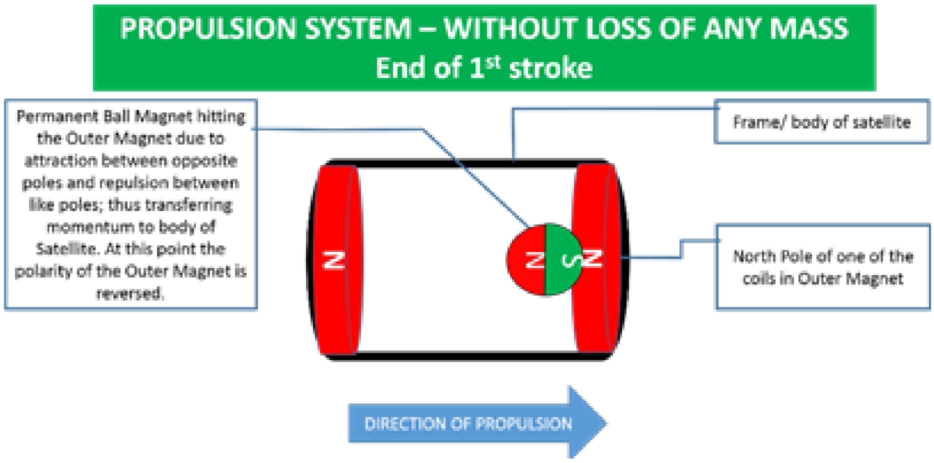

Figure 8

On impact of the inner ball magnet, the direction of current in the coils is reversed, thus polarity of these electro-magnets will also change. Now consider figure 9. On reversal of polarity, the ball will be pushed back due to repulsion between like poles and attraction between opposite poles. This will further push the satellite in desired direction until the ball reaches near left wall of the satellite. Here again the polarity is reversed and the system will again take the form of start-up phase as given in figure 7 earlier. The process can be repeated to achieve continuous propulsion in one direction. It is important to ensure that strength of magnetic fields produced by the coils on each side are so configured that the inner ball magnet impacts the side in which satellite is required to be propelled with maximum velocity in order to transfer maximum momentum in desired direction; whereas the movement of inner ball towards wall opposite to direction of propulsion is so controlled that it just slowly reaches near the wall without impacting it, thus bringing the device in start-up phase again. This can also be achieved by magnetizing only one side of the satellite/ device at one time.

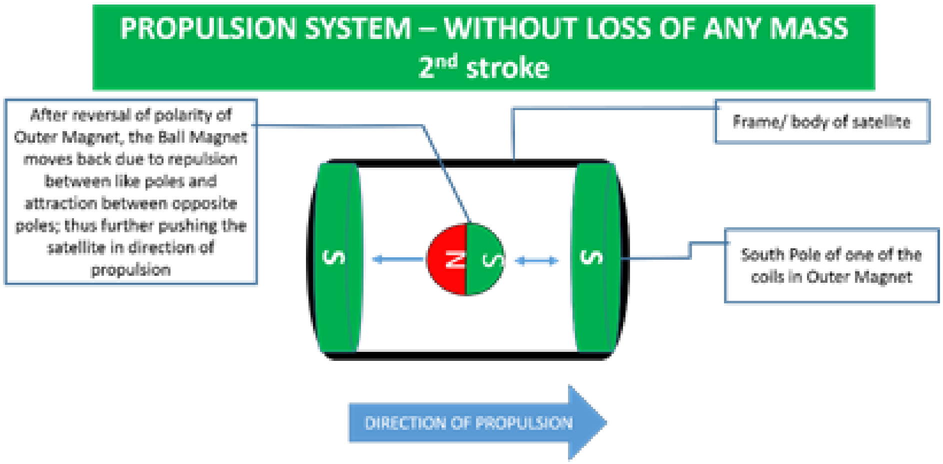

Figure 9

2.6. Construction for Propulsion in 3D

For sake of propulsion in 3 dimensions, construction as given in figure 10 may be considered. The principle described for propulsion on single axis remains applicable. However, addition of multiple coil magnets will provide flexibility of propulsion on all three axes (X, Y & Z).

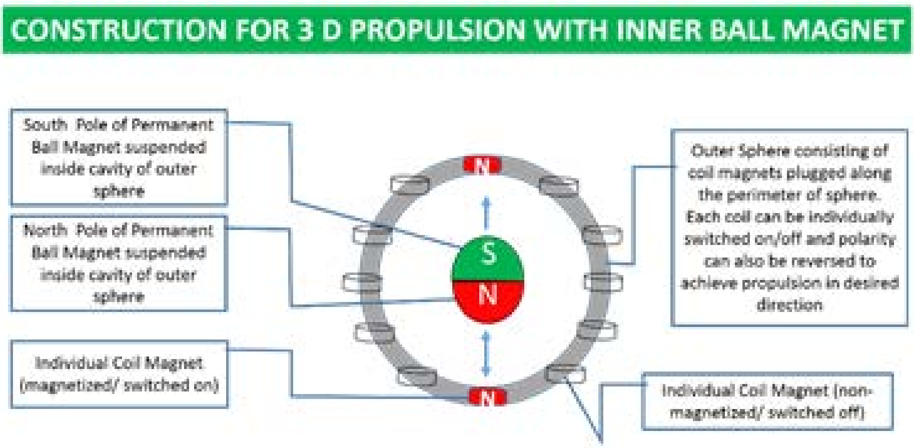

Figure 10

A simple ball of ferromagnetic metal may be preferred instead of inner ball magnet, to counter the problem of inner permanent ball magnet losing its magnetism due to repeated collisions with the outer walls of electromagnet. The only difference in this scenario will be that only one side of the satellite will be magnetized at one time instead of both.

