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Family of the Sun-and-Stars Time-Determining Instruments (*Ilseong-jeongsi-ui*) Invented During the *Joseon* Dynasty

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We analyze the design and specifications of the Sun-and-Stars Time-Determining group of instruments (*Ilseong-jeongsi-ui*, 日星定時儀) made during the *Joseon* dynasty. According to the records of the *Sejong Sillok* (Veritable Records of King Sejong), Sun-and-Stars Time-Determining Instruments measure the solar time of day and the sidereal time of night through three rings and an alidade. One such instrument, the Simplified Time-Determining Instrument (*So-jeongsi-ui*, 小定時儀), is made without the essential component for alignment with the celestial north pole. Among this group of instruments, only two bronze Hundred-Interval-Ring Sundials (*Baekgak-hwan-Ilgu*, 百刻環日晷) currently exist. A comparison of the functions of these two relics with two Time-Determining Instruments suggests that the Hundred-Interval-Ring Sundial is a Simplified Sundial (*So-ilyeong*, 小日影), as recorded in the *Sejong Sillok* and the *Seongjong Sillok* (Veritable Records of King Seongjong). Furthermore, the Simplified Sundial is a model derived from the Simplified Time-Determining Instrument. During the King Sejong reign, the Sun-and-Stars Time-Determining Instruments were used in military camps of the kingdom's frontiers, in royal ancestral rituals, and in royal astronomical observatories.

Keywords: sundial, clock, Sun-and-Stars Time-Determining Instrument (日星定時儀), Simplified Time-Determining Instrument (小定時儀), Simplified Sundial (小日影)

1. INTRODUCTION

The Sun-and-Stars Time-Determining Instrument (*Ilseong-jeongsi-ui*, 日星定時儀) is an astronomical instrument used for measuring the time of day and night (Needham et al. 1986). According to the *Sejong Sillok* (Veritable Records of King Sejong), there were initially four Sun-and-Stars Time-Determining Instruments. One was located at the Gyeongbok Palace, and another was presented to the Astronomy Bureau (*Seoun-gwan*, 書雲觀) in the capital. The remaining two were sent to military camps at the two northern boundary areas of the kingdom. As well as these, the Simplified Sun-and-Stars Time-Determining Instrument (*So-Ilseong-jeongsi-ui*, 小日星定時儀), abbreviated to the Simplified Time-Determining Instrument (*So-jeongsi-ui*, 小定時儀), was manufactured in order to lighten the weight of the original instrument for a marching soldier. The function governing alignment with the polar axis was eliminated from the Simplified Time-Determining Instrument as a result of reducing the number of parts.

Rufus (1936) introduced two relics known as the sundial and the moon-dial, whose outward appearance shows some similarities to the Sun-and-Stars Time-Determining Instrument, as described in the *Sejong Sillok*. After the Korean War (1950-1953), Jeon et al. (1984) undertook a reinvestigation of several Korean cultural, scientific, and technological artifacts. Through a comparison with the pictures of Rufus (1936), he found that the handles of the sundial and moon-dial were broken and lost. Needham et al. (1986) termed the two relics a sundial and a star-dial, but Song et al. (1994) referred to them

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collectively as the Hundred-Interval Sundial (*Baekgak-hwan-ilgu*, 百刻環日晷). Nam (1995), however, recognized them as a Sun-and-Stars Time-Determining Instrument.

A significant amount of previous research has concerned the study of this group of instruments. For example, Needham et al. (1986) described the Sun-and-Stars Time-Determining Instruments, as recorded in the *Sejong Sillok*. Specifically, they discussed their structural characteristics, how to measure time using the artifacts, and their historical significance with regards to the development of science and technology. Lee & Nam (1998) suggested a design for a restored version of the Sun-and-Stars Time-Determining Instrument. Nam (2002) described the role of the Sun-and-Stars Time-Determining Instrument as a means for time correction of the Automatic Striking Clepsydra (*Boru-gaknu*, 報漏閣漏), which was a standard clock of the *Joseon* dynasty. Lee et al. (1995) and Lee (2001) introduced the design and operating instructions of various astronomical instruments used in the *Joseon* dynasty, including the Sun-and-Stars Time-Determining Instrument. Kim et al. (2012) specified the improved functions of this instrument, as derived from the Simplified Armillary Sphere (*Ganui*, 簡儀).

In this study, we introduce the characteristics of both the Sun-and-Stars Time-Determining Instrument and the Simplified Time-Determining Instrument, made during the reign of King Sejong. Furthermore, we suggest a connection between these two instruments and the two relics belonging to the same group of instruments. We then describe the design and operating instructions of the two relics based on the analysis of Needham et al. (1986).

2. ANALYSIS OF THE LITERATURE

2.1 Sun-and-Stars Time-Determining Instrument

In 1437, King Sejong (世宗, r. 1418~1450) commissioned Kim Don (金墩, 1385~1440) to compose an introduction to the Sun-and-Stars Time-Determining Instrument. However, according to his confession, recorded in the *Sejong Sillok*, most sentences of the preface were actually completed by the King himself. The preface presented the characteristics of the Sun-and-Stars Time-Determining Instrument: the design and structure of the instrument, the specification of its parts, and so forth.

