Delivering New Ultrasound System to International Space Station

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Host Institution: **NASA JSC, Houston, TX, USA**

ISU Academic Advisor: **Dr. Nikolai Tolyarenko and Dr. Gilles Clement**

Acknowledgements
I want to thank to all people who helped me at NASA, especially Mr. Keith Tucker and Mr. Louis Lee. I also want to thank my advisors, Dr. Nikolai Tolyarenko and Dr. Gilles Clement who guided me during my study at ISU. As the result of help from many people and my effort, I am offered to stay at NASA JSC after the summer internship. I will work on different projects as a senior engineer, and I am confident that this ISU summer internship helped me to open a door to my future at NASA.

Abstract
Ultrasound has been used for medical purposes and experiments. The previous ultrasound, HDI 5000, was delivered to the ISS in 2001 and had expected its service life in February, 2012. Due to on-orbit ultrasound failure in February 2011, the delivery date of new ultrasound was moved to July 8, 2011, which is 7 months earlier than original delivery date. This report shows how the Ultrasound 2 team including myself worked to make new delivery date. Four-step approach, (1) understanding the project (literature search), (2) learning different documents, (3) performing certification tests and (4) participating crew trainings, were used to succeed my internship at NASA JSC. In addition, the participation in Summer Institution and other contributions are explained.

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1. Introduction

My Tasks at NASA JSC

Primary task (Ultrasound 2 system) and secondary task (Human Powered Centrifuge) were given to work during my internship at NASA JSC from May 23 to August 12, 2011. These projects are a part of Human Research Program (HRP). The Ultrasound 2 (U2) project is a collaboration project among JSC Human Health Countermeasures, JSC ISS Medical Project and Ames. Teamwork, which I have developed at ISU, was necessary to succeed this U2 project. Since the U2 project is the collaboration project, several project managers (JSC, Ames and Wyle as a contractor) exist. My mentor, Mr. Keith Tucker, is a chief engineer at NASA JSC. He is responsible for ensuring qualifications, attending control gates/meeting (Figure 1 and Table 1), and communicating among team members. To meet the delivery deadline in July, everyone in his group focused on the U2 project. Therefore, no other projects were preformed. In accordance with my mentor's suggestion, I focused on my primary task due to tight U2 delivery deadline. In addition to the given tasks, I contributed other projects, Human Test Subject and Actiwatch project. These additional contributions are explained in the section 9.

My tasks at NASA JSC were to understand product development process including reviewing process, testing and operating process. In addition, I was able to learn how each engineer and scientist from NASA JSC and Ames communicate to succeed the U2 project. Since the Ultrasound 2 project (U2) was at the final stage with tight schedule, I was able to participate phase 6 to 8 during 3 months. I remember that I studied the project life cycle at ISU, and I had opportunity to use the knowledge at NASA. According to the communication with other interns at NASA, my tasks were unique because the project was at the final stage, not research stage.

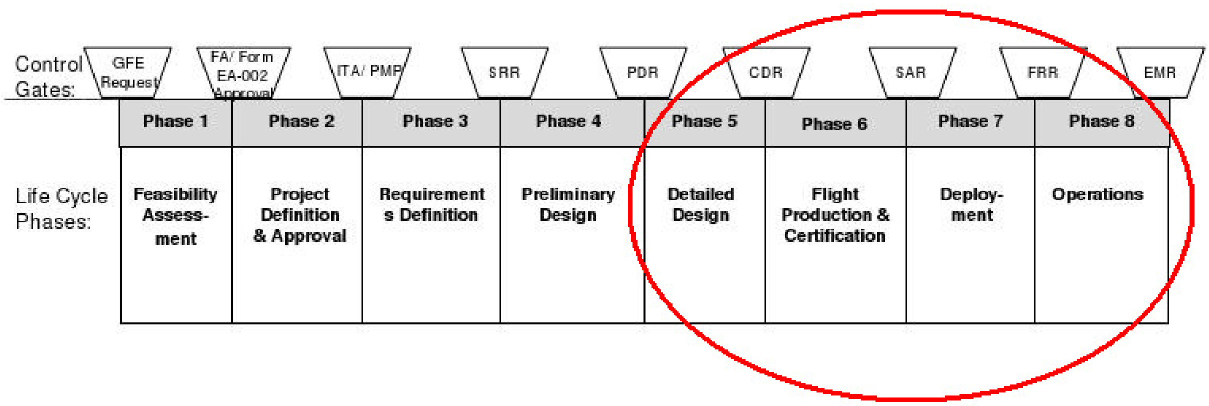

Figure 1 NASA Project Life Cycle (courtesy of NASA, 2006)

