Innovations on the Timekeeping Devices at King Sejong's Observatory *Ganui-dae*

Moon-hyon Nam

Abstract In the course of seven year's astronomical project launched by King Sejong (r. 1418-50) of the Joseon dynasty (1392-1910); beginning in 1432, the Royal Observatory installed fifteen kinds of astronomical equipment and timekeeping devices in the main palace grounds. Among these, five kinds were astronomical instruments. Ten kinds were timekeeping devices. Jang Yeong-sil (Unknown) invented two Striking Clepsydras: Ball-powered Striking Palace Clepsydra employed as a standard timekeeper, and Water- and ball-operated Striking Heavenly Clepsydra as an instrument to edify Neo-Confucian ideology. The Sun-and-Star Time-determining Instrument and its smaller version consisted of a sun- and star-dial mounting equatorial-polar alignment and thread gnomons. Two Small Simplified Armilla were used to observe celestial bodies and/or timekeeping at the palace observatory and Astro-calendric Office, respectively. The sundials, mounting an equatorial-polar alignment and/or all thread-gnomons Scaphe-, Plummet-, Horizontal-, and South-determining, were new and used at the observatory, Astro-claendric Office, military camps, public places and palaces. A portable water-clock, Traveling Clepsydra, was used for the royal family, the Astro-claendric Office and military camps. The Striking Clepsydras, the Sun-and-Star Time-determining Instrument and the Small Simplified Armilla were evaluated as Korean originals in the world history of astronomical instruments and clocks. Inventions and innovations in constructing the timekeeping device at the Royal Observatory attribute in large measure to King Sejong's state-supported science policies. Time-measuring devices are reviewed from the contemporary official records with extant relics and reconstructions.

Keywords King Sejong · Royal Observatory · Sundial · Star-dial · Striking Clepsydra · Sun-and-Star Time-determining Instrument · Small Simplified Armilla · Traveling clepsydra

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1 Introduction

Koreans have had a long history of clock making since the Three Kingdoms Period (BC 57–AD 935).[1] In the Silla kingdom, they ran the Office of Water-clock and installed a water-clock in the Hwangryong-sa (temple) in 718. In 554 Baekje sent calendar and astronomy experts to Japan to supervise calendar- and clock-making. Among the works of such missions were the water-clock made in 671 during the reign of Emperor Tenji (r. 661–671). According to Xu Jing (1091–1153) of Northern Song who visited Goryeo dynasty (918–1391) on a mission from China in 1123 and compiled his works describing Goryeo and their customs, he briefly described time-telling.[2] The Goyro government ran the Astro-calendric Office (*Seoun-gwan*) which took charge of the astronomical, calendar and clepsydral timekeeping matters. The Joseon dynasty (1392–1910) founders took over the Astro-claendric Office from the former dynasty and assigned it to astronomical, calendrical, meteorological, divinations, and clepsydral timekeeping duties. In 1398, Night Clepsydra (*Gyeong-nu*) was installed and the Clepsydra Office was erected next to the bell tower in the center of the capital. In 1424, King Sejong (r. 1418–1450) ordered the casting of the night Clepsydra (*Gyeong-jeom-jigi*) and replaced 1398 night-watch clepsydra.

King Sejong commissioned Jeong In-ji (1396–1478) who was supervising calendar studies "to research the classics, to create instruments and to provide experiments and verifications" in the fall of 1432 to equip a new observatory in the Gyeongbok-gung palace compound. In the course of the astronomical project, the Striking Palace Clepsydra at Announcing Clepsydra Pavilion began to herald standard time adjusted to the times of sunrise and sunset on the first day of the seventh lunar moon of 1434. And then, the Striking Heavenly Clepsydra and Traveling Clepsydra; the Scaphe-, Plummet-, Horizontal-, and South-determining-sundials; the Small Simplified Armilla, the Sun-and-Star Time-determining Instrument and the Small Time-determining Instrument were created and installed at the Royal Observatory (*Ganui-dae*), the Astro-calendric Office, a number of palaces, public places, with several copies of them being sent to military camps.

Sejong and his court scholar-officials, engineers and artisans were involved with the observatory project. The king initiated the project and contributed to the research, guiding the scholars Kim Don (1385–1440) and Kim Jo (former name Kim Bin, Before 1445) and royal court engineer Jang Yeong-sil (Unknown) for creating the Striking Clepsydras, and inventing the Sun-and-Star Time-determining Instrument. Moreover, he was a great thinker, a philologist who invented the Korean alphabet *Hangeul* and a cultural hero who was revered for fostering cultural creativity, revitalizing intellectual life, and encouraging technological and scientific advances.[3] Sigimondi (2012) asserted that King Sejong the Great and Sylvester II of the Roman Pontiff were strikingly similar in terms of their achievements in astronomy, music, philosophy, medicine and

[1] Nam (2008).

[2] "Reaching the hour, a time-teller beats the drum and suspends a time-tablet on the column. In the middle of a double-hour an official dressed in a red uniform stands in the left bearing a time-tablet, an official dressed in a green uniform bows and says "It is xx hour" and suspends the time-tablet on the column and leaves". (Xu 1123).

[3] Baker (1998), p. 174

various scientific disciplines.[4] Jeong Cho (Before 1434) took charge of classics, and Jeong In-ji oversaw equipping the Observatory. Yi Cheon was in charge of engineering and construction affairs with Jang Yeong-sil the chief royal court engineer, and they collaborated on the making of the equipment with Kim Don, Lee Soon-ji (Before 1465) and Kim Jo.[5]

In this chapter, the timekeeping devices created in the course of the astronomical project during 1432–1438 to equip the King Sejong's Observatory were introduced by citing the Records of Observatory (*Ganuidae-gi,* hereinafter referred to as "Observatory Records") in Chap. 77 of *Annals of Sejong* (*Sejong sillok*)[6]. In addition, recent studies on the timekeeping devices are reviewed from contemporary official records with extant relics and reconstructions.

2 Creation of the Time-Determining Instruments and Clocks

The astronomical project was launched to measure local Joseon time independent of that of Ming China. Sejong consolidated various libraries into the Hall of Worthies[7] (*Jiphyeon-jeon*), a royal institute functioning as an advisory body for the king to ponder pending national policies and issues. The Hall was responsible for most of the research on the classics and designs of the astronomical instruments and clocks created during the observatory construction project and calendar studies.

Table 1 summarizes the timekeeping equipment made during the 7-year project according to the Observatory Records. The water-clocks were arrayed on the west side of the Gyeongbok-gung palace, centering on the south of Banquet Area (Gyeonghoe-ru). The site was near the waterways, which provided drainage for the water-clocks. The Sun-and-Star Time-determining Instrument was located at the eastern part of the palace.

In the making of all instruments described above, the Korean version of the Chinese *Zhou* Foot-Rule was employed as the standard measure for scaling.[8] During the Imjin War with Japan (1592–1598), the standard measures were lost, and Yeongjo (r. 1725–1776) revived them in 1740 as shown in Fig. 1.[9] According to the 1740s ruler, the length of one *Ju-cheok* is equivalent to 20.7 cm and the Yeongjo promulgated the new ruler as the standard measures and used *Ju-cheok* to make the instruments such as the rain-gauges and water-level marker.

