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Real-World Oriented Mobile Constellation Learning Environment Using Gaze Pointing

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SUMMARY We developed a real-world oriented mobile constellation learning environment. Learners point at a target constellation by gazing through a cylinder with a gyro-sensor under the real starry sky. The system can display information related to the constellation. The system has original exercise functions which are not supported by existing systems or products by other research group or companies. Through experimentation, we evaluated the learning environment to assess its learning effects.

key words: *mobile function, constellation learning, gyro sensor, gaze pointing*

1. Introduction

Learning of astronomy is important and interesting for children and students, because it is attractive science and it relates to future industry. However, celestial bodies are too far to visit it or to touch it. Therefore, astronomy is a domain where computer technology is necessary and appropriate to assist learners understanding. Actually, various kinds of learning support by PC have been tried. They can be classified into two groups. One group is learning support environment that enhance observation in the real world, the other group is learning environment only in the virtual world. Virtual world here includes not only 3D world in a PC but also 2D contents in PCs.

Some studies using telescope are examples of learning support environment that enhance observation in the real world. Telescope in education (TIE) program is an education outreach project sponsored by the Mount Wilson Institute and the NASA/California Institute of Technology (Caltech) Jet Propulsion Laboratory (JPL) since 1991 [1]. However, TIE used professional reflecting telescope at the Mount Wilson Observatory. Until 1998, the telescope was not remotely controlled.

Robotic telescope [2] was first full-automatic telescope on the internet. However, the robotic telescope put emphasis on full automatic control. Learners were only able to submit queries to take photos of celestial bodies. After that, the robotic telescope takes the photo automatically while the celestial bodies can be seen in the sky with good weather condition.

Remote telescope [3] was first internet telescope in the world that can show live picture of stars, planets and the moon. Learners were able to control remote telescope from web user interface. There was a memorial attempt that learners in Germany controlled remote telescope located in Japan, and they watched live picture of the moon by using time difference between Japan and Germany [4]. Subsequently the user interface was changed into 3D planetarium on the web by using Java 3D. Learners select a star on the planetarium, and then the remote controlled telescope catches the target star [5]. In 2006, remote cooperative observation system for telescopes with P2P (Peer-to-Peer) agent network was developed [6]. Recently, Radio telescope also began to be used for astronomical education in Japan [7].

On the other hand, several simulators with computer graphics that have been developed for astronomical education are examples of learning environment only in the virtual world. Simulators of solar system, galaxies and gravitational lens of black hole were made by 3D computer graphics, and then they have been used in a theater in Science Museum in Tokyo [8]. This has been known as science live show "Universe" supported by Chimons [9].

Astronomical VR Contents [10] can simulate the universe from the earth to the great wall galaxies like traveling by spaceship. Recently, tangible interface is made for solar system simulator to help children understand solar system more friendly [11].

Stella Navigator is an astronomical simulator produced by Astroarts co. ltd [12]. It simulates night sky in any time and any place. It can simulate astronomical phenomena only from the earth viewpoint.

As research on a method of expression of space phenomena with CG animation, the collision of the comet Shoemaker-Levy 9 with Jupiter in July 1994 is simulated [13].

"Planetary simulator" [14] can also simulate planets' revolution around the sun, fixing not only target planet but also the planet of viewpoint. Therefore it can help generalized understanding of wax and wane of inner planets. The planetary simulator also supports viewpoint guiding function for self-learning.

Mitaka is a simulator developed in 4D2U project by National Astronomical Observatory of Japan [15]. It simulates seamlessly from the earth to the end of the universe at 13.7 billion light years away like traveling in the universe.

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Mitaka is very excellent software to understand the universe from the solar system to the end of the universe. It shows distance from the target celestial body, so that the learner can know the size of every structure in the universe.