Table 1 Control Gates (NASA, 2006)

GFE	Government Furnished Equipment
FA	Feasibility Assessment
ITA/PMP	Internal Task Assessment/Project Management Plan
SRR	System Requirement Review
PDR	Preliminary Design Review
CDR	Critical Design Review
SAR	System Acceptance Review
FRR	Flight Readiness Review
EMR	End of Mission Review

Difference between My Tasks and Research Oriented Tasks

When I started my internship at NASA, the 1st U2 unit was at the end of actual product line. This means that I dealt with all important processes which were necessary at the final stage of the production. The tasks include reviewing drawings, writing documents, assembling parts, communicating among engineers and performing certification tests. Since 4 units were made, many tasks were repeated. The final product was successfully launched on the last space shuttle program on July 8, 2011. After the launch, I contributed on closing documents and operating the U2 system. The detailed processes are explained in the section 3-6.

My internship started from basic understanding of what have been done and searching how I can contribute to the U2 project. Therefore, I studied some documents which I obtained from NASA engineers. The next section explains my short summary of the U2 project and the things that I learned from previous research.

2. Project Summary (literature search)

Ultrasound offers several advantages comparing to other diagnostic imaging tools. It is lightweight, safe, compact and instant imaging. The high frequency sound waves are sent into a body. When the waves encounter organs, some waves bounce back and other waves continue traveling. The probe is able to see reflected sound waves.

Crew members may experience a serious medical condition during long missions. Previous ultrasound weights 168 lbs, which is still considered as lightweight compared with X-ray and computerized tomography (CT) scan. High-Density Interconnect (HDI) 5000 which was delivered to the ISS in 2001 (Figure 2 left circle). In 2002, Dr. Peggy Whitson (NASA astronaut) commented that she was impressed in transferring the video images of her heart, kidney and bladder to the ground (NASA, 2004). She mentioned the potential use of ultrasound on Earth. In 2009, HRP identified a need to upgrade and replace the Human Research Facility (HRF) Ultrasound System. The U2 system includes (1) Commercial Off-The Shelf (COTS) ultrasound unit (General Electric Medical Systems, Vivid-q), (2) custom made external video/power converter (VPC) and (3) software interface on the Human Research Felicity (HRF) laptop. Vivid-q (Figure 2 right circle) and VPC weights only 30lbs, and it is 5.6 times lighter than the previous ultrasound system. Figure 3 shows how the U2 is used on board the ISS. Less space is needed for new ultrasound system. The original launch date was February 2012, but the schedule was moved to earlier date (July 8, 2011) due to current on-orbit ultrasound failure in February, 2011. The Ultrasound 2 team had to work hard to make the final product to meet the last space shuttle launch date. I am very happy to be one of team members.

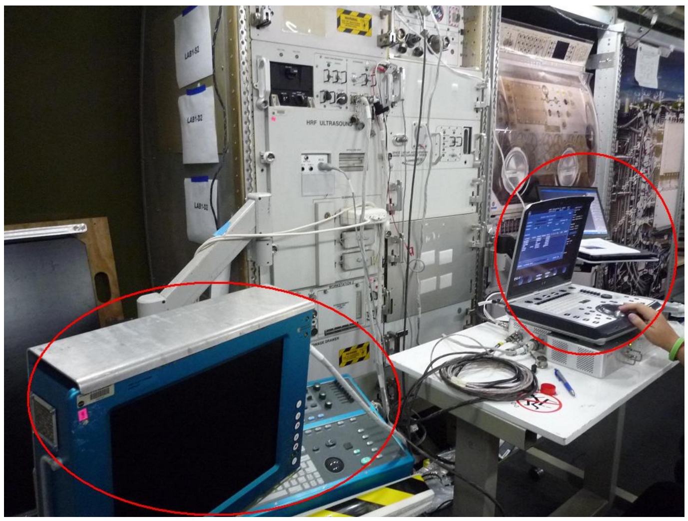

Figure 2 HDI 5000 (left circle) and Vivid-q (right circle)
Vivid-q is place on the VPC.

