Docking Video Transfer by On-Orbit Wireless LAN Communication and Application to the Docking Demonstration Mission on HTV-X

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Abstract

Japan Aerospace Exploration Agency (JAXA) is developing automated docking techniques to acquire one of the critical technologies to realize the sustainable activities on the future platform in Low Earth Orbit (LEO) and the future cis-lunar Gateway station. In the mission of "HTV-X," which is a next generation unmanned visiting vehicle and a successor to the H-II Transfer Vehicle "HTV," the automated docking techniques are planned to be demonstrated and it would be an opportunity to acquire a new space transportation system for Japan. Among the several major technologies required for the docking operation, as the first step, the technology of wireless transmission of docking monitor video was demonstrated in the last HTV mission in 2020 (HTV9), which is called "WLD (Wireless LAN Demonstration) mission." It successfully demonstrated the real-time video transfer from HTV9 to the ISS by wireless LAN communication and was the first time in the world that two spacecrafts succeeded in Wi-Fi communication on orbit. Based on this achievement, this technology will be applied to the automated docking demonstration mission on the HTV-X2. In addition to the demonstration on HTV9 mission, transferring an actual docking video and an integration into the ISS crew monitoring system will be performed as a next step.

This paper mainly presents the operational concepts of the automated docking demonstration mission on HTV-X2 and the method of the docking monitoring by using wireless LAN communication, including the technical challenges and improvements. The result of the demonstration on HTV9 mission, such as the evaluation of video quality and Wi-Fi link stability are also mentioned.
Keywords: HTV-X, HTV, ISS, Automated Docking, Wireless LAN, Wi-Fi

Acronyms/Abbreviations

AR	Active Soft Capture Ring
CDT	Centreline Docking Target
EWC	External Wireless Communication System
SFTP	SSH File Transfer Protocol
GN&C	Guidance Navigation & Control
GPS	Global Positioning System
HTV	H-II Transfer Vehicle
ISS	International Space Station
IDA	International Docking Adaptor
IDSS	International Docking System Standard
JAXA	Japan Aerospace Exploration Agency
JEM	Japan Experimental Module
JEMRMS	Japanese Experiment Module Remote Manipulator System
JDOCX	JAXA Docking Demonstration on HTV-X
LAN	Local Area Network
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
N2F	Node2 (ISS Harmony) Forward
N2N	Node2 (ISS Harmony) Nadir
N2Z	Node2 (ISS Harmony) Zenith
PM	Propulsion Module
PR	Passive Soft Capture Ring
RGPS	Relative Global Positioning System

RPU	R-bar Point Upward
RSSI	Received Signal Strength Indicator
SSC	Station Support Computer
SSRMS	Space Station Remote Manipulator System
ULC	Unpressurized Logistic Carrier
WAP	Wireless Access Point
WLD	Wireless LAN Demonstration
WP	Way Points

1. Introduction

1.1 JAXA Docking Demonstration on HTV-X

JAXA has developed a cargo transfer vehicle, called "HTV" (H-II Transfer Vehicle) which successfully completed all the nine missions to transport the resupplies to the International Space Station (ISS) during 2009 - 2020. After the HTV 9th mission completion, JAXA is now developing a successor to HTV, called "HTV-X," and the launch of its first mission is planned for around 2024. This is a new Japanese unmanned space vehicle and will be responsible for the next generation of space logistics which is not only to the ISS or new commercial space stations in LEO, but also to the future lunar orbital platform. In the 2nd mission of HTV-X, JAXA is planning to demonstrate the automated docking technologies, called JDOCX (JAXA Docking Demonstration on HTV-X) Project. HTV and HTV-X have used a berthing method when it arrives at the ISS, in which a spacecraft is captured by the robotic arm controlled by a crew, but this automated docking technologies enables the fully automated docking to the ISS without crew operations. This technology will be demonstrated for the first time in Japan and will be more crucial in the future transportation to the lunar station where crew members will not be always present.

