HORST: Holographic Orbital Return Storage Technology
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Abstract—Nowadays, space science is facing increasing problems with the amount of data collected from sensors in space and its transmission back to Earth. In this paper we introduce the novel Holographic Orbital Return Storage Technology (HORST) and its potential application in space industry. The proposed solution is a payload module which stores hundreds of terabytes of data on a robust 5D holographic disk. After the end of mission (EOM), the module is detached from the satellite and lowered into the Earth’s atmosphere, protected by a heatshield surface and a parachute. The recovery of the module allows the readout of big sensor data on Earth. Besides fulfilling the big demand for applications of this technology nowadays, this paper discusses several major use-cases for near-future concepts and missions. HORST will enable many possibilities for new science missions and business in space. Since there is no comparable alternative technology, the lack of competition and the increasing demand will allow HORST to become a key technology for space.

I. INTRODUCTION

In 1965, Gordon Moore accurately predicted that the number of components on an IC would double every year for the next 10 years. 53 years later (2018), this rule, which is later known as Moore’s Law, is still applicable. [1] With the increase in processing power and sensor accuracy, the amount of data measured, processed and stored is continuously growing – on earth and in space. For data transmission, most satellites rely on the electromagnetic microwave (L, S, C, X, Ku, Ka) bands, where insufficient transmission bandwidth and congestion is already a problem as of today. [2] To tackle this bottleneck for the present and near-future, this paper introduces the concept of a payload module to physically return data back to earth, instead of RF transmission.

II. HOLOGRAPHIC DATA STORAGE

Nowadays, two-dimensional data storage technologies (CD, DVD, Blu-ray Disk) are common which use only one layer to store data. The idea of the optical memory based on a femtosecond laser, writing in the bulk of transparent material, was proposed in 1996 and implemented in 2013 in Optoelectronics Research Centre, University of Southampton, where a 5D disk was created. In this case two more dimensions for data storing are added apart of the three spatial coordinates: The slow axis orientation (4th dimension) and the strength of retardance (5th dimension). (see figure 1) The more dimensions, the more data can be stored in the same volume. This technology allows to store 360 TB/disk! Nanostructured silica glass disks are used, because this material is resistant to rapid heat changes, mechanical shock and aggressive radiation. To change the structure of the glass to store data, a femtosecond laser is required. This technology allows to store data without degradation for hundreds of years and an infinite amount of read-cycles. [8]

III. PAYLOAD MODULE

The payload module itself is a round capsule with an outer ablative heat shield layer to protect the module from atmospheric reentry thermal pulse and mechanical shock. Inside the capsule, the module has stored a commercial off-the-shelf (COTS) parachute to enable a soft landing. The separation mechanism of the upper part of the heat shield hull to expose the parachute is critical and has to be developed and tested. Standard control electronics and a serial data interface like SpaceWire (LVDS) or CAN are also necessary, to connect the payload module with the satellite and to convey data further to the holographic laser writer. Also, a transponder for recovery tracking is necessary for the recovery. The density of the module shall be less than $10^{20}$ kg/m$^3$ because it has to float on sea water.

The main system, enclosed in the bottom of the module, is the holographic laser writer, which includes a laser with one or several wavelengths and a set of lenses and mirrors to focus the laser beam. It allows to write data on one or multiple nanostructured silica glass disks. The disks and the laser have to be bedded in a shock-absorbing supporting mount to increase the mechanical shock resistance.

IV. DATA RETURN TO EARTH

A. Target Return Orbit

Before the separation of the HORST payload module, the satellite must be in an very low earth orbit to initiate...
aerobraking to bring the module down to earth, since the module itself doesn’t contain any means of propulsion to lower the orbit. The orbit may be elliptical in case of soft aerobraking. However, the module is not designed for a steep, direct descent due to heat shield requirements. After detaching, the satellite could rise to a stable orbit again or be decommissioned into the atmosphere, depending on the mission goal.

B. Recovery

After the payload enters the atmosphere, a parachute will deploy to slow down its speed for landing. The landing itself will take place in a defined dropping zone, a sea area close to the shore. Its range is directed by many variables and include among others the orbit and the shape of the payload, as well as dynamic parameters like the weather conditions and jet streams. After landing, the exact location will be known due to a tracking device, which is included in the module. A contractor ship will follow the signal and retrieve the payload.