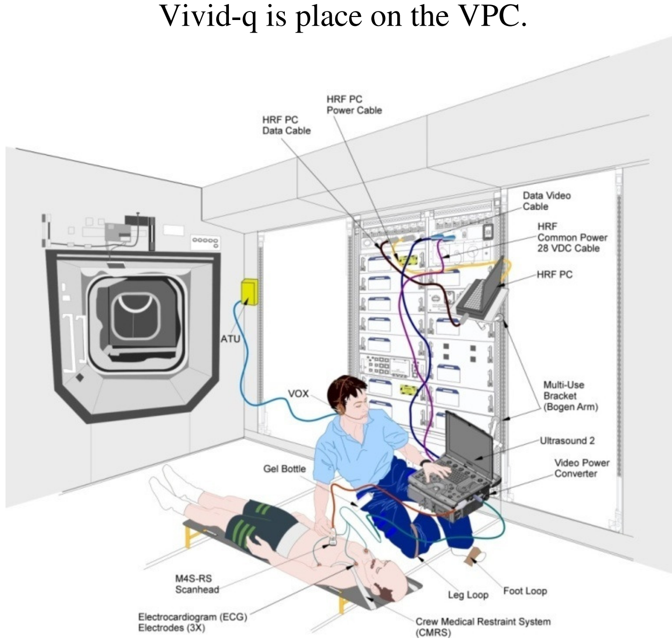

Figure 3 Ultrasound 2 System on Board International Space Station (courtesy of NASA, 2011)

Ultrasound imaging technology has advanced since 2001. Advancements include (1) the ability to capture and store data in electronic format (not video tape), (2) improved image display, (3) image display processing speed, (4) imaging capability, (5) portability and (6) reduced power usage (NASA, 2011). Initially, JSC included 6 COTS devices. Some examples of medical operation and research requirements by NASA are to be able to measure heart mass, heart volume, heart function, bladder volume, bladder wall thickness, vascular anatomy and musculoskeletal. Among 6 COTS, Vivid-q is the best fit for the use on board the ISS. The key factor for choosing Vivid-q was the size and weight. Vivid-q weights only 15 lbs and be able to fit in one of shelves. The Approximately 7000 Vivid units have been sold since 2005.

Before any modifications were made at NASA, functional tests were performed. One of major issues was green-colored corrosion product at a pin-socket interface (Figure 4). The corrosion was sampled and analyzed to receive any recommendations regarding to possible cleaning and treatment methods of the interface. According to Lockheed Martin, the observed corrosion is most likely copper carbonate (CuCo3), but also includes oxides and hydroxides of copper (Lockheed Martin Space Systems, 2011) After the analysis, the pin-socket interface was cleaned and coated with corrosion preventive lubricant.

According to my literature search and interview to project managers, I realized that NASA uses many COT devices (one is explained in the section 9). However, extensive tests are necessary to minimize failure in space. If the corrosion in Figure 4 is found on the ISS, the U2 system will need to be brought back to surface to fix the problem. This causes huge problems with cost and crew time.

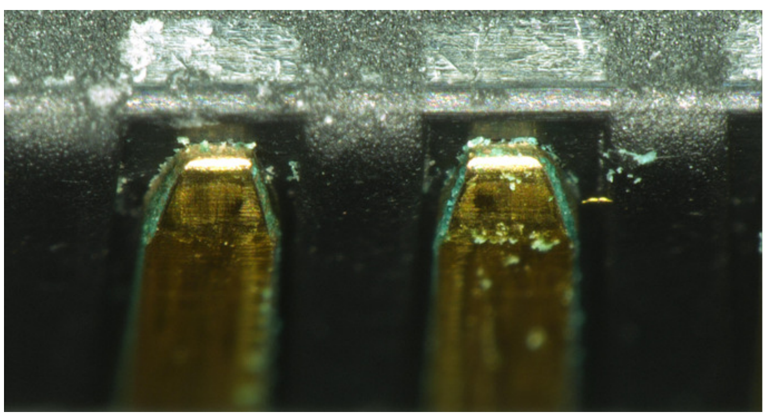

Figure 4 Corrosion at a pin-socket interface (courtesy of Lockheed Martin Space Systems, 2011)