The Sun-and-Star Time-Determining Instrument consists of four rings, an alidade, a wheel and handle, several columns, and a stand. It uses a simple design in which a set of rings is connected to the stand by a wheel and handle. There are two types of Sun-and-Stars Time-Determining Instrument. One has a coiled dragon column on a stone stand (hereafter, the 'ornate' design), established in the Gyeongbok Palace. The preface of the *Sejong Sillok* mainly describes the ornate design. The dragon column of the ornate design is erected on the stand, with the dragon holding the handle with its mouth. The other design uses a handle that is attached to a bronze stand (hereafter, the 'general' design). The general designs were sent to military headquarters in Hamgyeong Province and Pyeongan Province and also installed in the royal observatory within the Outer Astronomy Bureau (Seoun-gwan) in the Northern District (部) town of Gwanghwa-bang (坊), near the Changduk Palace (Mihn et al. 2010).

Three rings of the Sun-and-Stars Time-Determining Instrument are mounted onto the wheel, which is aligned to the plane of the celestial equator. The outer, middle, and inner rings are referred to as the celestial-circumference degrees-and-fractions ring (*Jucheon-dobun-hwan*, 周天度分環), the sundial hundred-interval ring (*Ilgu-baekgak-hwan*,日晷百刻環) and the star-dial hundred-interval ring (*Seonggu-baekgak-hwan*, 星晷百刻環), respectively (see Fig. 1). In China, referring to the rotation of a heavenly circle, the

Fig. 1. Sun-and-Stars Time-Determining Instrument reconstruction model (National Folk Museum of Korea) designed by Needham et al. (1986). ① pole-fixing ring, ② an alidade, ③ three rings, ④ a wheel and handle, ⑤ a dragon column, ⑥ a stand, and ⑦ a pool.

celestial circumference is divided into 365.25° (365^d ¼)[1] and a day is divided into 12 double-hours and 100 intervals. A crossbar in the wheel maintains the shape of the wheel. On the three rings, there is an alidade rotating at the center of the rings. Over the alidade, a pole-fixing ring (*Jeonggeuk-hwan*, 定極環) is supported by lateral pillars. The center of the alidade and the cross bar have a pinhole similar to a mustard seed. As the wheel of the instrument is oriented towards the polar axis, a selected star near the celestial north pole, seen through this hole, moves in a diurnal motion within the pole-fixing ring, which is actually a concentric double ring. The inner ring of the pole-fixing ring is much thinner than the outer ring. If the Sun-and-Stars Time-Determining Instrument was set up for measuring the time at night, the Heavenly Pivot (天樞, HIP 62572A) would rotate on the inner ring and the Angular Arranger (句陳, *α* UMi) would move between the two rings of the pole-fixing ring (Needham et al. 1986).

2.2 Simplified Time-Determining Instrument

According to the *Sejong Sillok*, the Simplified Time-Determining Instrument was manufactured after the development of the Sun-and-Stars Time-Determining Instrument. In the preface of the Simplified Time-Determining Instrument in the *Sejong Sillok*, its weight was reduced by omitting the pole-fixing ring, so that it could be easily transported in military camps. Removing the pole-fixing ring eliminated its function of orienting itself to the polar axis. The Simplified Time-Determining Instrument, however, used sighting threads, which were connected from a pole-fixing-like ring[2] to the end of the alidade, to measure the apparent solar time though the daytime as the two sighting threads were aligned with the sun. It appears that orienting the three rings to the polar axis allowed the substitution of the pole-fixing ring with a compass (*Jeongnam-chim*, 正南針) (Mihn 2009).

2.3 Simplified Sundial

The record of the Simplified Sundial (*So-ilyeong*, 小日影) in the *Sejong Sillok* is not described in detail. The Simplified Sundial was made and sent to Uiju in Pyeongan Province in 1438. However, it was clearly an astronomical instrument, as '*Ilyeong*' (日影) means 'a shadow cast by the sun.' In addition, the *Seongjong Sillok* (the Veritable Records of King Seongjong) report that an observational platform for the Simplified Sundial was created in 1489. During the reign of King Seongjong (r. 1469~1494), another Simplified Sundial would likely have been made and placed at Changdeok Palace.

Meanwhile, the *Yeongjo Sillok* (Veritable Records of King Yeongjo) indicate that three Simplified Sundial artifacts were created in 1771, with one each sent to *Gyeonggi-jeon* Pavilion (慶基殿) in *Jeonju* (全州), *Seonwon-jeon* Pavilion (璿源殿) in *Yeongheung* (永興), and *Ganghwa* Island (江華島) for use during royal rituals. Before the reign of King Yeongjo (r. 1724-1776), however, the time system adopted 96 intervals per day, similar to the Babylonian (Western) style. Dials of these Simplified Sundial artifacts made in 1771 were therefore graduated with 96 intervals not 100 intervals, which was the standard time system in the 15th century.

The Simplified Sundial as it existed in the 1400s was closely related to the Sun-and-Stars Time-Determining Instrument. First, this instrument was developed within ten months of the creation of the Sun-and-Stars Time-Determining Instrument. Second, their names were similar to each other. In fact, it is likely that the Simplified Sundial was named after the Simplified Time-Determining Instrument, in the same way as the Simplified Time-Determining Instrument was named after the Sun-and-Stars Time-Determining Instrument. Third, the Simplified Sundial was sent with the Movable Clepsydra (*Haeng-nu*, 行漏) and the *Manual for the Operation of the Clepsydra* (*Nuju-tongui*, 漏籌通義) for military or royal ancestral rites, as was the case for the Sun-and-Stars Time-Determining Instrument and the Simplified Time-Determining Instrument. Contextually, the Sun-and-Stars Time-Determining Instrument was developed as a clock for both day and night, after which it was changed to the Simplified Time-Determining Instrument, the Simplified Sundial, and other instruments.