Although various learning environments have been developed, there is few learning environment that connects virtual world and real world. It is important to observe real objects and real phenomena to learn science, because learners can understand not only the target objects or phenomena, but also understand the objects or phenomena in the real world with surrounding conditions and sceneries as an experience. Sometimes relation between the objects or phenomena and surrounding conditions are scientifically important. Therefore, we define real-world oriented learning environment as an environment in which learners can utilize real objects or real phenomena as learning materials. Real-world oriented learning environment can increase keys to recall learned objects from memories, since learners memorize not only learning objects itself but also attributes of surrounding environment or conditions as an experience. It facilitates memory recall. Simultaneously, it is necessary to utilize virtual contents effectively by using PC.

Consequently, our laboratory has been conducted studies for star search support and constellation learning support. We have developed a "constellation learning support environment incorporating finger pointing actions" [16]–[18]. By pointing at a target constellation in the real world, it presents information about the constellation on the system using text and voice. It facilitates the instruction of star names without identifying stars and reduces stress related to star observation. It also answers queries related to respective stars by detecting a pointed star with a magnetic position sensor worn on a fingertip and presents the answers with text and voice. Learners answer a question by pointing at a star in the real night sky. These features lead learners to match a learned star and a real star more quickly when looking up at the real night sky.

Nonetheless, the system presented in previous reports requires AC power and imposes location constraints that hinder their use in the real night sky. Their exercise functions also appear to be insufficient.

Nakajima and others developed a star observation support system using wearable augmented reality technology [19]. This method performs head tracking with a gyrosensor and superimposes and displays a projected image of a starry sky along with information about constellations on the HMD with video see-through type augmented reality. Although this system supports constellation observation, it is confined to added information: it has no learning support function such as an exercise function.

"DS hoshizora-navi" is a star navigation system functioning on Nintendo DS produced recently by Nintendo [20]. When holding a DS with an additional orientation sensor module up to the night sky, it displays constellations in that direction on the display screen. This method requires learners to identify stars by comparing the real night sky with a screen display on the DS. It is particularly difficult under circumstances in which only a single star is visible among the clouds. Moreover, the DS hoshizora-navi is not equipped with learning support functions such as an exercise function.

Google Sky Map, which is operable on a mobile terminal equipped with Android, can do the same things that the DS hoshizora-navi does, but it also is not equipped with learning support functions such as the exercise function.

This paper therefore presents a proposal of a real-world oriented mobile constellation learning support environment. It can use the actual night sky as learning content in the open air and is available for mobile use by unique gaze pointing interface with exercise functions. We also describe results of evaluation experiments.

2. Learning Goal and Specifications of the Environment

We set learning goals of constellation learning as follows.

(1) To learn names of constellations and names of main stars in the constellations.
(2) To learn layout and positions of stars in the constellations.
(3) To learn constellation lines and shapes of constellations.
(4) To learn relative positions to surrounding constellations.
(5) To learn relations between azimuth, elevation angle, time and the season in which the constellation can be seen.
(6) To learn constellation mythology.

To achieve the learning goals, we set specification of the learning environment as follows.

(a) To support virtual planetarium that can show starry sky when a learner put in date, time and location information.
(b) To use not only virtual learning contents in a PC, but also starry night sky in the real world as learning contents.
(c) To be able to know names of constellations and names of main stars in the constellations easily associated with real starry sky.
(d) To be able to draw constellation lines by learners associated with real starry sky.
(e) To be able to learn constellation myth associated with real starry sky.
(f) To be able to learn star's roles in a constellation associating with constellation image.

In the above specifications, the specification (a) helps to achieve the learning goal (1), (2), (3), (4) and (6). The specification (b) helps to achieve the learning goal (1), (2), (3), (4) and (5). Especially, goal (5) will be strongly achieved by this, since learner can memorize azimuth with real scenery, elevation angle with fatigue of his/her neck, and season with air temperature. This is prominent advantage of real-world oriented learning environment. The specification (c) helps to achieve the learning goal (1). The specification (d) helps to achieve the learning goal (2) and (3). The specification (e) helps to achieve the learning goal (4) and (6). Finally, the specification (f) helps to achieve the learning goal (1) and (2).

3. Preceding System

This section briefly explains the preceding system that was developed by our group [18].