After I completed basic research on the U2 project, I was ready to contribute the project. In order to meet an approaching deadline, phase 5 to 8 are condensed, and some process were performed simultaneously. This simultaneous process made the project more complicated because parts were needed to assemble before final drawings were released. My first task was to understand different terms used at JSC such as Task Performance Sheet (TPS), Quality Engineer (QE) and Quality Assurance (QA). Knowing acronyms is important because people are expected to know these in a meeting.

3. Task Performance Sheet, Quality Engineer and Quality Assurance

To ensure quality and safety of each task, NASA uses the system to check one task for multiple times. First, TPS is written by engineers/scientists. TPS is the document which explains each task step by step. It has to be written the way that anyone can follow and perform a task. Then, TPS is sent to QE to be reviewed. Once QE signs TPS, QA needs to review and inspect a task as necessary. I helped delivering TPS to QE and QA. This is a simple process, but it is important because any tasks cannot be performed without signed TPS. In addition to just delivering TPSs, I read through and tried to understand the contents because I was sure that I would be asked to write TPSs during my internship.

My next task was to review drawings. Our team including myself found many changes in drawings. Figure 5 shows redlines of the Video Power Converter (VPC) drawings. As the name indicates, everything in red indicates the items which need to be changed. I learned that good drawings make tasks easier afterward and speed up process. Conversely, not well-organized drawings confuse technicians and require 100 times more efforts for technicians to understand. For example, one part was manufactured in accordance with a drawing. However, due to the unclear drawing and numbering system, the wires to the USB port were connected backward and made a performance test to fail. Fixing the problem is harder because the completed unit must be disassembled and assembled in the correct way. Moreover, before any corrections were made, new TPS must be written. If the part was assembled with a good drawing, the wire connections took less than 10 munities. However, due to the mistake, it took a few days to get back to original schedule. As an engineer, I reconsidered the importance of accurate and clear drawings. Since the most of drawing were performed by engineers who involved in multiple projects in the different building, good communication techniques must be established to avoid mistakes.

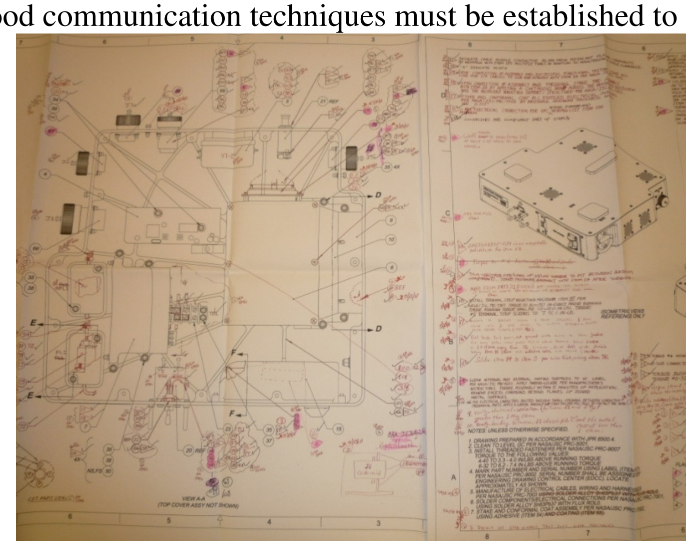

Figure 5 Example of redlines

My third task was to understand testing process. I performed Safety Evaluations, Quality Tests and Acceptance Tests and Science Verification Tests.

4. Safety Evaluations, Quality Tests and Acceptance Tests

As a structural engineer, a tensile test is not new to me. Tensile test is a material test in which a sample is subject to uniaxial tension until failure. I manufactured the sample wires and performed the tests. Good mechanical connections between wire and terminal lug (connector) were verified by tensile tests. Six samples were made and tested (Figure 6). I recorded the results in TPS.