3. THE FOUR RINGS

3.1 Sun-and-Stars Time-Determining Instrument

The method of measuring the apparent solar time and sidereal time by the Sun-and-Stars Time-Determining Instrument, according to the principle of the diurnal motion of the sun and stars, is described in the *Sejong Sillok* (Needham et al. 1986). On and over the wheel and handle of the Sun-and-Stars Time-Determining Instrument, four concentric rings (the celestial-circumference degrees-and-fractions ring, the sundial hundred-interval ring, the star-dial hundred-interval ring, and the pole-fixing ring) are set

1 In this paper, degree, minute, and second of the celestial circumference system are denoted as *d*, *b*, and *c*, respectively, in superscript, following the acronyms of *dou* (度), *bun* (分), and *cho* (秒) in Korean. This avoids confusion when an acronym of *miao* (秒), which means second in Chinese, is used.

2 A pole-fixing-like ring is only a single ring, not a double ring, which requires a triangular gnomon thread made by two sighting threads.

along the polar axis, parallel to the equator. The pole-fixing ring is supported by double pillars in a semi-cylinder or dragon shape on the alidade, which pivots in the center of the rings (Fig. 1).

There are three ways to use the Sun-and-Stars Time-Determining Instrument. First, it can be used to adjust the polar axis with the pole-fixing ring. Second, it can be used with the sundial hundred-interval ring and the alidade to measure the solar time. Finally, the star-dial hundred-interval ring, the celestial-circumference degrees-and-fractions ring, and the alidade can be used to measure the sidereal time. After a detailed analysis of the records pertaining to the Sun-and-Stars Time-Determining Instrument in the *Sejong Sillok*, Needham et al. (1986) precisely described the instructions related to this instrument and their astronomical meaning. In Fig. 1, showing the reconstruction model of the Sun-and-Stars Time-Determining Instrument designed by Needham et al. (1986), the main pillar is decorated with a coiled Chinese-style dragon. The appearance of this dragon sculpture differs from that of the column described in the preface of the Sun-and-Stars Time-Determining Instrument by Kim Don, which was decorated with a dragon and a cloud. The decoration of the dragon and cloud appears to be motivated by the dragon column (龍柱) and bent cloud column (雲架柱) of the Simplified Armillary Sphere in the relief style, instead of Vollplastik.

(1) Pole-fixing ring (polar-sighting ring)

The method used to fix the pole of the Sun-and-Stars Time-Determining Instrument is identical to that of a modern telescope with an equatorial operation system. The three rings of the Sun-and-Stars Time-Determining Instrument are adjusted by the pole-fixing ring. A small hole resembling a mustard seed is punched onto the center of the alidade and the crossbar. The first step in fixing the pole is to gaze at the pole-fixing ring through this pin-like hole. The pole-fixing ring consists of two concentric rings; the outer ring is 48 mm in diameter and 6 mm wide, and the inner ring is 29 mm in diameter and 0.8 mm wide. These two pillars, supporting the pole-fixing ring, are 207 mm long. If one sights from the crossbar, the polar distance of the outer ring is 5˚.7106 to 6˚.5602 and that of the inner ring is 3˚.8901 to 4˚.0042. When looking through this hole, the great star of the Angular Arranger (*α* UMi) enters between the outer and inner ring (Needham et al. 1986 and Figs. 2(a) and 2(b)), and the Heavenly Pivot (HIP 62572A) moves within the inner ring. If these stars show diurnal motion not far from the two rings, then the Sun-and-Stars Time-Determining Instrument is aligned at the polar axis.

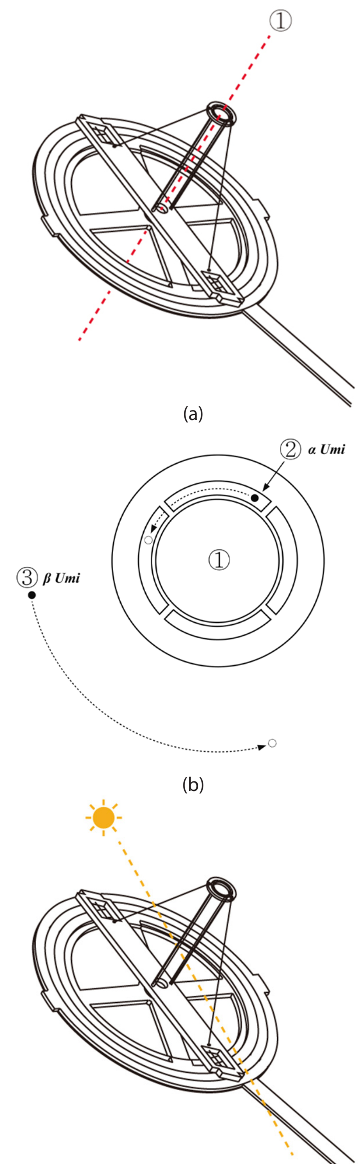


Fig. 2. Alignment of the polar axis of the pole-fixing ring in order to measure the sun. (a) polar axis (① the celestial north pole), (b) pole-fixing ring (① the celestial north pole, ② *α* UMi, ③ *β* UMi), (c) sighting threads.