The automated docking technologies consist of four major technologies, i.e., (1) docking mechanism, (2) relative navigation sensor, (3) Guidance Navigation & Control (GN&C) algorithm, and (4) crew's docking monitor system (see Fig.1). This paper focuses on the technology of (4), which JAXA had developed in advance of the demonstration of those technologies on HTV-X 2nd mission.

1.2 Docking Monitor with Wi-Fi communication

During the docking operation to the ISS, crew monitoring is required within 20m in relative distance of the final approach to the ISS. This is because while the docking itself is completed fully automatically, it is necessary for the crew members in the ISS to maintain a situational awareness and to be capable to command an abort in case of emergency. A video image of docking monitor is being streamed in real-time to the Station Support Computer (SSC) and the crew members monitor it during the docking operation (see Fig.2).

When transferring large size data (i.e., videos and sounds), the required bit rate is about several Mbps. However, the original communication system used between HTV-X and the ISS does not have enough bandwidth, which is only about 8 - 16kbps, because it was designed by JAXA only for the HTV mission to send commands and receive telemetries. In order to resolve the issue with minimum design impacts, we decided to utilize existing Wireless Access Points (WAPs) on the ISS and to apply Wi-Fi communication to transfer the monitor video to the ISS. There are two main applicable WAPs installed in the ISS docking port in Node2 Forward (N2F), which have clear line-of-sights from HTV-X approaching the ISS (see Fig.3).