Figure 6 Tensile tests

In addition to the tensile tests, many tests were required to certify U2. The tests (acoustic, fire, touch temperature, radiation, structural, shatterable materials sharp edges, corners, protrusions and/or pinch point, offgassing, etc.) were previously performed. I performed thermal cycle tests and vibration tests (Figure 7). Both tests are mainly to simulate the damages during launching. Once the device was delivered to the ISS, it is maintained the same condition as human living environment. Electromagnetic compatibility was also important to make sure the device does not affect to and by the ISS for sate operation.

Figure 7 Thermal tests (left) and Vibration tests (right)

The performance test was performed on June 2, 2011. The Figure shows that I helped evaluating the U2 unit. During the test, a problem was found and cause images not to transfer from main U2 unit to VPC. Transferring images to VPC are necessary to downlink the data from the ISS to NASA ground for diagnoses. After investigation, the wire connections which are explained in the section 3 were found.


Figure 5 Science Verification Tests in the Human Research Facility (HRF) lab

5. Crew Trainings

As understanding more about the U2 project, one engineer at Lockheed Martin invited me to attend Crew Manual Review meetings. Five short manuals (initial configuration, nominal operation, specific steps, data export and shut down procedure) were reviewed in the Space

Vehicle Mockup Facility (SVMF). I assisted an engineer from Lockheed Martin for reviewing process. The manuals are very simple, but these have to be clear and easy to follow to minimize crew time. During the meetings, a person who does not know well about the ultrasound operation used the manuals and made some comments. All buttons on Vivid-q are labeled with colors (pink, purple, green and blue) and numbered. Therefore, even if the crews are not familiar with the operation, flight surgeons can assist from ground by just saying color and number.

In addition to the manual reviews, I attended the crew trainings. At this time, the actual operations (scanning, taking images and transferring data) were performed. The first step was to show basic steps to a crew. A flight surgeon stayed next to an astronaut and advised what he needed to do. The operations were very simple because of manuals and color labels. The second step was for the flight surgeon to leave the mockup and advised the astronaut from approximately 20 meters away from the astronaut. The flight surgeon could see and communicate the astronaut by a video camera, Vivid-q screenshot and radio. This separation simulated the ISS and ground operations. Astronauts take images and downlink from the ISS, and flight surgeons see the down-linked images for diagnoses. I was amazed to see that the U2 system was actually working and was ready to launch on July 8, 2011.

6. Launch on July 8, 2011 and Afterward

The first U2 flight unit was sent to KSC on June 22. However, our team had many tasks to complete. Two more units are in process of building and testing. During 2 weeks, I checked drawings and TPSs so that these could closed with correct information. Basically, I checked that TPSs were written in accordance with drawings (part number, quantity, serial number, lot number and shelf life). When I found mistakes (the most of cases), I wrote modifications (MODs) and submit to QE and QA. Once MODs are accepted, TPSs can be closed after tasks are performed. All TPSs must be closed before finishing the U2 project. This task is important. As I mentioned before, good drawings make the entire process easier and faster. Therefore, I did my best to find errors and correct them.

Up to this point, I have only reviewed TPSs and MODs. Finally, I had chances to write TPSs and MODs. I wrote TPSs and reviewed very carefully by using my knowledge and experiences that I had gained at NASA. NASA Ames and JSC use different TPS. This means that the Ames TPS must be proved by JSC QE and QA. In addition to shortened project duration, this collaboration made the project more complicated.

On July 20, 2011, the Seabrook Association hosted a special event to honor the achievements of the tens of thousands of NASA civil servants and contractors who have contributed to the mission successes. I attended the tribe/ceremony and met many NASA people who contributed the mission. I am very proud to be a part of the tribe because I contributed to the last shuttle mission. STS-135 crew landed on July 21. On July 22, the Shuttle Return Celebration was held at Ellington field. Space Shuttle Atlantis was the final flight of the Space Shuttle Program. A 13-day mission to the International Space Station was completed successfully.