(2) Sundial hundred-interval ring

Measuring the apparent solar time with the sundial hundred-interval ring stems from the function of the hundred-interval ring in the Simplified Armillary Sphere. The sundial hundred-interval ring is attached to the wheel (輪) and is graduated at 100 intervals, with each interval divided into six fractions. Essentially, the extant Hundred-Interval Sundial has a scaling of 600 fractions, which is the least common multiple of 24 (hours) and 100 (intervals). This scale can represent 100 intervals and 12 double-hours. It is certain that this scaling was handed down from the sundial hundred-interval ring of the Sun-and-Stars Time-Determining Instrument to the Hundred-Interval Sundial. The end of both sides of the alidade has a square window and a transverse thread to read the time and position of the tick of the three rings (see Fig. 2 (c)). This thread is extended from the bilateral sighting thread and is connected across the center of the pole-fixing ring. Two sighting threads with an alidade, therefore, form two equal sides of an isosceles triangle (see Fig. 2 (c)). This is known as a triangular gnomon thread. If the direction towards the sun coincides with the front and back sighting thread for an observer, the alidade then indicates the correct time on the sundial hundred-interval ring.

(3) Celestial-circumference degrees-and-fractions ring

The celestial circumference degrees (365^d ¼) are carved onto the surface of the celestial-circumference degrees-and-fractions ring (hereafter 'the celestial-circumference ring'). In the case of the Sun-and-Stars Time-Determining Instrument, each degree of this ring is divided into four fractions. The celestial-circumference ring on the outside of the sundial hundred-interval ring is rotated, holding two ears (耳, protruding pieces). A special tick of this ring is a cardinal point for measuring the time at night. Once a year at the winter solstice, this cardinal point moves slightly counterclockwise in order to adjust the time.

At midnight during every winter solstice, the zero point of the celestial-circumference ring is fixed at the second star of the North Pole constellation (β UMi). The *Sejong Sillok* report that "the second star of the North Pole constellation is the most reddish and brightest star near the celestial north pole, and it is easy for everyone to find". In fact, β UMi is a circumpolar star with a magnitude of 2.05 and can currently be observed everywhere in Korea. The method for using the celestial-circumference ring is detailed below.

1. Find β UMi at midnight on the winter solstice and set the time at midnight with a clepsydra. Find the position of β UMi with the triangular gnomon thread of the alidade.
2. Mark the position of β UMi on the lateral side of the wheel.
3. Align the zero point (0^d) of the celestial-circumference ring on the marked position of the wheel.

The Sun-and-Stars Time-Determining Instrument considers the precession (歲差) of the winter solstice.[3] Today, the vernal equinox moves 1° clockwise approximately every 72 years (the reverse direction of the revolution of the Earth). The *Sejong Sillok* report that the celestial-circumference ring of the Sun-and-Stars Time-Determining Instrument was adjusted with regards to the date considering the precession calculated by the Shoushi calendar. The precession of the Shoushi calendar was 1^b 50^c per year when $1^d = 100^b = 10{,}000^c$, according to the chapter entitled the *Susi-ryeokyeong* (授時曆經, *Shushi-lijing*) of the *Goryeo-sa* (高麗史, History of the *Goryeo* Dynasty). Therefore, the precession of the Shoushi calendar was determined as 66.67 years per 1^d (=10,000/150) clockwise at the winter solstice (the celestial-circumference ring has to move counterclockwise). Meanwhile, in the chapter entitled the *Seonmyeong-ryeok* (宣明曆) of *Goryeo-sa*, the precession is $29{,}699^b$, when 1^d is $2{,}520{,}000^b$, indicating that it is 84.85 years per 1^d (=2,520,000/29,699) at the winter solstice.

Using the Shoushi Calendar calculation, it is also known that β UMi moved backwards by 1^b in 16 years and by about 1^d in 66 years. It is not necessary to correct the starting point of the celestial-circumference ring of the Sun-and-Stars Time-Determining Instrument for the first 16 years. Each 1^d in the celestial-circumference ring is divided into four fractions such that the celestial-circumference ring is turned a fraction counterclockwise once every 16, 16, 16, and 18 years (or once every 16, 17, 16, and 17 years), respectively, for each fraction. The Sun-and-Stars Time-Determining Instrument can therefore be applied to the Shoushi calendar precession corresponding to 1^d for 66 years. If the observation site changes, alignment with the polar axis should be performed again and the position of β UMi should be determined once more.

(4) Star-dial hundred-interval ring

The scale of the star-dial hundred-interval ring is equal to the sundial hundred-interval ring i.e. graduated with 100 intervals. In contrast to the sundial hundred-interval ring, the star-dial hundred-interval ring is used to measure the sidereal time at night. Though every star turns around the celestial north pole by diurnal motion, β UMi uses only the role of the hand of the clock as a star dial. The method used to measure time with the star-dial hundred-interval ring is as follows.

1. On the winter solstice, align the midnight (子正) mark of the star-dial hundred-interval ring to the zero point of the celestial-circumference ring.
2. Observe β UMi through the triangle gnomon thread and read the time indicated by the alidade thread.
3. Turn the star-dial hundred-interval ring clockwise every day by 1^d.