3.1 Virtual Planetarium

The preceding system had already supported the virtual planetarium. The virtual planetarium is a system that can show the starry sky on a display monitor. It can simulate the starry sky on which a learner uses the system. The virtual planetarium displays small circle in the center of the display monitor. When the learner drags the virtual planetarium by mouse, and a star come into the circle, the system tells the learner the name of the star and the constellation by text on the monitor and by voice from a speaker.

The virtual planetarium also can guide a learner to a target star or a target constellation, when the learner selects the target name from a menu. Specifically, the system shows a line from the center of the monitor to the target star on the virtual planetarium. Therefore, the learner can know where the target is by tracing the line.

The proposed system in this paper has inherited the virtual planetarium. Therefore, it can satisfy the specification (a) and (c).

3.2 Finger Pointing Interface

The preceding system supported a unique interface by finger pointing. The system used a magnetic position sensor system. The magnetic position sensor system was Isotrak II produced by Polhemus. It has two receivers. Each receiver can measure its position and orientation values with 6 DOF. It can transfer the values to PC in real time. By using Isotrak II, the preceding system realized finger pointing interface. A learner puts a receiver under his/her eye, and holds the other receiver by thumb and index finger holding out his/her arm. When the learner points at a target star, the system calculates eye vector between the receivers. Then, the system shows the starry sky of the virtual planetarium in accordance with the direction of the eye vector. In addition, the system tells the name of star and name of the constellation in the direction of the eye vector by voice from speaker and by text on the display monitor.

Disadvantage of IsotrakII is that it works only by AC power. Therefore, it cannot be used where AC power is not available. In addition, the main unit of IsotrakII is too large and heavy to carry all the time. These facts prevent it from mobile usage.

Moreover, IsotrakII generates magnetic field by a transmitter to measure position and orientation of receivers. Therefore, surrounding metals and magnets prevents from accurate measurement.

In addition, when using the system to determine the reference direction, calibration must be done. It takes quite long time to prepare for using the system.

Moreover, even if the calibration is done, it is difficult to get high accuracy which is less than a few degrees. It is because the vector calculated from two receivers cannot be completely parallel to the actual eye vector.

3.3 Exercise Function

The preceding system supported an exercise function which we call as constellation star's role exercise function. This function is developed based on specification (b) and (f).

A constellation consists of several stars. Some stars in a constellation form an image of the constellation, such as human, animal, bird, tool and so on. It is necessary for a learner to know which star forms which part of the constellation image. Constellation star's role exercise function trains the learner to get such knowledge.

For instance, constellation Cygnus consists of some bright stars forming a shape of swan. First, the learning environment requires a learner to point at the star located at the bill of Cygnus. Then, if the learner points at the star correctly by the finger pointing interface, the system tells him/her to point at the next star located at the body of Cygnus. If the learner points at wrong star, then the system repeats the same request.

Thus, the system always requires the learner to point at a star adaptive to a part of constellation image such as bill, head, tail, etc. By the constellation star's role exercise, the learner can associate the star with the part of the constellation image.

On the other hand, there was not any exercise function developed based on specification (d) and (e).

4. Proposed System

This section explains the proposed system that is developed based on a preceding system. The explanation also addresses constellation exercise functions.

4.1 Use of a Gyro-Sensor

The method presented herein uses an orientation gyro-sensor to identify the gaze direction. The orientation gyro-sensor is 3DM-GX1 produced by MicroStrain. The size of 3DM-GX1 is $64 \times 90 \times 25$ mm and 75 g. It is operated on 9 [V] AC power, but it also works with 5.2 v, 52 mA, so that it can be operated with battery. These specifications enable mobile usage.

3DM-GX1 utilizes the triaxial gyros to track dynamic orientation and the triaxial DC accelerometers along with the triaxial magnetometers to track static orientation. The magnetometers do not need calibration for getting orientation in the real world. The embedded microprocessor contains a unique programmable filter algorithm, which blends these static and dynamic responses in real-time. This provides a fast response in the face of vibration and quick movements, while eliminating drift. The stabilized output is provided in an easy to use digital format. Analog output voltages proportional to the Euler angles can be ordered as an option.