7. Annual Space Life Sciences Summer Institute

The class consists of undergraduate, graduate and post-doc students. Table 2 shows the list of lectures which were held as a part of the Summer Institute. I feel that some information is too basic for the students who have taken graduate level courses at ISU. The most useful lecture was a space suit demonstration by Dr. Drew Billingsley. The space suit is a complex system which limits dangerous radiation and maintains suitable pressure, temperature, breathable oxygen. I was able to see and touch a space suit. It has to protect human but has to have mobility. It is no surprise that a set of groves costs $10,000 because of its complexity, development and maintenance cost. New space suit, which is more fiberglass components and less weight, is underdevelopment.

Table 2 Annual Space Life Sciences Summer Institute Lecture Contents

Biomedical aspects of early interplanetary mission	Space medicine	Behavioral health and performance
Space food and nutrition	Space suit demonstration	Immune/microbiology
Commercial space flight	Bone and muscle	Radiation panel
Astronaut lecturer (3 times)	Exercise operation	JSC tour
Astronaut selection and training	Open innovation	

I enjoyed the presentations in the Summer Institute, but the main purpose for me to attend the presentations at Summer Institute was to meet people. When I had a summer internship at NASA Ames in 2007, I focused on my tasks too much and spent less time on meeting people. I believe that I missed a big part of NASA even thought I received group achievement awards due to my effort. At this time, the Summer Institute at JSC helped me to meet people. Therefore, I used this opportunity to talk to speakers after presentations and set up a meeting with them.

I had the first lecture on June 7, 2011. I met Dr. John Charles (who was a presenter of biomedical aspects of early interplanetary missions) and had a lunch meeting. Dr. Charles was a research engineer and now manager at NASA. During the lunch meeting, he and I discussed about the future of Human Powered Centrifuge. The meeting with Dr. Duane Ross (who was a presenter of astronaut selection & training) was one of the most useful meetings that I had at NASA. He introduced me a former astronaut, Mr. Kenneth Cockrell. He is working as a pilot at Ellington Field, NASA. Mr. Cockrell introduced me Mr. Mike Edmonds who is a chief engineer at Computer Science Cooperation. Mr. Cockrell and Mr. Edmonds showed me NASA aircraft such as T-38 (astronauts training), Gulfstream II (shuttle training), C-9 (reduced-gravity training), WB-57 (scientific work), modified Boeing 747-100 (shuttle carrier aircraft), Gulfstream III (administrative aircraft) and Super Guppy (carry oversized spacecraft components). Since I am a pilot, I am excited to see these aircraft.

On June 22, I attended the JSC tour. I went to the Neutral Bouncy Lab (NBL), ISS mockup building and Mission Control Center (MCC). The pool in the NBL is 40 feet deep and can hold 6.2 million gallons of water. During a training, several divers are underwater for 6 hours with

2-hour shift schedule. They are well trained and must maintain their health in good condition. As a holder of SCUBA diving license, I wanted to go and dive into the pool. Unfortunately, the pool was under maintenance, and I was not able to see astronauts' activities. Later, I went back to NBL with a Wyle scientist and was able to see all astronauts' activities in the pool. The space shuttle mockup in the ISS mockup building will be removed due to the end of the shuttle program. I feel that I am lucky to be a part of JSC to see the end of the program.

8. Human Powered Centrifuge (HPC)

Due to the launch date (July 8) for the U2 project, limited time was provided to work on the HPC project. However, I reviewed the past discussions between investigators and NASA. On July18, my mentor and I had a telecom meeting with engineers at Boeing. They will work on an air circulation system. According to my mentor, my work on this project is very limited now because we are waiting to receive a design from ESA and Boeing.

9. Other contributions

In addition to my primary tasks, I decided to contribute to additional 2 projects, human subject tests and Actiwatch project by JAXA.