Once the inner ball has impacted the magnetized side, the opposite side will be magnetized; thus attracting the ball in opposite direction, providing propulsion in desired direction. Same may be done in construction of device for other purposes like measurement of gravity, magnetism and data for INS.

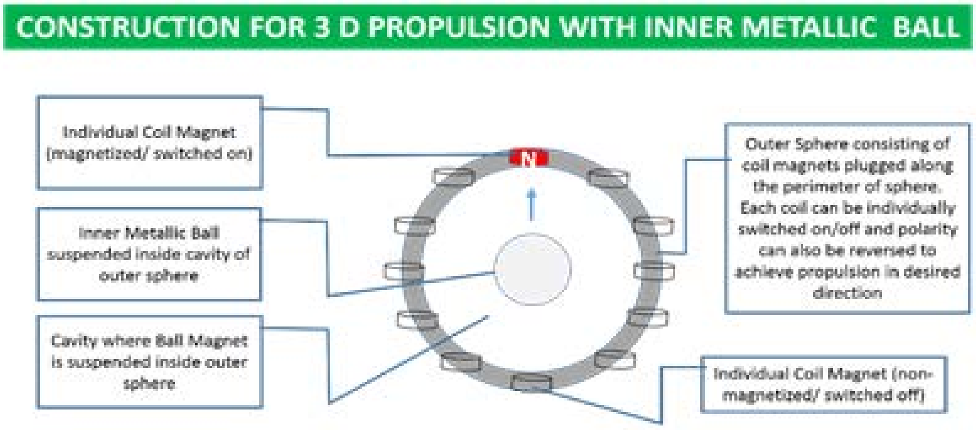

Figure 11

Two small devices suitably configured on either side of centre of gravity of the satellite may be used to provide spin stabilization as well as axis stabilization (See figure 12 & 13).

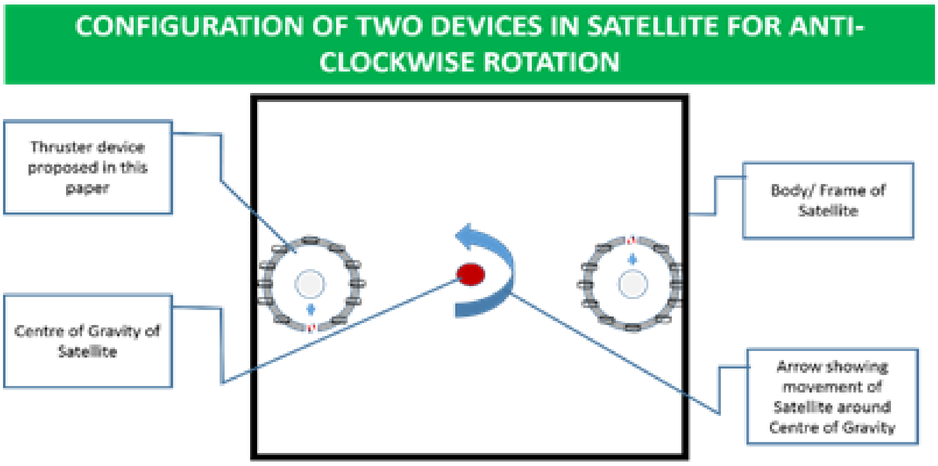

Figure 12

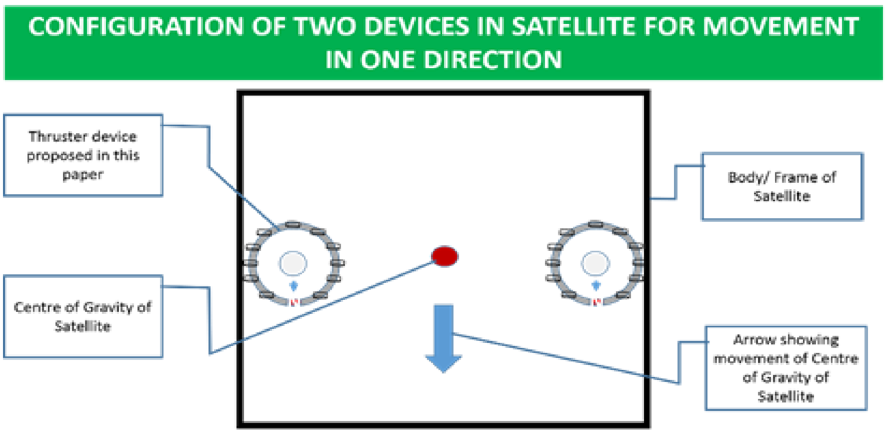

Figure 13

Similarly, a third device may also be added to provide better attitude control in all directions (See figure 14). Three devices arranged along three different walls of satellite. A combination of spherical or ring shaped or cylindrical devices may be used to economize mass and enhance performance.

