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AN APPROACH FOR SPACE DEBRIS CLEANING USING SPACE BASED ROBOTS

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Abstract— **Since the origin of space age, manmade satellites have been commissioned into the orbit and those satellites have a senility of twenty years. For about more than five decades, these dead satellites have been accumulating around earth's orbit, which contributes for significant amount of the debris. As a number of dead satellites in the earth's orbit are steadily increasing, space debris, if left unchecked, will eventually pose a serious hazard to near earth space activities and effective measures to mitigate it are becoming quintessential. Additionally, if those satellites were brought back, they can be cannibalized for materials which help reducing the production cost for new satellites. Many methods have been proposed earlier for space debris cleaning. But the target has mostly been smaller debris (1 – 10 cm) as it is fatal and proposes a serious mitigation. The approach of fetching back older satellites which is a major source for the debris formation in space has been minimally broached and they are not yet confabbed in a detailed way due to the entailed expenditure incurred in missions. In this paper we come up with a robotic satellite accoutered with weldable deorbit thrust rockets in the hull to target LEO dead satellites. The concept is to couple the de-orbiting rockets to the dead satellites and tote them back.**

Index Terms— **space based robot, space debris, de-orbit, deorbit thrusters, controlled de-orbiting, NISO.**

I. INTRODUCTION

Electronic satellites have a mean senility of 20 years and this is majorly due to the fatigue loading of the satellite power systems. Considerate amount of communication satellites have a large Area Mass Ratio (AMR). After their stipulated life, the satellites are either transported to a higher orbit (Grave Orbit) or left in the same [4]. These dead satellites constitute the major space debris occupying the orbit. The satellites mainly occupy either the Lower Earth Orbit (LEO) or Geo-stationary Earth Orbit (GEO). As of end of the year 2012, it's estimated that around 15,000 dead satellites occupy the LEO [4, 5, 11]. This may be a major problem in the near future for any lower orbit space activity or placing any new satellites in the LEO due to a high risk of collision between the live satellites and the debris [1, 2, 3, 11]. The integrity of orbital debris upon reentry is largely dependent on the size of said debris. For debris of size below critical value, the reentry creates enough aerodynamic drag for debris to burn out. Orbital debris seriously jeopardizes the future not only of human presence in space, but also of human safety on earth [1, 4]. While international efforts to mitigate the current situation and limit the creation of new debris are useful, recent studies predicting debris evolution have indicated that these will not be enough to ensure humanities access to and use of the near earth environment in the long term [1, 6]. Rather, Active Debris Removal (ADR) must be pursued if we are to continue benefitting from and conducting space activities [1]. Many active methods of space debris removal have been in the conceptualization and making for about a couple of decades. But the major problems faced in the active debris removal have always been in the mission cost.

Several space-faring nations are concerned about the increasing risk of space debris interfering with operational satellites. Although, no one knows when this will turn into a crisis, there is general consensus that sometime in the next one or two decades, the frequency of collision events in congested orbital regions will dramatically increase. The result will be a loss of access to an important part of space. Space debris in LEO is categorized based on its size, potential risk and possibility of detection [4]. An important fact is that, although the number of debris objects is many times higher for the small-sized debris, nearly all the mass of the LEO debris is concentrated in the large objects. In the long term, the large >10cm objects pose a greater risk. Their significance is that these larger masses could create large clouds of new, smaller, high speed debris when involved in a collision, thus adding substantially to the problem. As, the number of collisions between an intact object and a fragment has higher probability than impact between two intact objects (Kessler syndrome), many resulting fragments will then, in turn, pose a certain risk for the catastrophic destruction of another large orbital body, and so on [2, 4]. Once a certain debris density has been reached, this effect causes the debris population to continue growing, even without the launch of new objects. Therefore an effective and technologically feasible method for ADR should focus on intact objects that also have the advantage of a known size, mass and shape.

SIZE (cm)	Potential Risk	Detection	Number
>10	Complete destruction	Tracked	21000
1-10	Partial/total	Partially tracked	500000

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	destruction		
<10	Damage, can be shielded	Not tracked, statistically assessed	> 100 million

Table 1: Classification of Space Debris orbiting LEO [4]

The usage of space based laser systems has been proposed, where the laser targets debris of smaller sizes to reduce their orbital speeds. The mission describes the need for a defense mechanism setup in the space station with a large active surface area to detect the debris at a wide berth to avoid imminent collision. The collision of such hyper speed debris on the surface area of the space station may cause a hull breach and severe damage to the system in consideration. For this, the laser ablation sensors track the particles in approach and gives specific thrust vectors to evade the actions of debris in approach of the space station. A medium frequency laser has been suggested for a repeat based space-based laser system [3].