V. USE CASES

This new, versatile technology has many possible use-cases. In this section, we identified the main present to near-future use cases for the HORST payload module.

A. Safe Data Storage

An alternative use case is the safe storage of data in space. The data would be slowly transmitted by existing microwave RF systems. The properties of the holographic storage, mentioned in [1] make it an optimal safe long term data storage. In case of a major catastrophe on earth, the data will still be safe in orbit. This increases data redundancy for safe cloud storage architectures.

In February 2018, SpaceX launched a Falcon Heavy to a solar orbit, carrying a disk with this technology to safely store and preserve libraries of human knowledge. [4]

B. Data Transmission

For mid-future human Lunar or Martian bases, essential and up-to-date data can be slowly transmitted by existing microwave RF systems. However, big amounts of research, entertainment or informational data can be transferred from and to earth by the HORST module. For example, a resupply mission to a Lunar or Martian base could contain a HORST module with movies and music for entertainment, recent news and an incremental update of an encyclopedia like Wikipedia.

C. Space Very-long-baseline Interferometry

The main present to near future use case is the use of Very-long-baseline interferometry in a space satellite constellation (S-VLBI).

Fig. 3. S-VLBI usecase satellite visualization with separated HORST module [3]

1) Satellite Constellation with HORST Payload: With this technology, multiple satellites can build up a virtual radio telescope with a ultra high angular resolution. A longer distance between the individual radio telescopes translates into a higher angular resolution. [5] Therefore, the satellites shall be injected into a high earth orbit, where the distances between the satellites and earth is in the magnitude of tens of thousands of kilometers, which is one of the main advantages of S-VLBI.

This method of VLBI works by accurately sampling digital telescope data with the reference of an atomic clock and saving it onto the HORST payload module. At the EOM, the satellite orbit is lowered for reentry and the HORST module is separated. After the recovery of the HORST modules with all the constellation data, a high resolution image can be reconstructed on earth by a computing cluster.

Following payload modules are proposed:

- Radio telescope dish and receiver
- Accurate atomic reference clock (H maser), can be used from ESA’s GALILEO Mission
- RF Transceiver for calibration and satellite control
- HORST Module for big storage data return
Activities/ Telecommunications
Integrated Applications/
Data

E. Exploration and observation missions

The data return principle used in section V.C can also be implemented in other exploration and observation satellite payload missions. With the massive increase of available data storage capabilities, new sensors can start fully using their payload missions. With the massive increase of available data storage capabilities, new sensors can start using their payload missions.

D. Optical Space Transmission Star Topology Data Sink Gateway

In 2001, ESA achieved the first satellite to satellite laser transmission (Artemis satellite). Because of the shorter wavelength of light and the possibility to use multi-chronic light, very high data rates can be achieved.

To serve the data storage and transmission needs of multiple satellites, one or more satellite nodes with HORST modules and an optical laser transmission system can be positioned in the Low Earth Orbit (LEO). Multiple satellites can upload sensor data to these satellite nodes via high speed optical links. After a holographic disk on a node is full, the HORST Module can be detached to go back to earth, as described in section IV.

This system has the major advantage that the data acquisition systems is physically separated from the data storage and transmission system (HORST). This enables long satellite observation or exploration missions while the HORST node detaches the modules more frequently for shorter data transmission times. Examples for possible missions are discussed in sections V.C and V.E.

VI. IMPLEMENTATION STRATEGY

They key activities of HORST is the provision of a huge capacity of storage space, access to data in high resolution while ensuring their safety and stability. Regarding the analysis in the section HORST’s business case is mainly B2B (business to business). The main customers are from the scientific sector.

Because the module is brought back to earth, many components will still be functional upon recovery. The implementation goal is complete re-usability, apart from the full returned holographic disk.

VII. CONCLUSION

The holographic orbital return storage technology is the solution for huge data storing and delivery back to Earth, as this storage is dense (much bigger capacity comparing to technologies used now), resistant to time (stable over hundreds of years), radiation, temperature change and mechanical shock, what makes it a promising technology for future scientific and private sector use. By re-using the module and the use of COTS parts, the module is very cost effective. It will be useful for industry both in space and on Earth, as data is a key resource in our digital world. By working on the bandwidth bottleneck problem, described in section IV we created the concept of a device with many applications. There is no comparable alternative technology. The five use-cases discussed in section V enable new, daring science and business in space and on earth, but are only a fraction of what is and what will be possible.

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