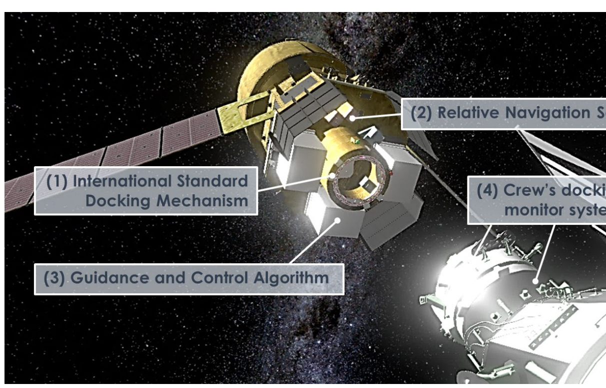

Fig.1. CG image of automated docking by HTV-X and its four major technologies

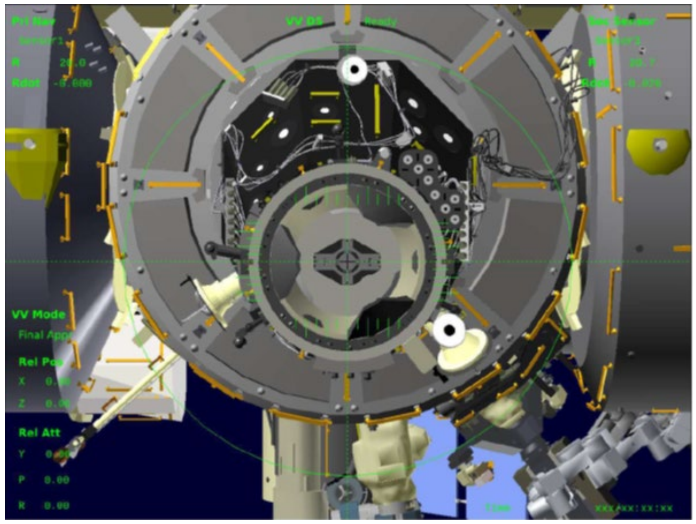

Fig.2. CG image of docking monitor video

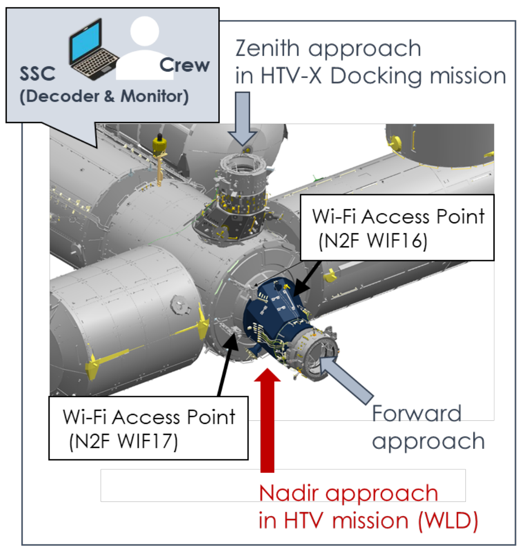

Fig.3. Two main applicable wireless access points on the ISS

2. Successful demonstration on HTV9

2.1 Overview of the WLD mission

In order to acquire the technology of crew's docking monitor system, which is one of the four main technologies introduced in Section 1.1, JAXA developed a mission instrument to demonstrate it as the first step and it had been implemented onto the HTV9. This section presents the results of this demonstration flight on HTV9 in 2020, which was called "WLD (Wireless LAN Demonstration) mission."

The objective of the WLD mission was taking a movie of the ISS from an approaching vehicle side and transferring the movie data to the ISS in real-time. The hardware system was composed of two assemblies and each one is respectively attached to HTV9's body (see Fig.4). The first assembly, called "ULC (Unpressurized Logistic Carrier) hole mission Assy," had Wi-Fi transponder and Wi-Fi antennas, and the second assembly, called "PM (Propulsion Module) surface mission Assy," had camera unit which was taking both still and moving images.

In addition, the WLD mission performed the wireless transmission of docking monitoring video with Wi-Fi communication as mentioned in Section 1.2, and it was the first case to use a Wi-Fi link successfully between moving vehicles in space. This achievement had been featured on Wi-Fi Alliance [1], the worldwide non-profit organization which drives a promotion of Wi-Fi. There was a similar mission at NASA which attempted Wi-Fi communication between two satellites in space [2][3].

2.2 Operational Concept

The operational concept of HTV mission is shown in Fig.5. In a rendezvous phase, HTV starts final approach to the ISS from the nadir side, about 500m under the ISS. After arriving at the capture point around 10m under the ISS, it is captured by the robotic arm, Space Station Remote Manipulator System (SSRMS), and moved to a berthing port on the ISS Node2 Nadir. For the WLD mission, the WLD systems were turned on and the Wi-Fi communication started when HTV9 reached 250m under the ISS. The main access point, which is one of the External Wireless Communication Systems (EWC) on the ISS as introduced in Section 1.2, was started to be used from 30m. During this approach, prior to the HTV9 arrival at the capture point, the Wi-Fi link establishment was confirmed, and the video data was continuously transferred via the Wi-Fi communication.

In a departure phase, after SSRMS sets HTV at the release position, HTV departs from the ISS by firing three maneuvers and go downwards from the ISS (See Fig.5). The WLD mission in this phase was only to measure the maximum range that could keep video streaming and the Wi-Fi communication with EWC.