During the year 1998-2002, the NASA designed and built the Propulsive Small Expendable Deployer System (PRoSEDS) to demonstrate electrodynamic deorbit of a 1-ton Delta II upper stage [13]. The mission was cancelled owing to a risk to ISS. The institute of Aerospace technologies, Japan Aerospace Exploration Agency (JAXA) proposed a small/micro satellite fitted with an Electro-dynamic Tether (EDT) technology for active debris removal. An EDT package can be used to lower the orbit of the debris without the need for propellant. But, capturing is an indispensable task for the retrieval of large space debris as those large space debris objects begins to tumble, because of the angular momentum remained in their altitude control systems when the failure occurs [7].

Electrostatic plasma break is a concept which combines the concept of a space based tether and plasma actuator to produce enough drag to reduce the orbital speeds and de-orbit the satellites. The concept is to produce negatively charged plasma against the orbital direction to induce a break in the orbital velocity coupled with a tether with a balancing weight. The coupled force of the tether and negatively charged plasma forces the satellite to lose the orbital velocity and prematurely descend to the lower orbit. In the proposed element a tether similar to the electrodynamic tether has been analyzed and has been found to be effective in the de-orbiting [7]. It has also been stated that the methods requires significantly less massive tether. The restriction in this case being it can only be used to tow smaller satellites in the LEO [8, 9]. The singular missions are both cost and time consuming procedures. The political and legal consideration is also a concussive problem to deal with. The international space laws prohibit technologies having attributes which may harm other nations. Taking into the factors stated above, the situation demands an extensively combining technology which incorporates all the above stated factors and further, is a cost effective mission with less political and legal implications [4].

However, in these discussed processes [6, 10] the object of the mission is to target single debris particle only and this involves a huge number of singular missions to clear the orbital debris. In this research, the goal is to explore the foresaid challenges and to propose an economically effective space debris removal technique using space based robot which can be a viable solution for multiple debris removal.

Proposed Concept:

This paper describes a concept where a Single semi-Autonomous Satellite Tracking ROBOT (SASTROBOT) is launched in to the space carrying disparate deorbit rockets in the hull. The mission involves the robot to seek dead satellites and attach a particular deorbit rocket depending upon the AMR of the said dead satellite. Further, the control of the dead satellite is handed over to the ground station. Thereafter the ground station fires the deorbit rocket to bring back the dead satellite in a controlled de orbit back to the earth surface.

The concept has multiple advantages into consideration. The relative mission carries about twenty deorbit rockets attached to SASTROBOT, which can be actively used to seek about eighteen dead satellites per mission. Further the robot can be brought back and fitted with new mission segments and sent back which makes it retrievable. Thereby, both the number of missions required and the mission cost involved in active debris removal is significantly reduced. Further during debris removal, initially the LEO can be concentrated by which significant orbit space can be made scant of debris and the lower orbit space missions can progress without the possibility of interference from the orbit debris. The conceptual diagram of a space based robot carrying different de-orbiting rockets is depicted in fig. 1

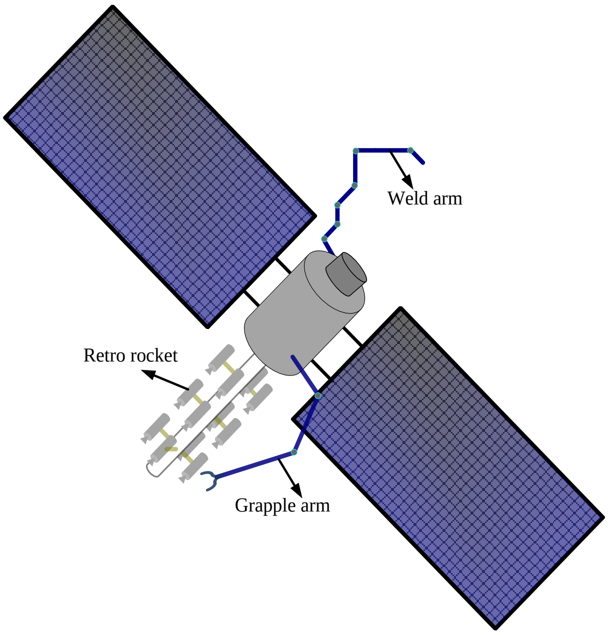

Fig. 1 Illustrated representation of SASTROBOT

SASTROBOT working principle:

Stage 1:

The decided mission is programmed into the on board controller at the base station. The initial target telemetry data is clearly programmed for trajectory launch and guidance protocols that have to be served during the launch. Significant care is taken to select a plethora of de-orbiting deorbit rockets and then fitted into the slots provided in the rear of SASTROBOT. The position and numeration of the rockets are then fed in to the controller. Then SASTROBOT is launched using a launch vehicle.