Using the celestial-circumference ring, the zero point (0^h) of the star-dial hundred-interval ring is lined up with the zero point of the celestial-circumference ring at midnight on the winter solstice. A sundial represents the local time as well as the apparent solar time at its location. According

3 According to the Chinese calendar, the position of the winter solstice, instead of that of the vernal equinox, was used as the standard of precession.

to the rotation of the earth, the midnight point every night is further than that of the previous night, after which the sidereal time becomes shorter by nearly four minutes every day compared to the solar time. As the star-dial hundred-interval ring turns 1^d clockwise every day, the Sun-and-Stars Time-Determining Instrument revises the interval to match the shortened sidereal time (capital A in Fig. 3 rotated 1^d in the direction of the arrow). Moving the star-dial hundred-interval ring by 1^d per day is performed in order to correct the sidereal time to the apparent solar time.

The *Sejong Sillok* notes that the position at midnight on the star-dial hundred-interval ring moves 1^d every day. After the winter solstice, the starting point of the star-dial hundred-interval ring moves by 1^d at the end of the first day, by 2^d at the end of the second day, and by 3^d at the end of the third day. Consequently, it moves by 364^d at the end of the 364^{th} day, reaching 365^d at midnight of the winter solstice of the next year (ⓐ in Fig. 3). In addition, the scale of 1^b remains that of the celestial-circumference ring. Therefore, from the next year, the starting point of the star-dial hundred-interval ring will be $364^d\ 3^b$ for the 1^{st} yr (ⓑ in Fig. 3), $364^d\ 2^b$ for the 2^{nd} yr (ⓒ in Fig. 3) and $364^d\ 1^b$ for the 3^{rd} yr (ⓓ in Fig. 3). In the *Sejong Sillok*, four tropical years (4歲) were referred to as '1 *jin*' (盡). As the fourth winter solstice and one day pass after the first winter solstice, the starting point of the star-dial hundred-interval ring coincides with the zero point of the celestial-circumference ring. The star-dial hundred-interval ring guidelines are very similar to the leap year of today, which adds an intercalary day at the end of February every four years. As explained in the previous paragraph, the celestial-circumference ring is rotated counterclockwise by 1^b every four *jins* for precession correction purposes.

$$\begin{aligned} 1\ \textit{jin} &= 4\ \text{(tropical) years} \\ &= 1{,}461\ \text{days}\ (=365\ \text{days/years} \times 4\ \text{years} + 1\ \text{day}) \end{aligned} \quad (1)$$

$$\begin{aligned} 1^d\ &\text{of the celestial-circumference ring} \\ &= 16.5\ \textit{jins}\ (=4\ \text{years}/\textit{jin} \times 4\ \textit{jin} + 2\ \text{years}) \\ &= 66\ \text{(tropical) years} \end{aligned} \quad (2)$$

3.2 Simplified Time-Determining Instrument

Although the *Sejong Sillok* noted that the Simplified Time-Determining Instrument was designed to remove the pole-fixing ring from the Sun-and-Stars Time-Determining Instrument, it has an alidade that serves as a star dial, though it requires a celestial-circumference ring, a star-dial hundred-interval ring, and triangular gnomon threads. For the creation of triangular gnomon threads, bilateral pillars are set up on the alidade of the Simplified Time-Determining Instrument, supporting a small hollow piece. In the *Sejong Sillok*, the instructions pertaining to the celestial-circumference ring and the star-dial hundred-interval ring of the Simplified Time-Determining Instrument describe it as very similar to the process of the Sun-and-Stars Time-Determining Instrument. The method for using the celestial-circumference ring is as follows.

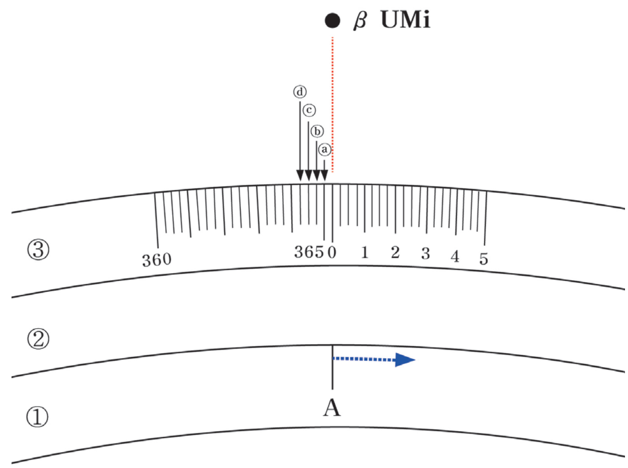


Fig. 3. Operation of the celestial-circumference ring and the star-dial hundred-interval ring of the Sun-and-Stars Time-Determining Instrument. ① star-dial hundred-interval ring (1^d right-handed rotation per 1 day), ② sundial hundred-interval ring (attached to the wheel), ③ celestial-circumference ring (after matching with the initial β UMi, $1/4^d$ left rotation per 16 years).

1. Find β UMi at midnight of the winter solstice and set the time at midnight with a clepsydra. Find the position of β UMi with the triangular gnomon thread of the alidade.
2. Mark a long tick at the position of β UMi on the lateral side of the wheel. Three ticks counterclockwise are drawn while becoming shorter and keeping a $1/4^d$-interval for each line.
3. Set the zero point (0^d) of the celestial-circumference ring at the longest line (1^{st} line) on the wheel side during the winter solstice in the first year.
4. Set the zero point (0^d) of the celestial-circumference ring at the next line (the 2^{nd}, 3^{rd}, and 4^{th} line) on the wheel side every winter solstice for three years (2^{nd}, 3^{rd}, and 4^{th} year respectively).
5. In the 5^{th} year, return the longest line and repeat, as in the new 1^{st} year.