[4] Sigimondi (2012), pp. 37–41.

[5] Nam and Nha (2015).

[6] The records is an article on the fifteenth day of the fourth lunar moon of nineteenth year (1437) after throne. An academician of the Hall of Worthies Kim Don wrote the records.

[7] Lee and Theodore de Bary (1997), op cit, p. 293.

[8] According to recent studies, Guo Shoujing used Astronomical Rule tianwen-chi, one chi equivalent to 24.5 cm to make his instruments at the Yuan observatory ling-tai in Dadu (now Beijing). (Ref. Wang (2011)).

[9] Nam (1995), pp. 271–304.

Table 1 Timekeeping equipment made for King Sejong's Observatory during 1432–1438

Name	Translation	Number of instruments made	*Sejong sillok* and others	Remark
1. *Ilseong jeongsi-ui*	The Sun-and-Star Time-determining instrument	4 (1-Royal Obs., 1-Astro-calendric Office, 2-Field Army HQ)	77: 7a–8b	King Sejong's memoirs, Kim Don's inscriptions with prefaces
2. *So gan-ui*	Small simplified armilla	2-set	77: 9a, 10a	Jeong Cho's inscriptions
3. *So Ilseong jeongsi-ui*	Small Sun-and-Star Time-determining instrument	Several	77: 9ab, 10a	Portable
4. *Borugang-nu* in the Boru-gak	Striking Palace Clepsydra in the Annunciating Clepsydra Pavilion	1-set 1-housing	65: 1a–3b 77: 9b–10a	Kim Don's memoirs Kim Bin's inscriptions with prefaces
5. *Heumgyeong gang-nu* in the Heumgyeong-gak	Striking Heavenly Clepsydra in the Respectful Veneration Pavilion	1 set 1-housing	77: 10a 80: 5a–6a	Kim Don's memoirs
6. *Angbu-ilgui*[a]	Scaphe sundial	2-public use, assume several in the palaces and the observatory	66: 1a 77: 10a *Jega yeoksang-jip* 3: 28b-30a[b]	Kim Don's inscriptions Guo Shoujing's *yang yi*
7. *Hyeonju-ilgui*	Plummet sundial	Several	77: 10a	Portable
8. *Haeng-nu*	Traveling Clepsydra	Several	77: 10ab	Guo Shoujing's *xing-lou*
9. *Cheonpyeong-ilgui*	Horizontal sundial	Several	77:10b	Portable
10. *Jeongnam-ilgui*	South-determining sundial	Several	77: 10b	Portable

[a] Treatise on Astrology 1 in the *History of Yuan* (Song Lian, 1976) 48 (*Yuan shi tian wen zhi*). Same as other notations in the table

[b] Lee (1445) Collections of the Chinese History and Writings on the Astronomy, Calendar, Instrument and Timekeeper

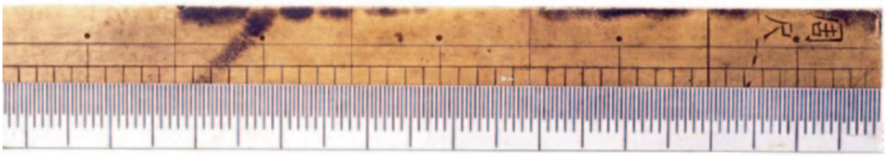


Fig. 1 Half-length of revived *Ju-cheok* (*upper part*). *Lower part* is modern scale. Doubling the length of ruler makes up one *cheok* equivalent to 20.7 cm. The graduation of a foot *cheok* was divided into ten *chon*, and a *chon* divided into 10-in. *bun* following the decimal system. (Collection of the National Palace Museum of Korea, Seoul). (Photo courtesy of Nam MH)

2.1 The Sun-and-Star Time-Determining Instrument

Until the Sun-and-Star Time-Determining Instrument was invented under Sejong, the nighttime measurement in Joseon mostly relied upon observations of the 28 lunar mansions to measure five night-watches. A star-dial, which was capable of measuring nighttime without knowing the seasonal meridian star, has not yet developed in East Asia.[10] Whereas sundials have been used for measuring daytime from remote antiquity, nighttime-measuring instruments were only developed after the Royal Observatory project was launched. In this instance, the Observatory Records describe the creation of the Sun-and-Star Time-Determining Instrument for measuring both daytime and nighttime in detail. According to the Preface of Sun-and-Star Time-Determining Instrument in the Observatory Records, Sejong got the ideas, "after dark, stars are used to divide the night" from the book *Zhou Rites* and "to determine the time by observing the stars, but they do not depict exactly the technique to measure with it" from the *History of Yuan* (*Yuan Shi*). Then a project was launched to develop a compound instrument of a star-dial and a sundial, which was christened as the Sun-and-Star Time-Determining Instrument.

Although there were devices called the "Time instrument for both day and night (*Urstrolabe*)" that are cited among the Islamic instruments (*Xiyu yixiang*) in the *Yuan Treatise* and a "Star-dial Time-determining Instrument (*Xing-gui ding shi-ui*)" in the *Biography* of Guo Shoujing (1231–1316) in the *History of Yuan*, no mention was made of how to make one.[11] Because it was very difficult to develop a new instrument from brief articles on *Zhou Rites* and *Guo's Biography*, Sejong studied the *Yuan Treatise* thoroughly and applied the components of the Simplified Instrument, to include equatorial ring, diurnal rings, alidade, pole-determining ring to create the Sun-and-Star Time-Determining Instrument for time-determining both the length of both daylight and nighttime hours. He made four instruments: one which was decorated with a cloud-dragon column for the palace (Fig. 2a), one for the Astro-calendric Office for regular observation, two for both military headquarters in Pyeong-an and Ham-gil -Province to support the work of guarding the frontier.

Kim Don continued the Preface, which was written by Sejong on the design and usage of the instrument at length. In this instance, the design and usage were illustrated through the Inscriptions followed by the Preface[12], and main content is as follows:

[10] Night time could be measured with the Simplified Instrument by observing a meridian star, but it requires knowing the meridian stars by seasonal time zone. Thus we don't call the Simplified Instrument a star-dial.

[11] Guo Shoujing, Biography, History of Yuan 164:51, p. 989.

[12] Needham et al. (1986), pp. 46–54.