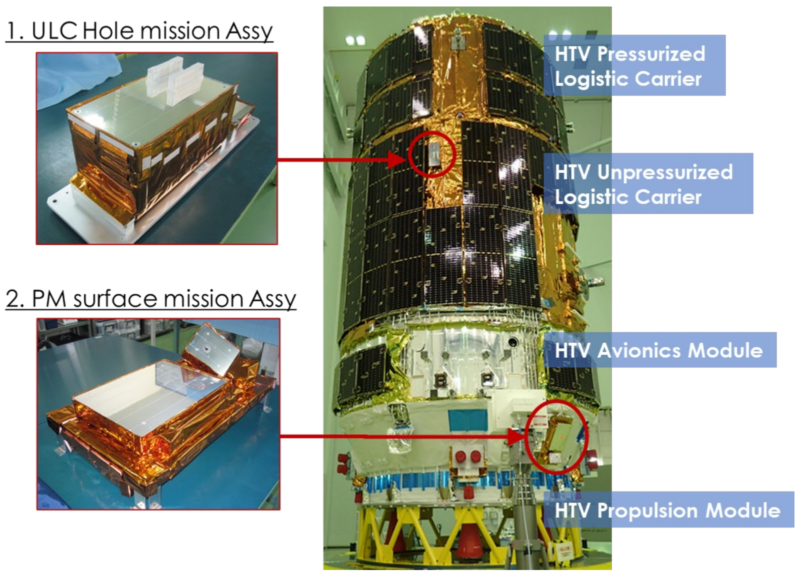

Fig.4. Two WLD assemblies attached to HTV9

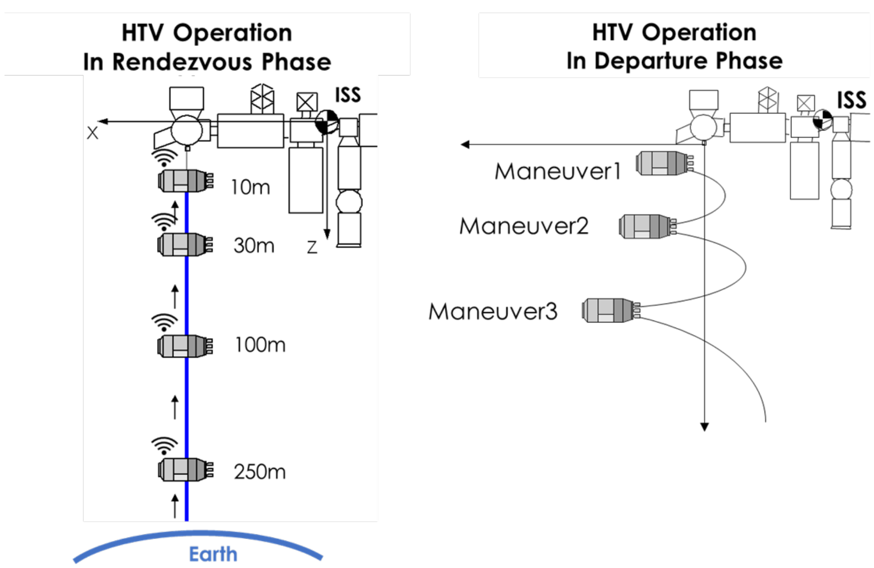

Fig.5. HTV Operation in rendezvous phase and departure phase

2.3 Result of the Demonstration

As a result, the WLD system had successfully established the Wi-Fi link and stably maintained stable streaming of the monitor video. The longest distance between WLD and EWC, before the Wi-Fi link became unavailable, was measured during HTV9's departure phase from the ISS, and it was about 1.5km. Before the Wi-Fi link was disconnected, the video data transferred to the ISS had remained clear until HTV9 arrived about 1km under the ISS. In addition, the video quality was clear enough to monitor the relative motion between HTV and the ISS as shown in Fig.6. The latency of streaming was also within 1sec, so the real-time monitoring by crew members was feasible. These results are described more technically in [4].

Through the whole evaluation of this Wi-Fi link stability and video data, the WLD mission proved that this system could be used for the HTV-X2 docking demonstration. This moving image, the view of the ISS taken from the nadir side was actually the world's first view.

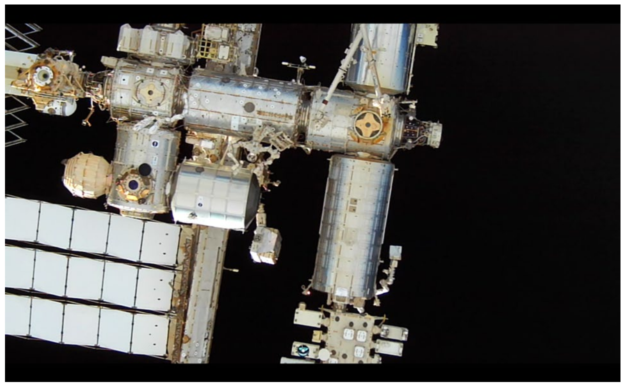

Fig 6. The video image taken by WLD (100m under the ISS)

3. Application to the real docking operation

3.1 Operational Concept of the docking mission

In describing how the achievements shown in Section 2 will be utilized in the real docking operation, this section firstly presents the operational concept of the docking demonstration on HTV-X 2nd mission.