Human Subject Tests

I volunteer to be one of test subjects for ongoing experiments. The reasons for volunteering the experiments are to meet people (PIs), to understand the process of experiments at NASA and to understand how test subjects feel during experiments. This experience is beneficial if I have a chance to be a PI or project manager in the future. I completed my physical exams, and July 11 was the first day of the experiment. The PI of the experiment is Dr. Scott Wood. This experiment is designed to examine how the brain responds to different combinations of tilt and translation motion during a simulated landing. During the tests, I was asked to open my eyes to tilt and then close my eyes to tilt. I learned the importance of having visual cue to make good tilt angle. I am expecting 2 more tests with Dr. Wood in August.

Actiwatch (JAXA)

NASA has recognized the importance of adequate sleep duration and circulation rhythm alignment. Actiwatch (Figure 6) can detect human movement by accelerometers and light intensity by a sensor. It examines the effects of space flight and ambient light exposure on the sleep-wake cycles of crew members during long duration stay on board the ISS. Dijk et al. (2001) quantified abnormal light-dark cycle could be one of factors for circulation misalignment. Sleep loss, decrements in neurobehavioral performance, and postflight changes in REM sleep were reported by crew members (Dijk et al. 2001). Earlier generation Actiwatches have certified and flown by NASA. Currently, NASA is working on new generation Actiwatch, and JAXA is interested in launching 3 watches in January, 2012. I attended a JAXA and NASA meeting and explained (translated) what modifications are necessary in order to use on the ISS. This watch is commercially available (COT), but it is modified for the use on the ISS. I explained to JAXA what kinds of modifications have done at NASA.

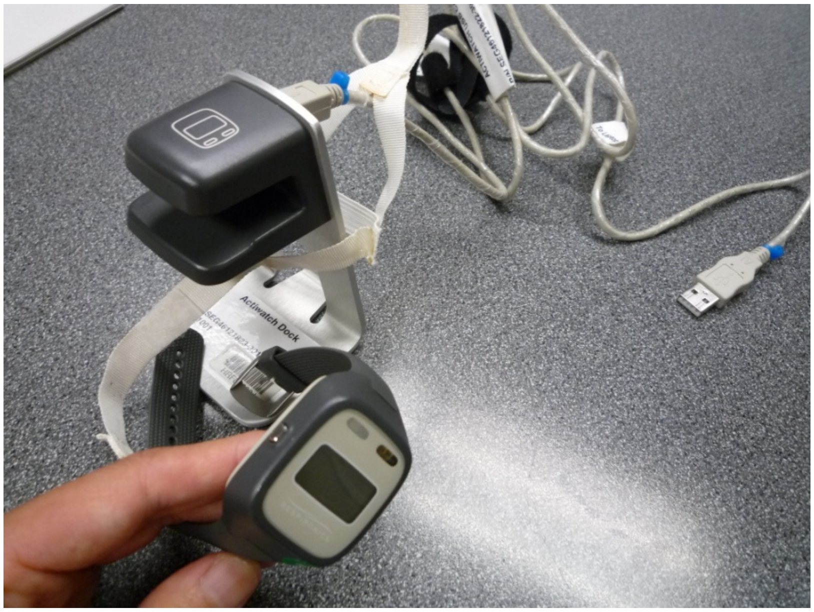

Figure 6 Actiwatch, docking and cable

After the first meeting with JAXA, the project manager of the Actiwatch at NASA offered me to explain about the project details. According to him, the first generation had been used about 10 years, and NASA purchased 70 new generation Actiwatches (including 12 in orbit now). A watch shows light intensity and activity numbers. As the personal assignment at ISU, I have worked on the accelerometers on board the ISS, and I am very impressed the work which was done at NASA for 10 years.

10. Conclusion

I successfully completed my summer internship at NASA Ames. During 3 months, I was able to work on the U2 project, which was launched on July 8, 2011. The study at ISU, especially product life cycles, helped me to understand the NASA process easier. I am very happy that our team became one to meet the tight deadline. Since this U2 project was a collaboration project among different groups, I realized the importance of having a good leader, my mentor. Even though our team experienced technical problems, such as the wrong wire connections, we were able to help each other to achieve one big goal, delivering new ultrasound to International Space Station. I strongly believe that the new ultrasound will help astronauts for diagnosing and performing new experiments. In addition, I contributed additional projects, Human Test Subject and Actiwatch project by JAXA. I am confident that this ISU summer internship helped me to open a door to my future at NASA.

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