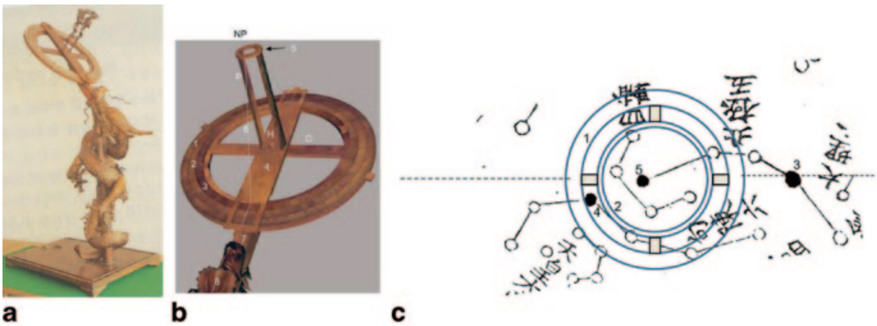


Fig. 2 The Sun-and-Star time-determining instrument. **a** Reconstruction by Moon-hyon Nam (author) in 1996. (Photo courtesy of Nam MH). **b** Enlarged components of the observation part. *1*: mobile celestial-equator ring graduated 365 $1/4^{d}$, each of four fractions set on the equatorial-wheel (external diameter 41.4, 0.8 cm thick, 6.2 cm wide) beneath; *2*: fixed sundial hundred-marks ring (external diameter 37.2, 0.8 cm thick, 1.6 cm wide) is graduated for solar-time determinations, with 12 double-hours and 100-marks of day-and-night; *3*: mobile star-dial (external diameter 34.7, 0.8 cm thick, 1.6 cm wide) is graduated same as sundial; *4*: 43.4 cm long pivoted alidade; *5*: pole-determining ring comprised of outer and inner rings; *6*: sighting-thread; *7*: equatorial wheel and its handle; *8*: dragon-column; *C*: cross-struts of the equatorial wheel; *H*: hole pierced in the pivot; *P*: 20.7 cm high dragon-pillar erected on each side of pivot for supporting the pole-determining rings; *NP*: North Pole. **c** Orienting the polar axis and equatorial plane using the star-dial pole-determining rings for observing Chinese fifteenth century circumpolar constellations. *1*: outer ring (diameter 4.7, 0.6 cm wide, 0.4 cm thick); *2*: inner ring (diameter 3.0, 0.8 cm wide, 0.4 cm thick); *3*: Imperial Throne (βU. mi.); *4*: Angular Arrangers (αU. mi.); *5*: Heavenly Pivot, the last star of North Pole constellations which begins with γU. mi

> [...] first, made a round wheel with cross-struts and a handle. It is set in the equatorial plane by making the north higher than the south. The coiled-dragon standing on the platform holds the protruding handle of the wheel in its mouth. The platform has a water-groove for leveling when needed. The three rings set on top of the wheel are concentric. The outermost one is celestial circumferential ring, and degrees and fractions are graduated on it[13]. There are two rings separately within celestial ring: sundial ring, graduated (12 double-hours and) 100-marks on it, and star-dial ring, likewise graduated. The time on the star-dial corresponds to the celestial degrees. As the outer and inner rings are mobile, the middle one is fixed. The surface of the rings has an alidade horizontally, and there is a pivot at the center. The pivot is penetrated by a hole no bigger than a mustard seed. The degrees, fractions and the times (of the rings) can be read through the slotted ends of the alidade. Two dragon pillars on each side of the pivot uphold the pole-determining rings. The stars are seen between the outer and inner rings. What stars are these? They are the Angular Arranger and Heavenly Pivot, used to locate south north and thereby determine the east west properly. How do they observe with it? They use threads. First, threads are extended from the pole-determining (outer) rings above and pass through the ends of alidade below. For measuring the sun, they use two threads, and only one for observing the stars. The constellation Imperial Throne is red and bright, and is near the celestial pole. So one can know the pole and the time also. The water-clock being used first to ascertain the midnight, and this is marked on the wheel and ring. Moreover, this is where the celestial circumference ring's tour of the heavens starts. Every night it passes through the celestial circumference, and the degrees and fractions ends and starts. The instrument is simple but sophisticated, and its use is comprehensive and full of detail [...].

[13] The circumference is 365 1/4d, i.e., same as the length of the days in a year.

We can infer the design of the instrument from the above-cited Inscriptions, Fig. 2a shows a reconstruction comprised of components for observation and a dragon-column standing on a rectangular base. Figure 2b shows an enlarged observation part of the instrument. The outer adjustable celestial-equatorial ring which was graduated 365 1/4^{d} (d is Korean notation of the Chinese degree *tu*) is intended to be shifted 1^{d} anti-clockwise every 66 years to compensate for slow processional movements of the equinoxes, with the North Pole. For daytime use, the fixed sundial ring was employed with the alidade and oblique threads to constitute a sundial. The alidade was set to the shadow of a sighting-thread falling along the center-line of the alidade and the time was then shown by the position of the thread on the sundial's 100-marks ring. For night time-determinations, the alidade was set through the axial hole in the pivot, a sighting-thread was aligned with the star βU. mi. as shown in Fig. 2c and solar time was shown by the position of the thread on the inner ring. This is for allowing the cumulative difference between solar time and sidereal time, so the star-dial ring was shifted 1^{d} clockwise per day relative to the circumference ring. A relic of the Observational Instrument made in the17th year (1486) of Seongjong (r. 1470–1494) patterned to King Sejong's are collected at the King Sejong Memorial Hall, Seoul.[14] Rufus (1936) took a photo of its original instrument named as "Oblique Sundial and Moondial, Yi".[15]

Up to now some Chinese scholars hypothesized that the "Star-dial Time-determining Instrument" is comprised of a Star-dial and a Time- determining Instrument[16]. Bo (1997) stated that all these past conjectures were wrong and the Xing-gui ding shi-ui is the same as the Korean *Ilseong-jeongsi-ui* and *Xing-gui* is not a star-dial; *Xing* means star, *Gui* means the solar shadow.[17] *Xing-gui ding shi-ui* depicted in the Biography of Guo is as follows:

> The sky has its Red Way [i.e., the celestial equator]; a circle serves in its place. The two poles rise and sink below it, with graduations marking [positions]; thus he made a Star-dial time-determining Instrument (*hsing-kuei ting shih i*).[18]

The Sun-and-Star Time-Determining Instrument is derived directly from the mobile equatorial ring and associated components of Guo Shoujing's Simplified Instrument. Sejong's astronomers did not merely duplicate the old instruments but also extended and improved upon them.[19] Sejong also was inspired by the Islamic instruments "Time-determining Instrument for both day and night (*Urstrolabe*)" and "Star-dial Time-determining Instrument (*Xing-gui ding shi-ui*)" of Guo.

[14] Nam (1995), pp. 105–108.

[15] Rufus (1936), vol 26, plate 17, Fig. 33.

[16] Chen (1955), p. 133.

[17] Bo (1997), p. 21.

[18] Translation taken from Sivin (2009), p. 204.

[19] Needham et al. (1986) pp. 52–54.

2.2 Small Sun-and-Star Time Determining Instrument

Kim Don wrote in the Observatory Records, “The Sun-and-Star Time-Determining Instrument is heavy and inconvenient for military use, prompting the construction of the Small Sun-and-Star Time-Determining Instrument. The design was same as the larger model, with slight differences. For example, the pole-determining rings were omitted to light the instrument and facilitate use in the field”. This instrument was very similar to the full-sized version, but the Observatory Records did not detail the size and materials used. No other records on this instrument and no relics are extant. Needham et al. (1986) has studied this in detail by comparing it with a Chinese equatorial sundial with double-ended alidade and triangular-gnomon thread.[20]

2.3 Small Simplified Armilla

Jeong Cho’s Inscriptions on the Small Simplified Armilla says, “The best instruments are simplest. The old Simplified Instrument was bulky and ladder-like in its purlin and columns. New one has been made to be portable. So it is even simpler than the old Simplified Instrument”. This smaller instrument is made with a bronze column, and uses equatorial assemblies i.e., components of the equatorial ring, hundred-mark ring and mobile solar-declination ring, of the Simplified Armilla as both the equatorial and azimuthal assemblies. The mobile solar-declination ring and hundred-mark ring employed as the standing movable ring for observing altitude and Eum azimuth ring for reading azimuth which constitute the azimuthal assemblies. When the equatorial assemblies are held by a column in a slanting position parallel to the equatorial plane, the mobile declination ring is set along the polar axis. Thus, when the mobile declination ring is set straight upward on the column, the equatorial assemblies can be used for all positional measures. Several columns and supporters of the Simplified Instrument are omitted, and only one column supports equatorial assemblies. Two Small Simplified Armilla were made, one on the platform near the Royal Council Hall and the other on the Small Simplified Armilla platform (*So-ganui-dae*) in the Astro-calendric Office, which remained at the original location (See Fig. 4). Figure 3 shows the Small Simplified Armilla reconstructed by the KASI and Fig. 4 shows the relics of the Small Simplified Armilla platform on the later Astro-calendric Office (The name *Seoun-gwan* was changed to *Gwansang-gam* in 1466).