Stage 2:

The launch vehicle places SASTROBOT in the LTO. The orientation of the robot is corrected and telemetry data is verified. Then it is upstaged to the LEO orbit behind the first dead satellite.

Stage 3:

Following the data provided from the ground, SASTROBOT seeks the first dead satellites and closes in. Seeking is done in such a way that the robot approaches the dead satellite from the rear and using the control rockets relative velocity of the both objects is zeroed.

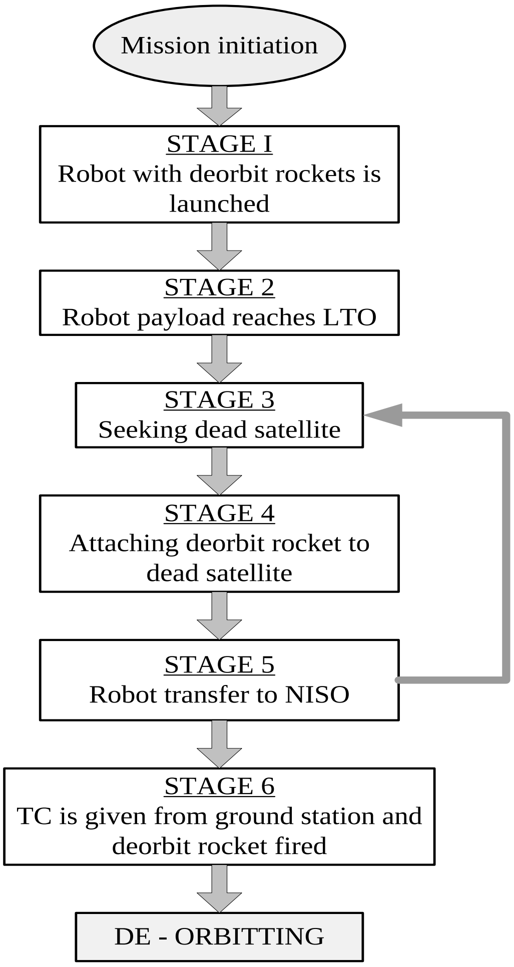

Fig 2. Flow chart of the mission initiation to deorbiting

Stage 4:

Confirming relative velocity and the AMR of the satellite, suitable de-orbit rocket is then selected and retrieved using the grappling arm. The weld arm then proceeds to place the flux cable (Nano metric gold wire). The rocket is fused with the dead satellite body by cold welding process [12] in a relative angle for a controlled de-orbiting.

Stage 5:

Grappling and welding arms are released from the dead satellites after confirming fusion of the deorbit rockets. Then the ground station is provided with the information of the deorbit rockets to be fired. Then the retro rockets available in SASTROBOT fires and it transfers to NISO.

Stage 6:

The dead satellite with de-orbiting rocket as a piggy back travels to its perigee position. When the suitable position has been achieved, a telecommand is given by the ground station to fire the rockets. Confirming the ignition, the de-orbiting rockets thrust vector is suitably programmed by the base station for a controlled de-orbit maneuver. Base station may program the dead satellite to fall at any designated collection area. The collection area is determined in such a way that there is no human loss due to the retrieval machinations. The detailed mission profile is shown in the fig. 2.

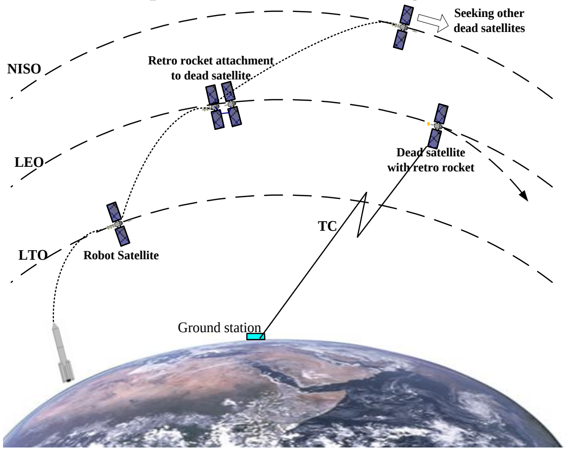

Fig 3. Typical Mission Profile

Non-Interference Seeking Orbit (NISO):

Noninterference seeking orbit is slightly above LEO. It is defined by the ground station. The SASTROBOT seeks other dead satellites placed in LEO. When an optical feed of a dead satellite is received, the image is then transmitted to ground station. If the confirmation is received from ground, then the SASTROBOT follows the same operation procedures.