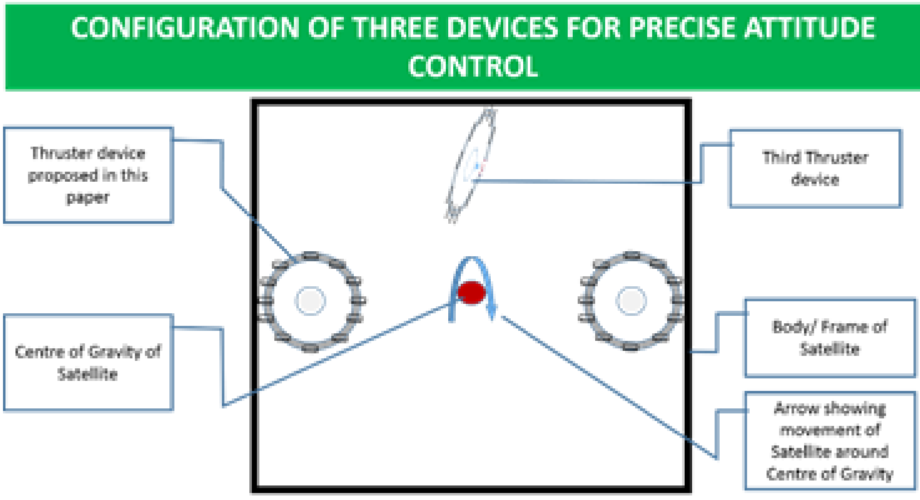

Figure 14

3. Compactness & Sensitivity of Device

The device may be made compact by miniaturizing the magnets and sensors depending upon the technology available and their innovative use. Nano-magnets[10] (grains of ferromagnetic metals) can be used in the construction of the device to make it more compact and more sensitive. There is no limit to the expected miniaturization of the device. It may weigh up-to few hundred grams or even lesser. However, in case of propulsion system, the size/ mass of inner ball will correspond to the size of satellite to be propelled.

4. Applications and Significance of Device

The proposed device has the potential to replace the existing propulsion systems due to the reason that it is likely to produce better thrust without loss of any mass; relying on power source which can be provided by solar panels. This will pave way for prolonged missions in space and miniaturization of satellites. Moreover, the device can be used to provide redundancy and add accuracy to existing gyroscopes, accelerometers, magnetometers and gravimeters installed in missiles and satellites. In nutshell the device itself can take the form of an autonomous satellite with addition of power source along with communication and computation instruments. In addition to the ones described here, the proposed device can find many industrial and daily applications here on earth; where measurements of magnetic fields, gravity or linear & angular displacements are involved.

5. Possible Variations in Basic Construction of Device

The device can be modified in many ways. Some of the variations in proposed design are as under:-

- External light source may be replaced with a light source inside the ball magnet; facilitating the exact measurement of angular and linear displacement of the Ball Magnet with respect to outer Magnet.
- The casing of the device in which coils are plugged may be Ring shaped, Cylindrical or Spherical. Number of coils in outer perimeter will be determined by specific purpose for which device is being used.
- Shape and size of Inner suspended ball may be changed as per requirement.
- Sensors as proposed here may be added or deleted as per requirement.

6. Limitations of Study

Although construction of proposed device is based upon well-established principles which don't require any further explanation like Law of Inertia, Faraday's Law of electromagnetic induction and Magnetic Levitation utilizing a combination of coil and permanent magnets, yet there is a need to confirm the validity of the concept through experimentation. Moreover, many videos [11] are available online which confirm the validity of the concept of magnetic levitation using permanent or electromagnets.

7. Recommendations

Following design parameters need to be evaluated with experimentation depending upon specific roles envisaged for the device:-

- The size, mass and strength of the Inner and Outer Magnets depending upon use.
- Materials used for magnets need to be carefully selected keeping in view robustness and need to minimize vibrations especially while designing propulsion/ attitude control system.
- Type of light source and Photo detectors. (Commercially available ones may be used)
- Initial calibration of the device for measurement of initial parameters.
- Shielding/ isolation of the device from external magnetic fields when being used as INS and for measurement of gravity.
- Determination of the components of gravity and magnetism during initial calibration and during subsequent operation.
- Inner suspended ball may be a permanent magnet or a metal for various uses envisaged for the device.

For accurate measurements, the device can be used for propulsion or measurement of magnetic field or gravity or as INS sensor at a time. Thus satellite computer needs to be programmed accordingly. However, when two or three such devices are used in the satellite for propulsion. These may also be used for navigation or measurement of gravity and magnetism when not required for propulsion/ attitude control; as single device can also perform propulsion/ attitude control.

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