The gyro-sensor can obtain three axial rotation angles, Roll, Pitch, and Yaw. Of those, Roll is not used for this study because it represents values of change in twisting actions of the gyro-sensor. The direction in which a learner points is obtainable from the gyro-sensor output value.

4.2 Gaze Pointing

We use the device depicted in Fig. 1 as the gaze pointing interface for this study. It is a device with the gyro-sensor attached to a cylinder by a magic band, which is used by the same action as peering at the night sky through a telescope. However, the cylinder does not have any lens inside. The weight of the cylinder is 370 g. The weight of the magic band is 22 g. The weight of the sensor is 75 g as described before. Therefore, total weight of the gaze pointing interface device is 467 g. It is light enough to hold in one hand.

The length of the cylinder is 532 mm. The inside diameter is 38 mm. The scope of the cylinder when peering through it is approximately 4 degrees. Apparent diameter of the moon is 0.5 degrees for reference. Therefore, the scope of the cylinder is small enough and smaller than any constellation. However, small scope simplifies pointing at a star by using it as follows: When a learner uses it, he/she hold it and peer by one eye, however, he/she should open also the other eye. Since there is no lens in the cylinder, the learner can recognize stars or constellations by opening both eyes with the same infinite focal distance. It is easy to point at a target star by simultaneously using both one eye through the cylinder and the other eye without the cylinder.

An advantage is that it has higher pointing accuracy for constellations than pointing at constellations by finger with magnetic position sensor. Particularly when the night sky is obscured by clouds and when constellations are difficult to view, looking at the night sky with a cylinder simplifies location of a target constellation. What a learner has to do is to point at a target star in the center of the view through the cylinder.

The gaze pointing is much easier to point at a target star compared to DS hosinabi or google sky map. DS hosinabi or google sky map displays the starry sky on the monitor of mobile machines, however, the learner has to identify the target star by comparing the real starry sky with virtual starry sky on the monitor. When the real night sky is obscured by clouds and when constellations are difficult to recognize, the identification is very difficult for the learner. Therefore, gaze pointing is always useful, even if the sky is obscured by clouds.

Moreover, the gaze pointing is also much easier to point at a target star compared to preceding system with finger pointing. The preceding system needs calibration by several stars before usage. Therefore, the preceding system is difficult to use, if the sky is obscured by clouds.

The system inherited virtual planetarium from preceding system described in 3.1. When a learner points at a constellation using the gaze pointing interface, sensor data are transferred to the PC. The system analyzes the direction in which a learner is pointing in real time. Then the virtual planetarium displays starry sky in the direction on a display monitor. In addition, the system tells the name of the star and the constellation of the gazing point with voice from speaker and with text on the display monitor. There is not any constraint of allocation between the system screen and observing direction with the gaze pointing device in the real night sky or mobile use

The system configuration with the gaze pointing interface is shown in Fig. 2. The orientation gyro-sensor communicates serially to the PC. Data are transferred in real time. There is no buttons on the cylinder nor the orientation gyro-sensor, therefore, we use Wii remote controller to utilize only its button function. By pushing the button of Wii remote controller, a learner can submit data of orientation gyro-sensor as the target star's location data that the system requires, when operating the constellation mythological exercise function or the constellation line-drawing function. Wii remote controller communicates with the PC via Bluetooth. When the learner use Wii remote controller, he/she hold the gaze pointing device in one hand, and the Wii remote controller in the other hand.

4.3 Expansion of Exercise Functions

The preceding system had a constellation exercise function.

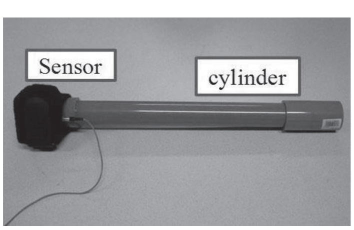

Fig. 1 Gaze pointing interface device.