To realize the automatic docking, the ISS is equipped with two International Docking Adaptors (IDA) which are compliant with International Docking System Standard (IDSS). While HTV-X is berthed at Node2 Nadir (N2N) port by SSRMS for the resupply mission, the docking port located at Node2 Zenith (N2Z) side, IDA2, is used for the docking demonstration. In addition, there are various reflectors and targets around the IDA for relative navigation between the ISS and docking vehicles. Centreline Docking Target (CDT) which is located at the centre of the IDA is used as a target of docking monitor system (see Fig.7).

The mission of docking demonstration will start after HTV-X completes all the resupply mission and departs from the ISS, and then re-rendezvous to the ISS. As shown in Fig.8, HTV-X will firstly perform a fly-around at a range of 300 ~ 400m around the ISS while maintaining the attitude pointing to the ISS and will be inserted into the ISS zenith side which is called "R-bar Point Upward (RPU)" at about 300m. There are two methods of trajectory control during the fly-around: in "Impulsive Fly-around," HTV-X performs impulsive maneuvers using the Relative GPS (RGPS) navigation, and in "Circular Fly-around," HTV-X performs a continuous thruster controls using the relative navigation sensor (LiDAR). After departing from RPU, HTV-X starts the approach to the docking port through a few Way Points (WP) in the coordinate system of the docking system ring (Fig. 9). Close to the docking port, HTV-X will transfer to the free drift mode and the soft capture sequence will start between Active Soft Capture Ring (AR) on HTV-X side and Passive Soft Capture Ring (PR) on the ISS side. After that, all docking sequence is completed when each docking planes are fully mated with the hard capture systems.

For the operation of docking monitor system, the video transfer via Wi-Fi communication will start during the phase of impulsive fly-around and continue until the end of the docking. In addition, Wi-Fi communication will also be used during the docked phase to transfer a very large data to the ISS in a short time with SSH File Transfer Protocol (SFTP), because the various telemetry data of active docking mechanism are acquired and stored in the memory throughout the docking sequence for technical evaluation on the ground.