[20] Op. cit. pp. 60–63.

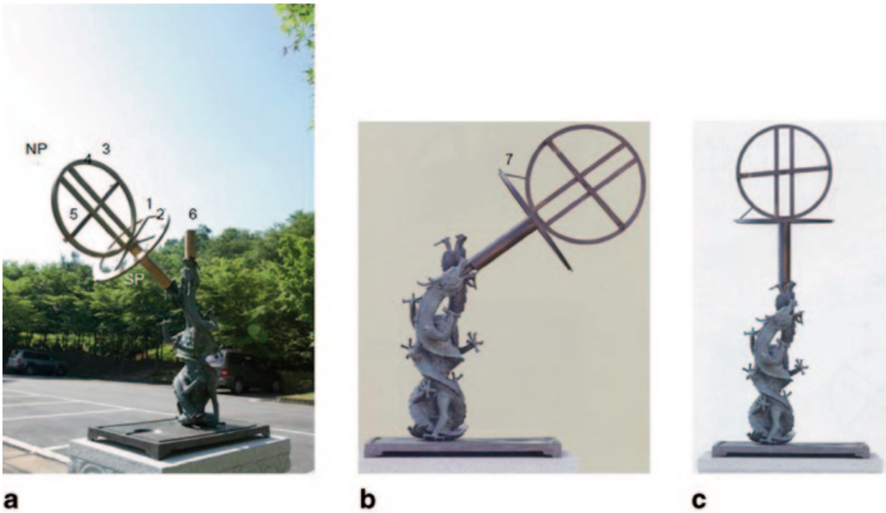


Fig. 3 The small simplified Armilla (reconstruction). **a** Components. *1*: equatorial ring graduated position of the stars and constellations north and south of the equator regard to 28 lunar mansions and celestial circumference degrees 365 1/4^{d}; *2*: hundred-mark ring graduated 12 double-hours and 100-mark; *3*: four displacement (mobile declination) ring can turn east and west and carries a sighting alidade; *4*: cross-struts; *5*: alidade can move north and south; *6*: center of the earth; *NP*: North Pole; *SP*: South Pole. **b** When the small simplified Armilla is used as the equatorial assemblies. **c** When the small simplified Armilla is used as the azimuthal assemblies. (Adapted from Kim et al. 2013, pp. 36, 38)

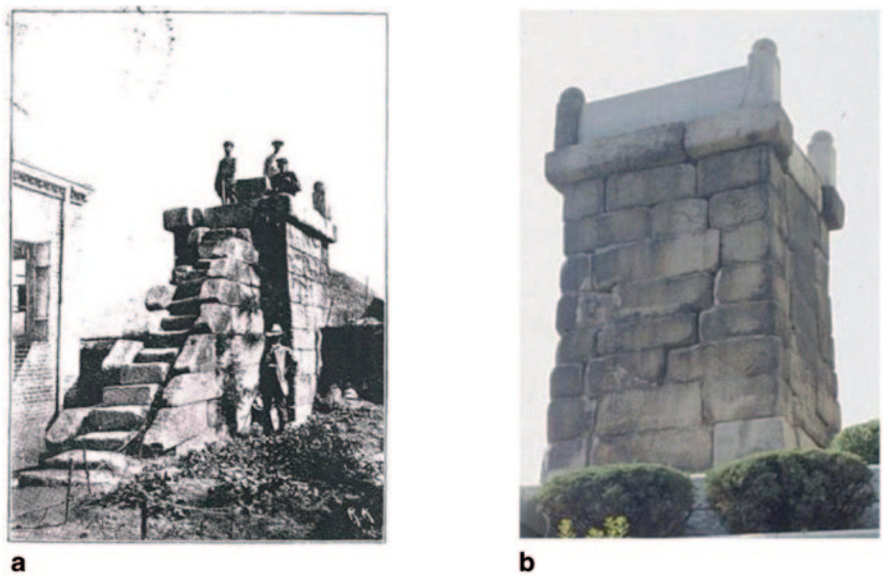


Fig. 4 Relics of the small simplified Armilla platform. **a** Photo of the relics around 1913. (From "A Short History of Astronomical Observation", *Daily Handbook*, Incheon Observatory of Joseon Government-General, 1913). **b** Relics of the small simplified Armilla platform on the premises of the later Astro-calendric Office. (Photo: Nam 1995)

2.4 The Striking Palace Clepsydra in the Announcing Clepsydra Pavilion

The Striking Palace Clepsydra (*Jagyeok-gung-nu*) was developed by Chief Royal Court Engineer Jang Yeong-sil under the guidance of Sejong in 1433, and it began to announce standard time in Hanyang from the first day of the seventh month of the 16th year (1434) of Sejong's reign. The account on the making of the Striking Palace Clepsydra was written by Kim Don and Kim Bin as the Records of the Announcing Clepsydra Pavilion. The text includes Memoirs by Kim Don, Inscriptions with Preface by Kim Bin. The new clepsydra was named after its housing as the Clock of the Announcing Clepsydra Pavilion (*Borugang-nu*) officially or "Palace Clepsydra" (*Geum-nu*) literally.

The uniqueness of the Striking Palace Clepsydra was its capability to announce dual-times automatically with visual and audible signals: 12 double-hours (1 double-hour, or *si*, corresponds to two of today's hours), and five night-watches and their points (each watch, *gyeong*, was divided into five *joem*, resulting in twenty-five time subdivisions per night from dusk to dawn. Each watch corresponds to about 2 h today.) Thus the clepsydra was used as a standard timekeeper to announce the time of the curfew alert *Injeong* ("people at rest") in the evening and the removal of curfew *Paru* ("quit the clepsydra") in the morning, and mid-day drum *Ogo* ("quit morning services") following the sunset and sunrise in the capital Hanyang. To change the clepsydra's indicating-rods corresponding to the length of the night-watches to the seasonal variations, *Manual on the Calculation and Usage of Clepsydra Indicator-rods* (*Nujutongui*) were compiled according to sunrise and sunset hours of Seoul in 1437. Eleven pairs of indicator-rods with Fortnightly Periods different graduations were used during a year.[21]

The story of the Striking Palace Clepsydra in the Observatory Records is very concise, so more expanded descriptions are cited from the Memoirs of Kim Don on the clepsydra as follows:

> The king worried about potential errors and mistakes made by the time-announcing officials, so he commissioned Chief Royal Court Engineer Jang Yeong-sil to make wooden immortal figures to announce the time automatically, without human involvement. The construction of the time-announcing machinery was preceded by building of the three-pillar-wide pavilion, and a two-story box was built in the space between the eastern pillars. The three wooden puppets were erected on the pedestal of the upper story as sounders, announcing double-hours by a bell, night-watches by a drum and the number of watch-points by a gong. Below the lower story was set up a horizontal wheel arraying a line of 12 double-hour figures around the circumference. Each figure was carried on thick iron rods that allowed it to pop up and down bearing a time-tablet to announce one of twelve double-hours in sequence.