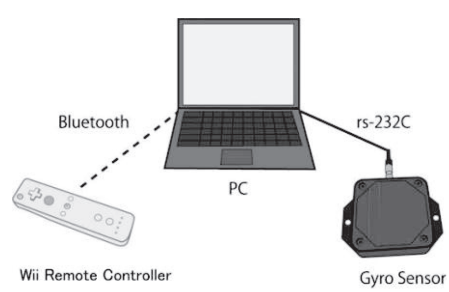

Fig. 2 System configuration with gaze pointing interface.

It was the constellation star's role exercise, and a learner can associate the star with the part of the constellation image. However, the system is insufficient for constellation learning functions because it is impossible to learn mythology among constellations and picture of constellations. This study constructs the following functions:

· Constellation mythology exercise function
· Constellation line-drawing function

Figure 3 presents the system workflow for constellation exercise functions. At the beginning, (A) A learner decides an exercise function he/she will use, and he/she selects an item to learn from the self-exercise panel. Then, (B) the system asks a question or a request to the learner by showing text on a dialog on a display monitor and simultaneously reading the text by text reading software. After that, (C) the learner holds the gaze pointing interface in accordance with the direction of the appropriate constellation or star in the real starry sky. Then, (D) if the learner thinks the constellation or the star is correct as an answer to the question or the request, he/she pushes the button of Wii remote controller. Then, the orientation sensor data are transferred to the PC. After that, immediately the system checks the answer. If (E) the answer is correct, then the system proceeds to next question or next request. If (F) the answer is wrong, the system repeats to ask the same question or request to the leaner until he/she answers correctly.

4.3.1 Constellation Mythological Exercise Function

This gives an opportunity to learn in the real night sky in relation to a constellation myth and a constellation. The constructed system has realized the constellation mythological exercise function on the theme of myths about Cassiopeia, Andromeda, Cetus and Perseus.

We set learning goal (6) in chapter 2 to learn constellation myth. We set more detail goals as follows.

(6-1) To memorize the story of constellation myth and scene in which the constellation appears.

(6-2) To learn relation between constellation picture in the myth and layout of stars in the constellation.

(6-3) To learn constellations and relative positions of the constellations by associating with the myth.

We describe how the constellation mythological exercise works and how it can help to achieve the above learning goals.

Initially, the system starts to tell the myth story by text on a dialog as well as presentation by voice. Then, the system stops telling when a constellation appears in the story. Then the system requests the learner to point at the constellation in the real starry sky by gaze pointing. This process helps the learner to achieve the learning goal (6-1).

When the learner finds the relevant constellation in the real starry sky with gaze pointing interface, he/she marks a star in the constellation on the virtual planetarium by pushing the Wii remote controller button. Simultaneously, the system checks the orientation sensor data, and decides whether or not the learner is pointing relevant constellation. If the learner is right, the system superimposes constellation picture on the constellation in the virtual planetarium. This process helps the learner to achieve the learning goal (6-2). Then, the system proceeds to the next scene and displays it with text, and encourages the learner to answer about the constellation appearing next. If the learner is wrong, the system repeats to request the learner until he/she answers correctly.

A constellation myth includes several constellations. Therefore the system continues above process until the myth come to the end. The whole process helps the learner to achieve the learning goal (6-3).

The screen scene of the constellation mythological exercise function is portrayed in Fig. 4.

4.3.2 Constellation Line-Drawing Function

Constellation line-drawing function is a function enabling learners to draw straight lines among stars. Figure 5 presents a screen scene in the constellation line-drawing function. Dashed lines in the Fig. 5 are the lines drawn by learners. Constellation line-drawing function is operated as a drawing method using the following procedures:

(1) Point at a star by gaze pointing as the starting point of a constellation line.
(2) When pressing the Wii remote controller button, the selected star on the virtual planetarium turns red.
(3) Point at the next star by gaze pointing while keeping the button pressed.
(4) When releasing the button, a constellation line is displayed between the two stars on the virtual planetarium.