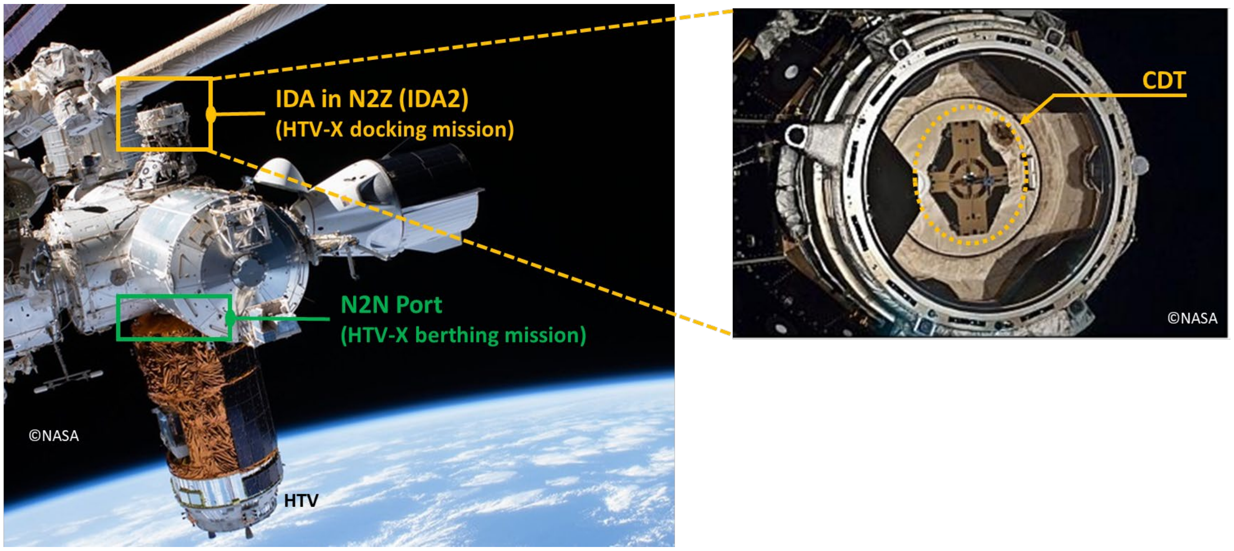

Fig.7. ISS ports for HTV-X berthing and docking

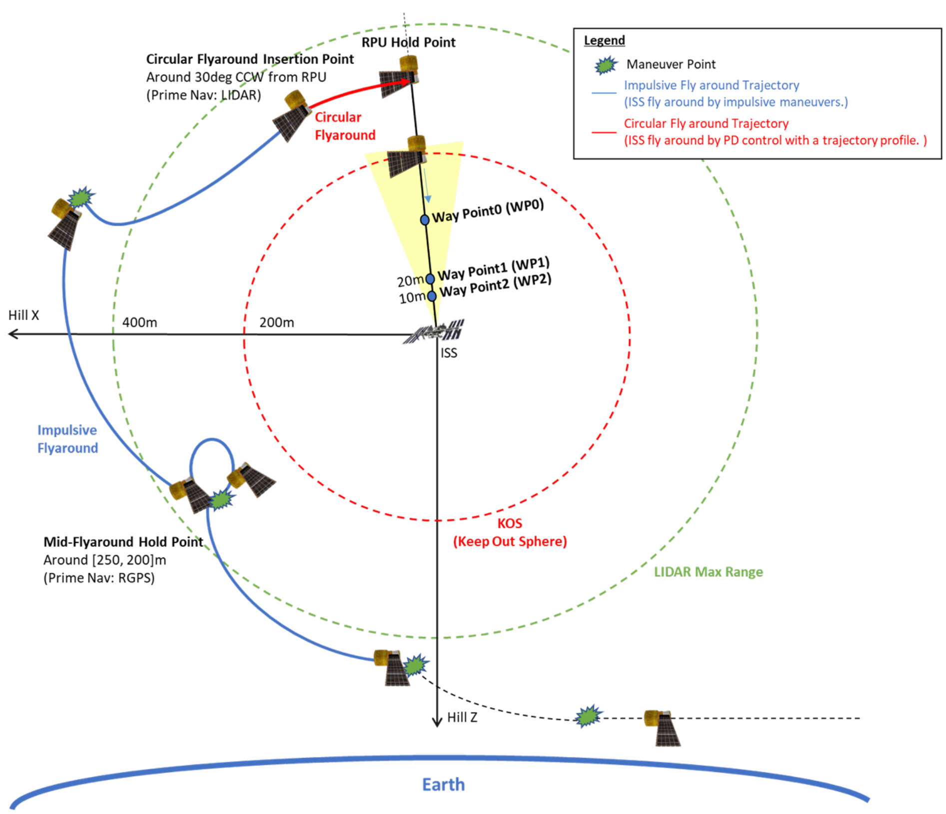

Fig.8. Concept of the fly-around trajectory in the docking demonstration

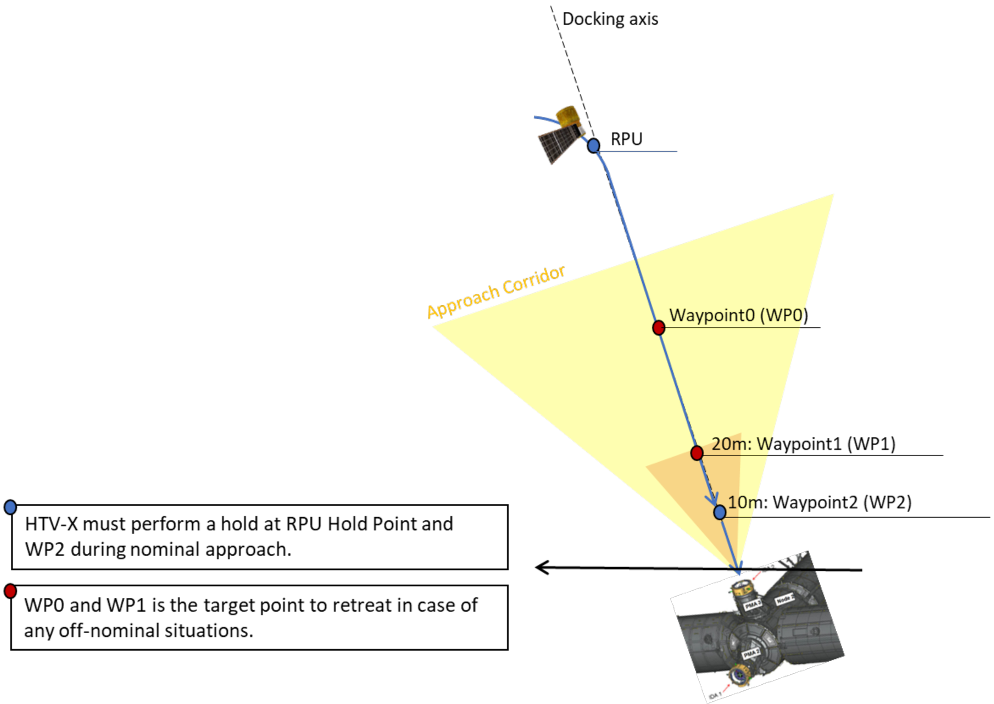

Fig.9. Concept of the final approach and way points

3.2 Technical differences from the WLD mission

As mentioned in Section 1.2, crew monitoring during the docking approach is required from 20m in terms of a situational awareness. For this purpose, the method of video transfer via Wi-Fi communication for the docking demonstration on HTV-X 2nd mission will be the same as that demonstrated in the WLD mission on HTV9. However, since the docking monitor system will be an essential element for the automated docking technologies and will have different requirements than the WLD mission, the following three technical differences should be mentioned.

(1) System configuration

As shown in Fig.10, the components for the docking demonstration will be mounted next to the HTV-X's unpressurized cargo on Unpressurized Cargo Stage Structure (UPCSS). The active docking system, which is docked to IDA2, will be installed on the top of tunnel shape structure, called "DOCAN (DOCking mechanism Adaptive Node)," and the main components of the docking monitor system, Wi-Fi antennas and camera units, are located beside DOCAN and inside DOCAN, respectively. Such a system configuration is very different from that of the WLD mission, so a multi-path effect for Wi-Fi communication and the camera's field of view, which should maintain the line of sight to the CDT throughout the docking approach should be evaluated carefully. In addition, another difference of a system configuration is that the docking monitor system is designed with redundancy because the final docking approach operation will be delayed with it failed.

(2) Imaging conditions for crew monitoring

In the WLD mission on HTV9, video transferred to SSC was not actually monitored by crew members. However, in the docking demonstration on HTV-X 2nd mission, the video images of the docking monitor system will be displayed on SSC with the grid lines' overlay (see Fig.2), so that crew members can monitor the attitude and position errors of HTV-X in real time by using the stripe pattern on CDT and can command abort if needed. In order to provide the images for such an actual crew monitor operation, it is necessary to evaluate the image quality with various patterns of camera setting and LED light operation, taking into account different lighting conditions caused by sunlight on orbit. The LED light, which is attached to the camera unit and operatable from both crew members and the ground, is also the differences from the WLD system. Currently, as shown in Fig.11, a camera imaging test was carried out in a dark room using CDT mock-up as a preliminary evaluation.