According to Kim Don's Memoirs, the Striking Palace Clepsydra consisted of six modules (the labels M-x indicate the module number as shown in Fig. 5) as follows. M-1: An inflow-type water-clock system with a dual-time measuring and dual-time

[21] Details See Nam (2014).

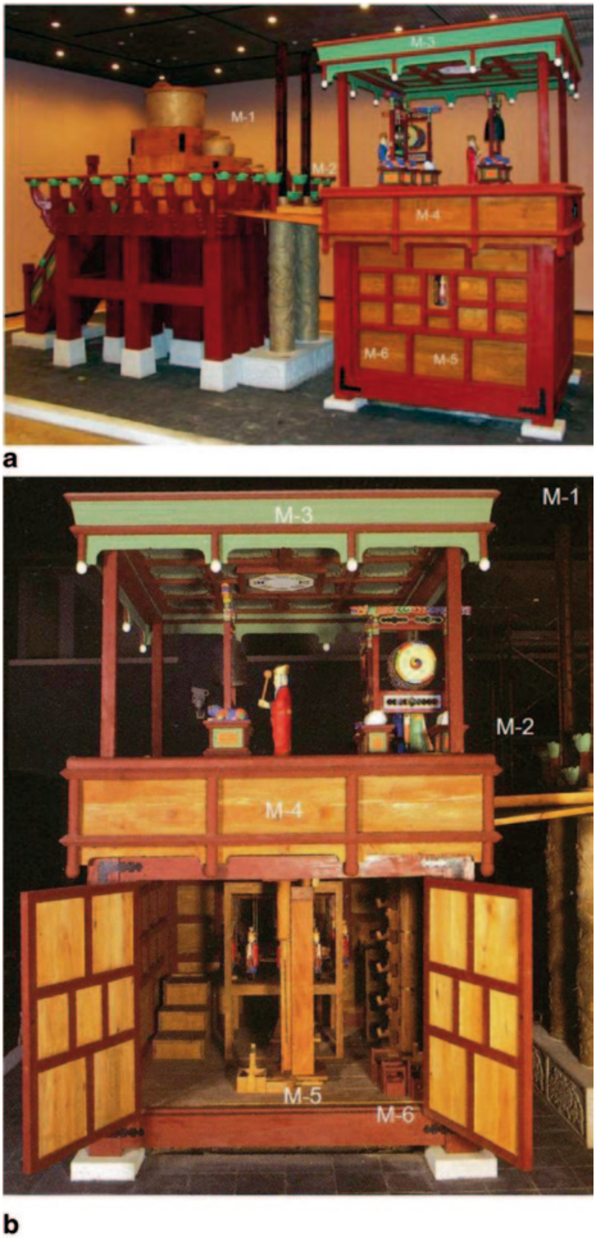


Fig. 5 The Striking Palace Clepsydra of King Sejong created in 1434, **a** South elevation, **b** Inside of the dual-time announcing system. (Rear view) The labels are same as in the text. Exhbition of the National Palace Museum of Korea, Seoul. (Photo courtesy of Nam MH)

small-ball releasing mechanisms to mark the beginning of each double-hours and each night-watch and their points; M-2: Transmission routes connecting the two systems M-1 and M-3 via dual-time small-ball receiving funnels and guides; M-3: A dual-time announcing system operated by dual-time large-balls at the beginning of each double-hour, and at each night-watch and their points.; M-4: A dual-time small-ball-to-large-ball converter; M-5: The double-hour machine; M-6: The night watch-point machine.[22]

To reinstate the Striking Palace Clepsydra, the Cultural Heritage Administration (CHA) of Korea launched a national project in 2004–2005 commemorating the scheduled opening of the new National Palace Museum of Korea supposed to be inaugurated in 2006. The construction of the replica was carried out from 2004–2005 under contract with Konkuk University, with which the author of this chapter (Moon-hyon Nam) has been affiliated. The reconstructed instruments worked well and announced dual-times exactly. It has launched daily operations starting in November 2007 for permanent exhibition as shown in Fig. 5.[23]

Ball-driven mechanisms enabled the time-announcing mechanisms to work discretely while securing effective energy transmission and accurate time-keeping through the reconstruction studies.[24] Importantly, the night watch-point announcements by pre-programmed float-rods enabled the Striking Palace Clepsydra to operate as a kind of programmable computer. This clepsydra operated on a closed-loop system whereby it continued to work as long as smaller balls were loaded into the small-ball-holders above the inflow-vessels and the rest into the large-ball-channels of the ball-rest-release mechanisms. As such it is similar to the Candle and the Elephant Clocks of Al-Jazari (1206).[25] As Needham et al. (1986) argued, the elaborate time-annunciating mechanism using ball-operated jack-works was inspired by Al-Jazari's 1206 clocks, which were not copied but instead were adapted to fit the Korean time-keeping tradition by the eminent mechanical engineer Jang Yeong-sil and his supporters.[26] The Striking Palace Clepsydra was a key machine in the history of clock-making, mechanism and machine science.

2.5 The Striking Heavenly Clepsydra in the Respectful Veneration Pavilion

The descriptions of the Striking Heavenly Clepsydra in the Observatory Records are very concise and provide an ample view of what the clepsydra looked like. In this instance, Kim Don introduced the makers of the clepsydra, which was not mentioned in the Observatory Records, in his memoirs as follows:

> Respectful Veneration Pavilion (*Heumgyeong-gak*) has been completed [on the seventh day of the first lunar moon of the twentieth year (1438) of Sejong's reign]. Daehogun Jang Yeong-sil installed it; however, its scales and exquisiteness of the systems resulted from the

[22] Nam (2012), pp. 91–94.

[23] National Palace Museum of Korea (2007).

[24] Nam et al. (2010).

[25] Nam (1995), pp 185–186; Al-Jazari (1206), pp 58–70; Romdhane and Zeghloul (2010), pp. 1–20.

[26] Needham et al. (1986), p. 42.

Fig. 6 Image of the Striking Heavenly Clepsydra. (South elevation). *1* model sun; *2* four jade female immortals; *3* four guardian gods; *4* hour-jacks and three warriors; *5* 12 Spirit Generals of the Zodiac; *6* Dragon double-hour immortal; *7* figure dressed as an official; *8* inclining vessel; *9* rural scenery sculpture. Numbers are same as that of the text. (Adapted from Nam 2012)

> king's wisdom. The pavilion is located at the vicinity of the royal council hall at the main palace [*Gyeongbok-gung*]. The king ordered Kim Don to write a memoir [...].