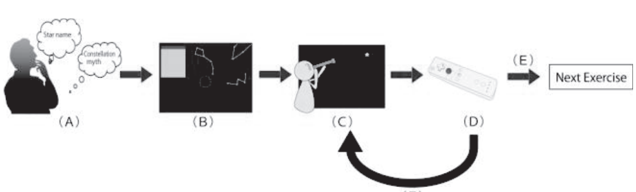

Fig. 3 System workflow for constellation exercise function.

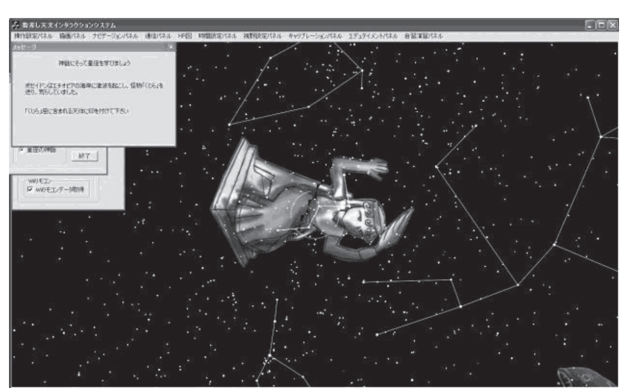

Fig. 4 A scene of the constellation mythological exercise.

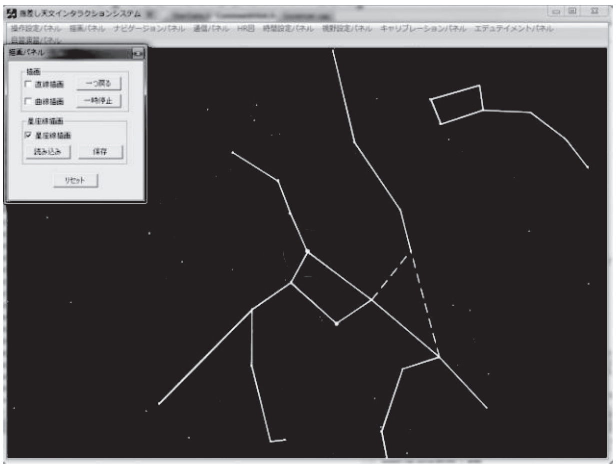

Fig. 5 A scene of the constellation line-drawing function.

To draw more constellation lines, repeat procedures (1)–(4). Constellation lines can be stored as data; data saving is possible with the data output function and the data read function.

This function enables learners to draw an original constellation. It is an effective method particularly for younger people to foster an interest in astronomy.

Also, in the future, a function to learn existing constellation lines can be imagined as the following: the system presents a question about existing constellation lines; a learner draws constellation lines on the virtual planetarium by gaze pointing in the real night sky; and the system matches the drawing with the correct existing constellation lines.

5. Evaluation Experiment

5.1 Purpose

We verified the usefulness of the constellation mythological exercise by comparing experimental group with control group. The experimental group learned out of doors with the constellation mythological exercise in the system and the control group learned indoors with a book of constellation mythology. We also conducted a questionnaire survey to examine the usefulness and problems in the interface.

5.2 Method

The experiment was performed from 3rd to 7th February 2010 at the roof terrace of building-A for experimental group, and room-A705 for control group, at faculty of systems engineering in Wakayama university. The moon ages were from 18.3 to 22.3. It means that the experiment was performed from 3 days after full moon. Every night had clear sky. The experiment was performed at least 1 hour after the sunset, since the sky became dark enough to see stars.

Subjects of this experiment were nine Japanese students (5 male students, 4 female students) aged from 20 to 23. One of male students belonged to graduate school of the faculty of systems engineering. The other students were senior students or junior students of faculty of systems engineering. First, we asked them to fill in a questionnaire sheet to assess their knowledge of constellations. Then we explained the method of this experiment. Before the experiment, we also asked subjects to use the system freely for a few minutes to become accustomed to its operation.