(3) Video transfer in fly-around trajectory

As shown in Fig.3, the WAPs used for docking monitor are visible from Nadir and Zenith sides and can be used in both trajectory of Nadir and Zenith approach. Therefore, the successful results of the Wi-Fi link stability in the WLD mission are expected to be valid in the docking demonstration as well. However, since the docking demonstration on HTV-X 2nd mission includes the fly-around trajectory, video transfer via Wi-Fi communication will be performed not only during the final docking approach but also during the fly-around for the purpose of acquiring some images around the ISS. This attempt is expected to be feasible because the fly-around radius will be much shorter than the largest distance of Wi-Fi communication shown in Section 2.3, and it can also be utilized for the port relocation operations in the future.

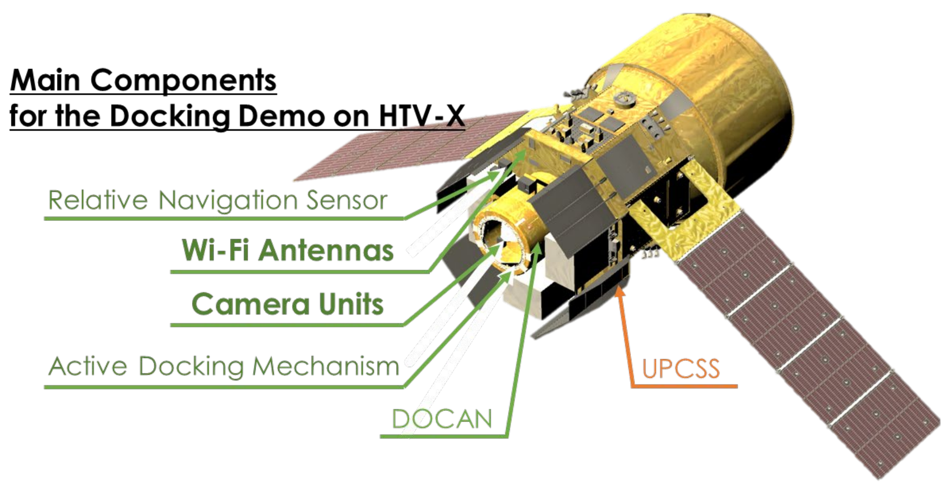

Fig.10 Main components for the docking demonstration on HTV-X

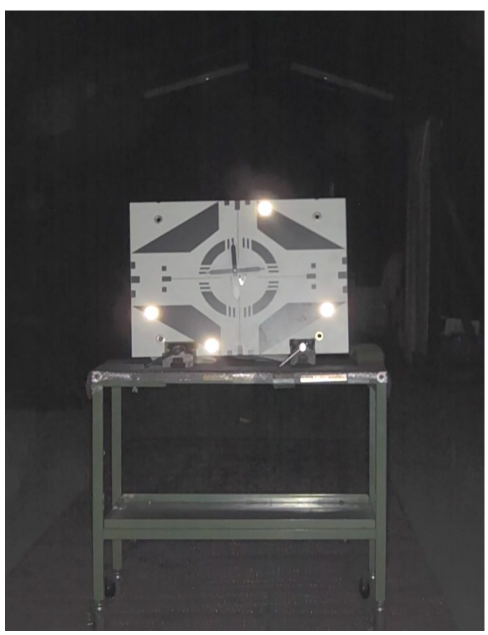

Fig.11 Dark place camera imaging test with LED light using CDT mock-up

4. Conclusions

Among the four major technologies of the automated docking, this paper focused on "crew's docking monitor system," which had developed in advance. The WLD mission on HTV9 in 2020 was the first success to use a Wi-Fi link between moving vehicles in space, and the movie streamed by WLD was the world's first view of the ISS, which was taken from the nadir side. As the next step, the achievement is going to be utilized in the docking monitor of the docking demonstration on HTV-X 2nd mission. The operational concept of the docking demonstration which is conducted after the HTV-X resupply mission and its technical developments from the WLD mission were also mentioned.

JAXA will continue to develop not only the docking monitor system but also the other automated docking technologies to achieve a success of the demonstration.

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