We can infer that Chief Royal Court Engineer Jang installed it and the main ideas came from the king who wanted to have a splendid heavenly clock capable of displaying a revolving model of the sun, time-announcing jackwork figures, rural scenes of four-seasons and an inclining-vessel. In this instance, we have descriptions of the making of the heavenly clepsydra in the Observatory Records. The entry is summarized as numbers in Fig. 6 as follows: A model sun (1) attached to a mechanism revolves the mountain, four jade female immortals (figures) (2) are erected on the multi-colored cloud, each facing in one of the four cardinal directions, and strikes a golden bell with a wooden mallet to announce the double-hours. At the same time, the Four Guardian Spirits (Eastern Blue Dragon, Southern Red Bird, Western White Tiger and Northern Black Snake) (3) face in the four cardinal directions. At the southern foot of the mountain are an hour-jack and three warriors (4) that announce the double-hours, night-watches and points with respective musical instruments similar to those devices of the Striking Palace Clepsydra. On the ground are the 12 Spirit Generals (figures) of the Zodiac (5), occupying their respective positions, and behind them are holes. At 5th double-hour, the Hour of the Dragon, the hole behind the Dragon opens, the immortal (6) with a time-tablet comes out, and the Dragon figure stands still. The process continues with other hours in succession. At the south of the mountain, an officially-dressed (Fig. 7) with a silver bottle pours water into an inclining vessel (8)[27]. Rural scenery sculpture (9)

[27] The vessel lies on its side when empty, stands upright when half full of water, and falls over again when full. This vessel was understood to serve as an instrument to remind of moral standard, i.e., "humility receives benefit, full brings upon loss".

cited from the *Ode of Bin* depicts peasants working around the mountain in the four seasons.

The uniqueness of the clepsydra was its capability to demonstrate celestial movements and to announce the 12 double-hours and five night-watches and their points automatically with various visual and audible signals. As its name implies, it was used in conjunction with edification rather than observation. It was reconstructed in 1554 and again in 1614 after the destruction by fire. The last version destroyed in 1656. It was maintained for 218 years, and the technical details might have been handed down and innovated upon to make subsequent armillary clocks from the seventeenth century onwards in Korea. Information related to making astronomical clocks made it possible to conjecture plausible technical features.[28]

2.6 Traveling Clepsydra

According to Kim Don's Observatory Records, it was small and simple in design and consisted of a water-delivering vessel, a water-receiving vessel and a siphon for water flow and changeover. The receiving vessel was changed between the Rat-double-hours (*Jasi*) and Horse-double-hours (*Osi*), or between Rabbit- (*Myosi*) and Rooster-double-hours (*Yusi*), i.e., they would run for only 6 double-hours at a time. It seems to be an inflow-type water-clock graduated 6 double-hours on the wall of the vessels or with a float and indicator-rod. A floating-siphon might be used for dripping the water to provide a constant flow, instead of an ordinary siphon as shown in Fig. 7.[29] Recently, Hua (2004) argued that the Traveling Clepsydra might come from Li Lan's steelyard clepsydra employed floating-siphons.[30]

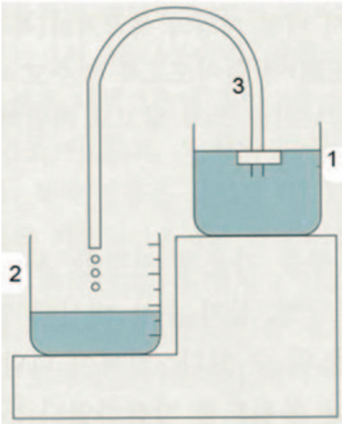


Fig. 7 Traveling Clepsydra (reconstruction drawing). *1* water-delivering vessel; *2* water-receiving vessel; *3* floating-siphon. (From Nam 2002, p. 72, Fig. 1–34)

[28] Hahn et al. (2000).

[29] E.g., Heron-type floating-siphon described in Mayr (1970).

[30] Hua (2004).

Guo Shou-jing made traveling clepsydra (*xing lou*) during the reign of Temur (r. 1294–1307) for the occasions when the emperor journeyed for the suburban and ancestral sacrifices.[31] The scholars working with Sejong might have been inspired from Guo's clepsydra and made similar ones for the royal journey for suburban royal tomb's and shrines. Several of those were sent to both military headquarters to support guard duties, and those kept at the Astro-calendric Office.

2.7 Scaphe Sundial

Kim Don described the sundial very briefly in his Observatory Records: "Ordinary people were ignorant about time-reckoning. Therefore two Scaphe Sundials were made, with the (12) double-hour Guardians of Zodiac—Rabbit, Dragon, Snake, Horse, Sheep, Monkey, Rooster, Dog, and others—drawn inside them, to enable the common people to tell the time. One was set up in front of the Benevolent Government Bridge and the other on the south street of the Royal Ancestral Shrine". Actually they were set up during the observatory project in the tenth lunar moon of the 16th year (1434) of Sejong's reign, and Kim Don wrote inscriptions on the sundial at that time. According to the inscriptions, it was made of bronze in the shape of a kettle. A circular gnomon was set up at the South Pole axis toward the North Pole, and graduated with a reticular scale—12 longitudinal hour-circle lines and 13 latitudinal solar-declination lines—inside the semi-circular scaphe.

Figure 8a shows a reconstruction of Sejong's sundial and the example of the relics from the seventeenth century onwards. It was assumed that this sundial used the equatorial coordinates, the celestial circumference 365. 25^d, the 12 double-hours with 100-mark system in a full day and the latitude of Hanyang 38 $1/6^d$ depending on the Great Concordance calendar (Datong-li). On the other hand, seventeenth century's revivals used the same coordinates, 360°, the 12 double-hours with 96-mark system and the latitude of Hanyang as 37° 39′ 15″, based on the Temporal Model calendar (*Shixian-li*) and latitude of Joseon capital. On the winter solstice, the shadow of the tip of the gnomon falls on the uppermost solar-declination line and on the lowermost line on the summer solstice. Following the movement of the sun, the shadow moves from the left to right, i.e., clockwise (CW), and it falls on the center-line at high-noon. One can tell the time of day by reading the hour-circle lines and the season in Fortnightly Periods by solar-declination lines. As shown in Fig. 8b Sejong made the sundial by transforming the armillary sphere and celestial globe by removing the upper part of the horizontal ring (lip), and held up the hemisphere by four dragon columns standing on the cross-water-grooves for orienting and leveling. On the lip was inscribed the locations corresponding to the 12 double-hours.

The Scaphe sundials were made of ceramic, marble, and ivory in various types and sizes until the end of the twentieth century and the royal court sent several

[31] Famous Servitor of the Yuan dynasty, Grand Astrologer Guo, p. 17b.