After that, experimental group learned with the constellation mythological exercise in the system. Control group did so using a book of constellation mythology. Then the subjects in both group orally explained a constellation myth by pointing the constellations with their naked fingers without using any sensors or systems under the real night sky as a post-test.

If subjects could not find some of the constellations, they were allowed to use navigation function of the virtual planetarium. We counted instances of navigation function usage for seeking constellations in the system. Thereby, we verified the learning effects of associating constellation mythology with constellations in the actual night sky.

The reason why the subjects did not use the gaze pointing system when they pointed at constellations at post-test, is that the system immediately told the names of stars and constellations with voice in accordance with the orientation of gaze pointing interface. Therefore, we were afraid that subjects were easily able to find the constellation in the real sky by swinging the gaze pointing interface around, if they used it. This could prevent us from verifying the learning effects.

Subsequently, subjects in both group explained the constellation myth under the real night sky. Seven key sentences comprising the story were prescribed in terms of the constellation myth. It was identified whether or not those key sentences were included in the explained content by the subjects.

After finishing post-test, both group exchanged their learning method. Experimental group experienced indoor learning with book of constellation and control group experienced outdoor learning with the system. Therefore, subjects in both groups were able to compare both learning method and to evaluate system usability and usefulness. We implemented a questionnaire survey to determine the system usability. We asked respondents to evaluate questions (1)–(5) using a five-item scale and to fill in comments freely in answer columns of questions (6) and (7).

(1) Sense of physical fatigue
(2) Sense of mental fatigue
(3) Usability of the gaze pointing interface
(4) Usability of the Wii remote controller
(5) Whether constellation mythological exercises are fun?
(6) Advantages of learning with the book
(7) Advantages of learning with the system

Table 1 Results of constellation mythological exercises.

Learning with the system	Subject	A	B	C	D	E
	The number of wrong answers in constellation mythology	1	3	3	1	1
	Times navigation was used	1	0	0	0	6
Learning with the book	Subject	E	F	G	H	
	The number of wrong answers in constellation mythology	4	0	0	0	
	Times navigation was used	2	8	4	4	

Table 2 Results of the questionnaire about usability and usefulness. (Number of subjects of each score)

Score (1:Poor, 5:Excellent)	**1**	**2**	**3**	**4**	**5**
Sense of physical fatigue	1	5	0	1	2
Sense of mental fatigue	0	2	3	2	2
Usability of the gaze pointing interface	1	0	5	2	1
Usability of the Wii remote controller	0	2	3	2	2
Constellation mythological exercise function	0	1	2	4	2

5.3 Results and Study

First, we conducted a questionnaire survey to elicit constellation knowledge. Specifically, we asked four questions as follows: "Have you ever searched stars by using star charts or planetarium software?", "Describe constellation names which you can recognize in the real starry sky by its shape without using any tools"; "Describe names of stars as much as you know"; "Describe constellation mythology that you have read." Results revealed that the number of constellations that subjects knew were fewer than five; subjects were almost entirely beginners of constellation learning. The reason why we decide it, is that Japanese people usually learn Big Dipper (Ursa Major), Cassiopeia and Orion in elementary schools. In addition, a person usually knows his/her zodiac constellation on his/her birthday. Therefore, usual people know four constellations. However, they cannot know more, if they learn more consciously.

Next, we describe result of the evaluation experiment for the constellation exercise. Table 1 displays the number of wrong answers in constellation mythology and the number of times the navigation was used. The less a learner remember the constellation mythological story, the more the number of wrong answers. The less a learner remembers the relative position of constellations, the more the number of times the navigation was used.

The frequency of use of the navigation indicates that the subjects could associate constellation mythology with the constellations by using the constellation mythological exercise under the real night sky. However, when particularly addressing learning of constellation mythology, the usefulness of the constellation mythology exercise is not well established, because the number of wrong answers in constellation mythology in experimental group was not superior to control group.