According to the *Sejong Sillok*, the wheel of the Sun-and-Stars Time-Determining Instrument is 4 *pun* (8.3 mm) wide, allowing it to be used to mark lines that grow shorter per fraction. However, the scales of the celestial-circumference ring are distinguished from those of the Simplified Time-Determining Instrument and the Sun-and-Stars Time-

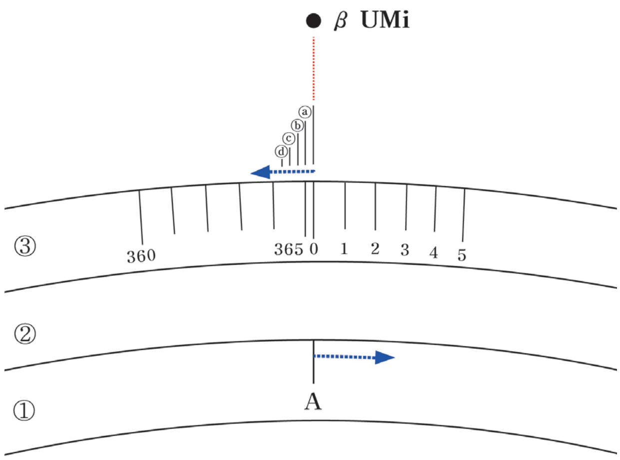


Fig. 4. Operation of the celestial-circumference ring and star-dial hundred-interval ring of the Simplified Time-Determining Instrument. The function of three rings is identical to Fig. 3, except that the celestial-circumference ring has only 366 ticks.

Determining Instrument. The celestial-circumference ring of the Simplified Time-Determining Instrument was likely graduated with only 366 scales without fractional ticks (Fig. 4).

Meanwhile, the instructions on how to use the star-dial hundred-interval ring are as follows.

1. During the winter solstice, align the midnight mark of the star-dial hundred-interval ring to the new zero point of the celestial-circumference ring.
2. Observe β UMi through the triangle gnomon thread and read the time as indicated by the alidade thread.
3. Turn the star-dial hundred-interval ring clockwise by 1^d every day.

As the zero point of the celestial-circumference ring is set at the β UMi position throughout observation, the celestial-circumference ring of the Sun-and-Stars Time-Determining Instrument moves one fraction backward (counterclockwise) every 16 years. The celestial-circumference ring of the Simplified Time-Determining Instrument, however, must turn $1/4^d$ (one fraction) every year. After one year, a difference of one fraction (0.25^d) arises between the starting point of the star-dial hundred-interval ring and that of the celestial-circumference ring. While the star-dial hundred-interval ring of the Sun-and-Stars Time-Determining Instrument can have its starting point set every day in units of fractions owing to the degrees and fractions of its celestial-circumference ring, the starting point of the Simplified Time-Determining Instrument cannot be moved by fractions due to the absence of fractional ticks in the celestial-circumference ring. To address this defect, the zero point of the celestial-circumference ring moves one fraction counterclockwise every winter solstice. Therefore, the n-th degree of the celestial-circumference ring represents the n-th day after the winter solstice. The zero point of the celestial-circumference ring of the Simplified Time-Determining Instrument is initialized every four (tropical) years.

On the other hand, it is not easy to visually correct the precession with the Simplified Time-Determining Instrument. However, similar to the usage of the Sun-and-Stars Time-Determining Instrument, one fraction can move counterclockwise in the Simplified Time-Determining Instrument during the first winter solstice after 16 years. Moreover, under these circumferences, if it runs in the same manner for 16 years, it is possible for the Simplified Time-Determining Instrument to be applied to a precession.

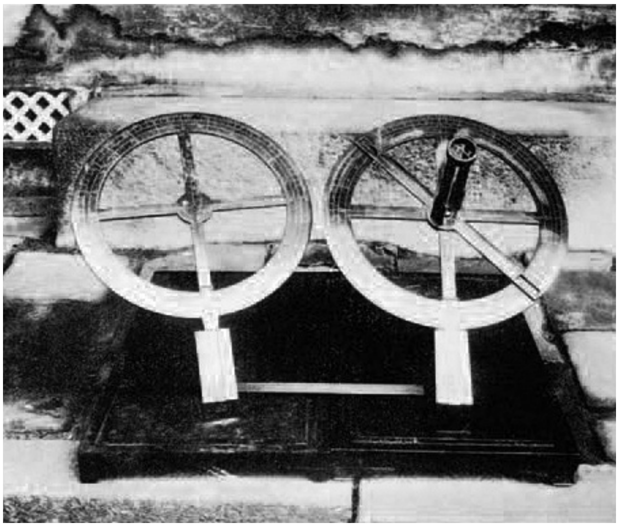
4. RELATED RELICS

4.1 External Properties and Usage

Rufus (1936) introduced two relics, which had the shape of the sundial hundred-interval ring, in the late period of the *Joseon* dynasty. After 50 years, Needham et al. (1986) noted that these two relics were similar to the Sun-and-Stars Time-Determining Instrument. These relics were partly damaged after the Korean War (Needham et al. 1986) and owned by different entities (Song et al. 1994).