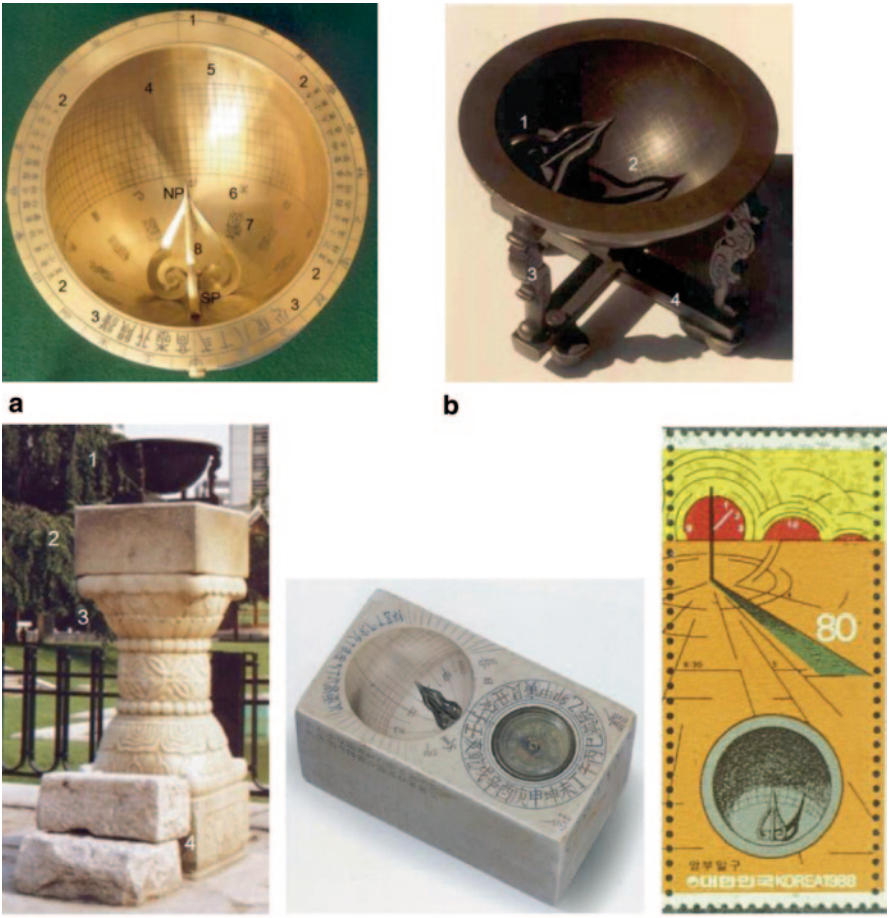


Fig. 8 **a** The Scaphe Sundial of the King Sejong following Kim Don's inscriptions on the *Angbu-ilgui* (a reconstruction): *1* the locations corresponding to the double-hours are inscribed on the lip; *2* names of the half of the Fortnightly Periods are inscribed from the winter solstice (*top*) to summer solstice (*bottom*) on the right side and from the summer solstice (*bottom*) to winter solstice (*top*) are on the other side; *3* latitude of Hanyang 38 1/4^{d}; *4* thirteen solar-declination lines; *5* twelve double-hour-circle lines; *6* names of the double-hours from Rabbit *myo* to Rooster *yu*; *7* double-hours guardian spirits inscribed; *8* burning flame-like gnomon set up at South Pole axis toward North Pole. (Reconstructed by Nam 1996 and donated to the Museum of the Konkuk University, Seoul). **b** Relics of the eighteenth century revivals of the Sejong's Scaphe Sundial *1*: gnomon; *2*: shadow of the gnomon; *3*: dragon columns; *4*: cross-water-groove for orienting and leveling on the stand. The diameter of the lip is about 35 cm and the radius of the hemisphere is about 30 cm. The characters and graduations are silver inlaid. (Collection of the National Palace Museum of Korea, Seoul). (Photo courtesy of Nam MH). **c** The Scaphe Sundial on the stand: *1*: Scaphe sundial; *2*: hexahedral stand; *3*: lotus and lotus leaves; *4*: sky-peach pattern. (Height: 136 cm) (Photo courtesy of Nam MH, *Deoksu-gung* palace, Seoul). **d** Portable Scaphe Sundial made of marble in 1908 by Kang Moon-su (After 1862). Collection of the Seoul Museum of History. The length 7.2 cm; height 3.1 cm; width 3.8 cm. (Photo courtesy of Nam MH). **e** A stamp with a Scaphe Sundial (*Angbu-ilgui*) was issued to commemorate '1988 Seoul Olympic Games by the Department of Post and Communication, Korea

marble-made portable ones to Qing's court as gifts similar to those shown in Fig. 8d[32]. Figure 8e shows a stamp with a Scaphe Sundial (Angbu-ilgui) that was issued to commemorate the 1988 Seoul Olympic Games by the Department of Post and Communication, Korea. Needham et al. (1986) said that it was innovative and a conspicuous tribute to the public-spirited beneficence of the ruler.[33]

2.8 Plummet Sundial

Kim Don wrote about the sundial in his Observatory Records and his words can be summarized as follows: A rectangular stand is 0.63 c (13.0 cm) long, a column set up in its northern part. There is a pool on the southern part, north of the column was engraved with a cross and suspend a weight by a plumb line from the top of the column, above it. In this instance, it was unnecessary to fill the water in the groove for leveling, because the sundial adjusted itself automatically. The (12 double-hours) with 100-marks were inscribed around a small disc with a diameter 0.32 c (7.0 cm); this had a protruding handle to fit into a dovetail slot positioned obliquely from the column. The hole in the disc had a thin thread through it that connected to the top of the column above, and to the southern part of the stand below. The thread casts a shadow on the disc, so the time was given by the locations of the shadow in the 12 double-hours with one hundred-marks graduations.

We can depict the general view of the sundial following the above-descriptions as follows: The column is placed near the north end of the base's centerline. The sundial was a portable; 13.0 cm long base and set up a 7.0 cm diameter disc, inscribed with 12 double-hours and 100 marks on both faces. The protruding handle of the disc was inserted into the dovetail slot on the base obliquely to fit to the equatorial plane of Hanyang 37.5° to the vertical. A thin thread was used to connect to the top of the column behind the slot and the small hole mimicking the South Pole in the southern edge of the base through a hole at the center of the disc at right angles, thus forming a pole-pointing thread-gnomon. In the base, there is a pool for a floating compass-needle for orientation. In this instance, a bronze sundial as shown in Fig. 9a was discovered at Buddhist temple (*Haein-sa*) where the *Tripitaka Koreana Goryeo Daejanggyeong-pan*[34] housed from the early fifteenth century. It was revealed that the sundial was the Sejong's.[35] Figure. 9b shows a reconstruction. It was a good case of the equatorial type instrument innovating from Guo Shoujing's Simplified Instrument and is acknowledged as the oldest thread-gnomon pole-pointing portable sundial known to exist.

[32] I ST (1986); Jeon (1998), pp. 72–73; Sivin (2009), p. 200.

[33] Needham et al. (1986).

[34] Goryeo Daejanggyeong-pan (80,000 Tripitaka Koreana woodblocks), acknowledged as the best and oldest intact version of Buddhist canon in Chinese script ever assembled. As such it has provided a very important contribution to the advancement of the Buddhist faith worldwide and was designated as a World Cultural Heritage by UNESCO in 1995.

[35] Nam (1995), pp. 108–113, figure-appendix 3–29.