One reason might be the abundance of information in the book. In particular, visual information from illustrations strongly might affect the learning of subjects in control group. Another reason could be that subjects in experimental group were unable to concentrate on the constellation mythology exercise because they were compelled to learn constellation mythology along with the position of constellations. Also, subjects might be unable to concentrate on the constellation mythology exercise because it was outdoor learning in the cold winter night.

As described above, we cannot conclude that learning by constellation mythological exercise function is superior to learning by a book. The reason why we compare learning by the system with learning by a book is that we thought learning by a book is quite common method to learn constellation mythology. However, the conditions were much different between learning by the system and learning by the book. The differences included so many parameters that it was difficult to decide the factors that caused the results.

Next, we present results in the questionnaire items (Table 2). Answers varied throughout the whole questionnaire. However, regarding physical fatigue, scores of three and less accounted for the majority of responses, which is attributable to the burden on holding the gaze pointing interface during the exercises. We received an overall evaluation that they enjoyed the constellation mythological exercise function.

Finally, we introduce the freely described comments in Tables 3 and 4.

The advantages of using the system are shown in Table 3. Many comments related to advantages of the system were the following: the pleasure of learning while watching the actual night sky; and information, such as the position of constellations, and myths remain in memory. Making learning fun engenders increased desire to learn. Therefore, using the system affects learning.

By contrast, advantages of learning with the book were listed as shown in Table 4: feeling less fatigue because pointing actions are not required; information sources are plentiful; learning at their own pace. The system includes

Table 3 Advantages of using the system.

Easy to take in because of ability to identify constellations under the real sky.
Easy to grasp the constellation positions.
Pleasure felt when finding stars.
Easy to remember because a sense of distance, positional relations, and brightness can be experienced.
Learning by searching stars under the real sky is fresher and therefore easier to retain in memory than learning by reading.
I can actually see the real thing. Enjoyable.
It seems practicable continuously because it uses the real night sky.
Easy to remember as an experience because it is learning while watching the real night sky.
It can be experienced. Pleasure of searching.
I can understand the positional relations of the real starry sky.

Table 4 Advantages of learning with the book.

Less exhaustive because it does not involve physical body movements.
It has pictures.
The text has abundant information. It is meaty in content.
Easy to understand because it has illustrations.
I can re-read the text any time I want to.
Not tiring. Warm. Shorter than the system in terms of learning hours.
Unaffected by weather conditions.
I cannot take it in because I work very hard at pointing with the system, but I can concentrate on a story with the book.
I can read it in my own way. I can turn back to sentences I like.

problems such as not being able to concentrate on learning because it requires pointing actions. In addition, the system necessitates expanded information because the book has advantages attributable to its abundance of information sources.

6. Conclusion

This study replaced a magnetic position sensor used in previous studies with a gyro-sensor to make this system mobile. Using the system examined in previous studies, we constructed a mobile constellation learning support environment.

We evaluated the constellation mythological exercise function of the system by comparing experimental group with control group. The result indicates that the learning by the system seems to be appropriate to learn the positional relations of the real starry sky. By contrast, the result also indicated that the learning by the book seems to be appropriate to learn the story of the constellation myths. In other words, constellation mythological exercise function does not seem to support to learn the story of the constellation mythology. This is probably because learning of mythological story is imaginative cognitive task. Learning with a book seems to be able to promote the imaginative cognitive task more than learning with the system. If we increase virtual learning material in the system as much as the material in the book, the system could promote mythological story learning. Currently, the best way to learn constellation totally is to learn it by using both the system and the book. The system and the book can make up for disadvantages each other.

On the other hand, we have not evaluated yet constellation line-drawing function. As described in the section 4.3.2, we have a plan to extend constellation line-drawing function. That is one of our future works.

Our future challenges also include improvement of the gaze pointing interface to reduce a sense of physical fatigue, and construction of an environment enabling learners to learn at their own pace by expanding information in the exercise functions. Information sources provided by the system have limitations. Therefore, we are considering production of a framework by which learners learn by teaching each other. Currently, we are considering construction of a collaborative learning system.

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