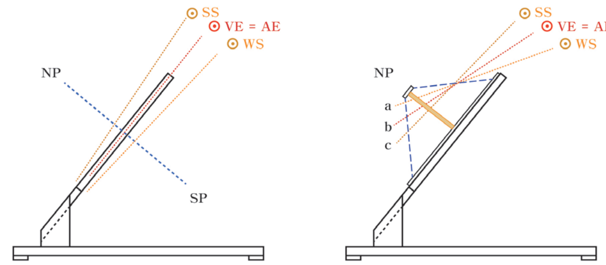
As noticeable in the relic shown in Fig. 5, the wheel supported by a crossbar is equal to that of the Sun-and-Stars Time-Determining Instrument, and distinctive in that a scale of 100 intervals is drawn on the surface of the wheel. Another characteristic is that both relics do not have the celestial-circumference ring or star-dial hundred-interval ring of the Sun-and-Stars Time-Determining Instrument. In Fig. 5(a), there is a hole at the center of the crossbar, and the 100 intervals are engraved on the reverse as well as the front of the ring. This is the same type of equatorial sundial as the Plummet Sundial (*Hyeonju-ilgu*, 懸珠日晷) of the early period of the *Joseon* dynasty. Using a gnomon with a stylus or thread through the center, it measures the solar time between the winter and summer seasons (refer to Fig. 6(a)). Both relics have a total of 600 scales by dividing one interval into six fractions, making it possible to measure time in more detail than the Plummet Sundial or the Planisphere Sundial (*Cheonpyeong-ilgu*, 天平日晷), another equatorial sundial made during the reign of King Sejong.

Unlike those in Fig. 5(a), the relics in Fig. 5(b) have the typical structure of an alidade and triangular gnomon thread. Over the alidade, a small ring is sustained by two straight semi-cylindrical pillars to the side of the center of the alidade and crossbar. The alidade is pivoted to track the sun in order to measure the solar time during all seasons,



(a) (b)

Fig. 5. Two types of *Baekgak-hwan* relics (Rufus 1936).



(a) (b)

Fig. 6. Conceptual drawing of the sun measurement process using two types of the sundial hundred-interval ring (NP: north pole, SP: south pole, SS: summer solstice, VE: vernal equinox, AE; autumnal equinox, WS: winter solstice).

although the scales of 100 intervals are only drawn on the upper side of the wheel (ring). Although the sun is under the equator, triangular gnomon threads can secure a bilinear view when aimed at the sun (refer to Fig. 6(b)).

The small ring in Fig. 5(b) over the alidade cannot be considered as a pole-fixing ring. The pole-fixing ring of the Sun-and-Stars Time-Determining Instrument consists of a concentric dual ring, and the axle-hole under this ring is pierced in order to aim at the stars near the celestial north pole. In this sense, this relic may be considered a Sun-and-Stars Time-Determining Instrument. Nevertheless the relic in Fig. 5(b) is not a moon-dial or star-dial as suggested by Rufus (1936) and Needham et al. (1986), as it is a type of sundial. The fixed 100-interval scale cans only be used as a sundial in conjunction with the Sun-and-Stars Time-Determining Instrument and the Simplified Armillary Sphere, created during the early period of the *Joseon* dynasty.

An unusual aspect of Fig. 5(a) is the fixed status of the wheel and handle. The wheel and handle is oblique at 16˚ on the baseline (the north-south line) of the stand (Jo 1995). However, it is not known why the handle is tilted on the base alignment. It is associated with the direction of the observation platform, which is not precisely oriented true north. For example, the *Gwancheon-dae* (觀天臺) observation platform (Korean Treasure No. 1740) is oriented approximately 8˚ from true north (Jeon & Nha 1983) because the directions of the major buildings of the Changdeok Palace are also oriented approximately 8˚ from true north. As the handle in Fig. 5(a) has a different direction from the baseline of its stand, its wheel can be oriented towards the north pole (Mihn 2009).

4.2 Designation

The two relics in Fig. 5 serve as sundials with fixed sundial hundred-interval rings, which were made in the early period of the *Joseon* dynasty. The Simplified Sundial is an astronomical instrument that also displays this characteristic. As noted in Section 2.3, the Simplified Sundial was created during the reign of King Sejong and Seongjong (hereafter referred to as 'the Sejong Simplified Sundial' and 'the Seongjong Simplified Sundial', respectively). The Sejong Simplified Sundial was manufactured within ten months of the Sun-and-Stars Time-Determining Instrument. The alidade and pole-fixing-like ring shown in Fig. 5(b) suggest that this relic is a descendant of the Simplified Time-Determining Instrument.

Meanwhile, the relic in Fig. 5(a) could be logically assumed to be the Seongjong Simplified Sundial. Interestingly, the stand of this relic is engraved with an inscription. According to the inscription, it was made in 1478 (Song et al. 1994). This correlates with records of the *Seongjong Sillok*, and an observational platform for the Simplified Sundial was built in 1489. While the Sejong Simplified Sundial was sent to another location, the Seongjong Simplified Sundial was installed inside of a palace.

From the picture of the sundial by Rufus (1936), we find that the wheel and the stand of the hundred-interval ring that belonged to King Sejong of the Great Memorial Hall (hereafter 'SGMH') are not an original pair. The SGMH stand has a skewed joint for the insertion of the wheel and handle, and its wheel (hundred-interval ring) has an alidade without a pole-fixing-like ring and two pillars. The former is a stand of the Seongjong Simplified Sundial, and the latter is a wheel of the Seongjong Simplified Sundial. It is also inaccurate to consider that the Simplified Sundial with alidade was made in 1487, as noted in Song et al. (1994). During the Korean War, it appears that the wheel and handle were broken and separated from the stand, and this pair changed hands and became paired in some way.