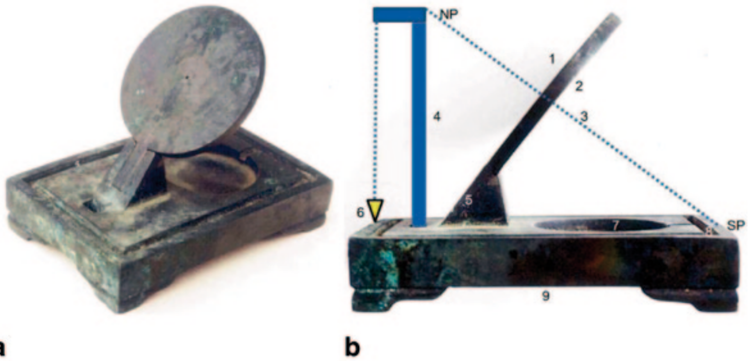
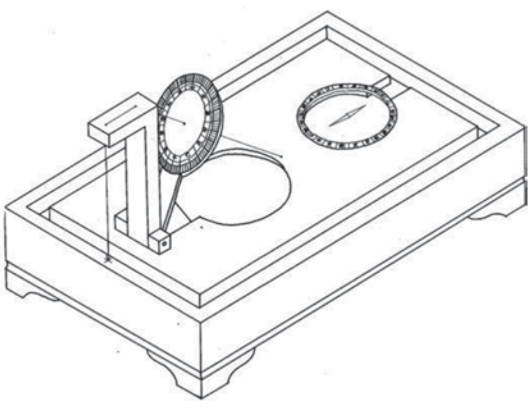


Fig. 9 Plummet Sundial. Collection of the Haein-sa Buddhist temple, Hapcheon, Gyeongnam Province, Korea. **a** Relics intact; a time-dial inscribed with 12 double-hours and 100-marks inserted into the dovetail slot, and a square hole *4* for the column (lost) on the north of the base. (Base 129.3 cm long, 8.3 cm wide, 2.5 cm high, water-groove for leveling and a pool for floating compass-needle for orientation). It seemed that Yejong's (r. 1469–69) Queen Ansun donated it to the temple for merit from the Buddha. (Photo courtesy of Nam MH). **b** The Plummet Sundial (a reconstruction). *1* time-dial (front face); *2* time-dial (back face); *3* thread; *4* column; *5* handle of the time-dial; *6* weight and the incised cross; *7* pool; *8* water-groove; *9* base; *NP*: Celestial North Pole; *SP*: Celestial South Pole. A threaded hole was pierced in the center of the time-dial and a thread stretched out to the north and south perpendicular to the dial. (Adapted from Nam 1995, p. 114)

2.9 Horizontal Sundial

This sundial was similar to the Plummet Sundial on its design in general, but it had a pool more to the north and a column set up to the center of the base. A thread ran from the south to the top of the column, holding up and pointing to the south. It was used to tell the time on horseback and for journeys. Figure 10 shows a conjectural reconstruction of the sundial, the two pools on the base; one in the south for floating compass-needle for orientation, and the other for folding the dial and the column when out of use.

Fig. 10 Horizontal Sundial (reconstruction drawing). (Perspective view) The dial and the column are folded into the pool below when out of use. (From Nam 1995, p. 115)



2.10 South-Determining Sundial

Kim Don wrote in his Observatory Records about the construction and the use of the South-determining Sundial. He said that traditionally one who wanted to examine the heavens to know the time used a compass certainly, but the South-determining Sundial could align the south-north axis automatically for determining south without a compass. The components of the Four Displacements ring [mobile ring] of an armillary sphere were transformed to make this instrument, passing the sighting-alidade that has a round hole on one side and a square aperture on the other side between the split rings of the mobile solar-declination ring. On the inside of the solid ring was carved a meridian line. The sighting-alidade reset according to the sun's north-polar distance of every day. And the rays of the sun formed a circle on the equatorial half-ring which was inscribed with day time 'marks' opposite the square aperture. Therefore, the sundial determines the south and tells the time naturally. This portable instrument might be used for fixing the south of various instruments equipped at the Royal Observatory. Figure 11 shows a reconstruction of the South-determining Sundial according to Kim Don's Observatory Records.

Fig. 11 South-determining Sundial (reconstruction drawing). *1*: Fixed Horizontal ring is graduated to indicate the 24 azimuth directions as well as the azimuths of sunrise and sunset during the 24 Fortnightly Periods. It was held up by the top of the 0.59 c (12.2 cm) high south column (hidden) and used for equalizing sunrise and sunset at the summer solstice; *2*: Four Displacements ring which received its pivots in the 0.11 c (2.2 cm) below the top of 1.1 c (22.7 cm) long north column and 0.038 c (0.7 cm) below the top of the south column. And it was graduated with the degrees of the celestial circumference, from North 16^d to 167^d there was a slot in the ring and engraved a meridian line on the inside of the rest; *3*: Cross-struts carrying a sighting-alidade; *4*: Alidade having a round hole one side and a square aperture the other side; *5*: Equatorial half-ring inscribed day time 'marks'; *6*: Square aperture for reading the 'marks' of the equatorial half-ring; *7*: Round pool 0.26 c (5.3 cm) in diameter having water-grooves reaching to the both ends and encircling the columns; *8*: Stand 1.25 c (25.8 cm) long, 0.4 c (8.2 cm) wide at both ends for a distance of 0.2 c (4.1 cm), and 0.1 c (2.0 cm) wide and 0.85 c (17.5 cm) long waist; *9*: Weight for leveling opposite to the cross below. *NP*: celestial North Pole; *SP*: South Pole; *S*: Solar rays. (Adapted from Nam 2002, p. 71)

3 Conclusion

The Neo-Confucian tenet of "Observing the Heaven and Granting the Seasons to the people" prompted the rulers to produce calendars for farming and the reckoning of the time of day. Objects of the astronomical project were initiated by King Sejong during 1432–1438 in Joseon dynasty, aiming to facilitate celestial observation and timekeeping equipment at the newly constructed palace observatory. Astronomical instruments and clocks of Chinese History Books and medieval Islamic science and technology inspired King Sejong's court scholars and engineers to construct the observatory and devise equipment. This equipment included two monumental timekeeping installations Striking Clepsydras, a compound of a sun- and star-dial mounting an equatorial-polar alignment and thread gnomons Sun-and-Star Time-determination Instrument and its smaller version, the celestial observation and/or time-keeping instrument Small Simplified Armilla, the sundials mounting an equatorial-polar alignment and/or all thread-gnomons Scaphe-, Plummet-, Horizontal-, and South-determining-sundials, a portable water-clock Traveling Clepsydra were created. In the course of the program, chief court engineer Jang Yeong-sil invented liquid-driven ball-falling and the ball-driven discrete motion-controlling mechanisms inspired by the medieval Islamic technology and employed these to make Striking Clepsydras. These clocks deserve to be called the first hydro-mechanically engineered dual-time clock in history of horology. Inventions and innovations in constructing the timekeeping installations and making of portable clocks at the palace observatory is attributed in large measure to King Sejong. His research and development (R&D) policies on equipping the observatory can be appraised as follows: state-supported R&D programs; portability and automation; practicality, adaptability and standardization. The Striking Clepsydras, the Sun-and-Star Time-determining Instrument and the Small Simplified Armilla have been evaluated as Korean originals in the world history of astronomical instrument and clocks.

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