Telemetry and command system:

The command and telemetry systems are each one link transmission systems. The command system has its transmitting terminal on the ground and the receiver in the satellite. The telemetry system on the other hand, transmits from the satellite and the signals are received on ground. By means of command system, the magnetic/mechanical latching relays in the SASTROBOT are controlled from the ground. These commands are sent to the satellite by coded signals modulated on a carrier in the VHF band. Telemetry system also uses a VHF carrier to transmit encoded information from the satellite.

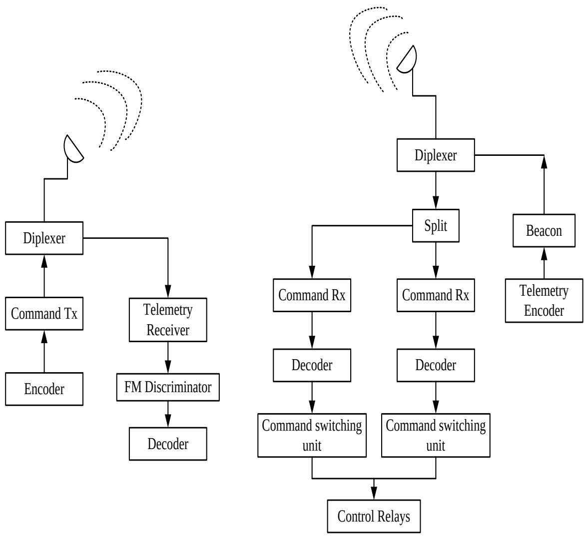

Fig 4. Conceptual block diagram for command and telemetry system (left-ground station to satellite, right-satellite to ground station)

The command system transmitting terminal consists of a command encoder which generates the specified code and a VHF command transmitter which is amplitude modulated by the command signal. The output of the command transmission goes through the ground diplexer to the command tracker Antenna and is radiated to the satellite. The signal picked up by the satellite helical antenna goes through the satellite diplexer and a splitting arrangement in to two command receivers. The baseband pulses out of each receiver drive a decoder which activates the proper relay through action of the switching unit.
The telemetry system transmits information from the satellite back to the ground. The transmitting equipment in the satellite consists of a telemetry encoder whose output is modulated and then goes through the satellite diplexer to the helical antenna where it is radiated. The telemetry signal is picked up on the ground by the command tracker antenna and then goes through the ground diplexer to the telemetry receiver.

It then passes to the discriminator where the baseband signal is separated out from the carrier signal thus reducing the unwanted signals to interfere. Information can be decoded from the discriminated baseband signals using decoder.

CONCLUSION

The fore said concept of a multi mission space based robot (SASTROBOT) can be a viable solution for space debris cleaning. It has been concluded as a system which is economically a positive and active solution for space debris cleaning. The new proposed concept of removing multiple space debris (approx. 18 dead satellites) on a single mission might be a much needed solution for the current scenario. Compared to other solutions proposed in active debris removal, the concept may be used for targeting medium to large debris which accounts for effective cleaning of LEO. If adapted, it may be clearly an essential alternate for the previously proposed methods. Further research suggests that the robot may be used to carry other payloads as well making the missions to be more than removal of orbital debris. It may be also used as a carrier robot with multiple smaller satellites as it payload having different locations and orbits as its final destinations. Also, it may be fruitful to combine the payloads according to relevance of the mission. It may be concluded that with imminent requirement of space debris cleaning a combined technology from different space age nations to create a technology may be a paramount. SASTROBOT design acclaims the combination of several advantageous technologies for cleaning of obsolete debris

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ACRONYMS

ADR – Active Debris Removal
LEO – Low Earth Orbit
GEO – Geo-stationary Earth Orbit
SASTROBOT – Semi Autonomous Satellite Tracking Robot
NISO – Non-interference Seeking Orbit
AMR – Area Mass Ratio
LTO – Low thrust Transfer Orbit
VHF – Very High Frequency