It is possible to confirm the mismatch between the stand and the wheel (or the hundred-interval ring) through an examination of the broken part of the handle. In Fig. 5(a), the handle of the relic remains but is not inserted into the joint, whereas in (b), the relic is completely inserted. If we inspect the broken part of the Simplified Sundial, the hundred-interval wheel in Fig. 5(a) has a small remaining arm (a part of the handle), but in Fig. 5(b) it has no arm (Song et al. 1994).

5. CONCLUSIONS

Here, we investigated the design and mechanism of the Sun-and-Stars Time-Determining group of instruments, two relics (Simplified Sundials), and related literature. The Sun-and-Stars Time-Determining Instruments of King Sejong are mainly divided into three types: an ornate design, a general design, and a simplified design (the Simplified Time-Determining Instrument). We presume that there are at least two types of Simplified Sundial, which utilize a 100-interval daily system and which are affected by the Simplified Time-Determining Instrument. These five types of astronomical instruments are shown in Table 1.

The weight and functionality of the Simplified Time-Determining Instrument was reduced in order to be more convenient to move. The Sun-and-Stars Time-Determining Instrument and the Simplified Time-Determining Instrument were sent not only to the Astronomy Bureau, but also to the border of the *Joseon* dynasty to help with military activity. Knowledge of the time within a palace or military camp would have been very important during that period.

The Sun-and-Stars Time-Determining Instrument is a sundial of the apparent solar time and a star dial of the sidereal time during daytime and nighttime, respectively. According to an analysis of the instructions for the star-dial hundred-interval ring and the celestial-circumference ring, we recognize that people during the *Joseon* dynasty understood the difference between a tropical year and a sidereal year, and they applied it to the Sun-and-Stars Time-Determining Instrument. According to the star-dial hundred-interval ring and the celestial-circumference ring, the Sun-and-Stars Time-Determining Instrument was also corrected to consider an intercalary day every 4 years and a precession every 66 years (Needham et al. 1986).

Table 1. Classification and properties of the Sun-and-Stars Time-Determining Instrument's family

Main components	Sun-and-Stars Time-Determining Instrument 日星定時儀			Simplified Sundial 小日影	
	Ornate (1437)	General (1437)	Simplified (1437)	Sejong (1438)	Seongjong (1487)
Pole-fixing ring (定極環, *Jeonggeuk-hwan*)	○	○			
(Small) central pillars 柱	○ (dragon)	○	○	○	
Alidade (界衡, *Gyehyeong*)	○	○	○	○	
Triangular thread gnomons 繩	○	○	○	○	
Sundial hundred-interval ring (日晷百刻環, *Ilgu-baekgak-hwan*)	○ (Single-sided scale)	○ (Single-sided scale)	○ (Single-sided scale)	○ (Single-sided scale)	○ (Dual-sided scale)
Star-dial hundred-interval ring (星晷百刻環, *Seonggu-baekgak-hwan*)	○ (Single-sided scale)	○ (Single-sided scale)	○ (Single-sided scale)		
Celestial-circumference degrees -and-fractions ring (周天度分環, *Jucheon-dobun-hwan*)	○ (Single-sided scale)	○ (Single-sided scale)	○ (Single-sided scale)		
Crossbar, Wheel & Handle 十字距, 輪柄	○	○	○	○ (wheel=ring)	○ (wheel=ring)
Dragon-pillars 龍柱	○				
Stand 趺	○ (stone)	○ (bronze)	○ (bronze)	○ (bronze)	○ (bronze)
Platform 臺	○	-	-	-	○
Installation site	Gyeongbok-gung palace	royal observatory, army camps in border area	army camps in border area	Uiju	Changdeok-gung palace
Number of manufacture	One	Three	Several	One	One
Status	Loss	Loss	Loss	Existence see Fig. 5(b)	Existence see Fig. 5(a)

The Simplified Time-Determining Instrument differs in two aspects from the Sun-and-Stars Time-Determining Instrument. One is that the pole-fixing ring is changed to a single ring and the other is a reduced number of scales on the celestial-circumference ring from 1,461 ticks to 366 ticks. Nevertheless, the function of the Simplified Time-Determining Instrument as a star-dial generally matched that of the Sun-and-Stars Time-Determining Instrument.

Rufus (1936) introduced two relics of the celestial-circumference wheel. We consider these relics as Simplified Sundials, mentioned in the *Sejong Sillok* and the *Seongjong Sillok*. These artifacts were used only as sundials, as there were no pieces of the star-dial hundred-interval or the celestial-circumference ring, which also functioned as a star-dial. Specifically, it is concluded that the Sejong Simplified Sundial is a transformed version of the Simplified Time-Determining Instrument, although Needham et al. (1986) presumed that this instrument was a star-dial with an alidade, central pillars, and triangle gnomon threads. The Seongjong Simplified Sundial has a simpler structure than that of the Sejong Simplified Sundial; only the dual-side 100-interval wheel (ring) remains on the Seongjong Simplified Sundial.

The *Sejong Sillok* mentions that King Sejong himself composed nearly all of the content of the Sun-and-Stars Time-Determining Instrument, from the manufacturing method to the instructions. This fact implies that King Sejong acquired significant astronomical knowledge. The Sun-and-Stars Time-Determining Instrument progressed to the sun-and-star dial, adding the capability of measuring the sidereal time in perfect harmony with the operation of the three rings.

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