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Acceptance and adaptation of octants and sextants in Japan during the eighteenth and nineteenth centuries

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Abstract
This paper[1] overviews the introduction, acceptance, and adaptation of octants and sextants in Japan during the eighteenth and nineteenth centuries. Octants first appear in the Japanese literature in the 1770s. In 1783 Motoki Ryoei, a well-known interpreter and scholar, first translated a Dutch book on octants by Cornelis Douwes. From that date, octants continued to attract wide interest from Japanese professional and amateur astronomers and land surveyors, and a considerable number of books on octants and sextants were published up to the 1860s. Around 1806, an octant was made for the first time in Japan. Owing to the strict seclusion policy adopted by the Tokugawa shogunate during the Edo period, the Japanese adapted octants as a convenient instrument for land surveying rather than for navigation, and even unique range finders were also invented as a modification. It was not until after the mid-1850s that octants were used for marine navigation.

Keywords: *Octants, sextants, Vernier scale, Japan, latitude, land-surveying*

1 INTRODUCTION

Japan is a geographically-isolated country, and as a terminal station of the Silk Road throughout its history was often under the strong cultural influence of foreign countries. Astronomy was no exception. For about a millennium from the sixth century, the influence came exclusively from China and Korea. Then, from the second half of the sixteenth century until the completion of Sakoku (the national seclusion policy) in the 1630s, which was intended to protect against invasion of Christianity, Western astronomical influences were introduced from Europe, mainly by the Portuguese. After the relaxation of import prohibitions that had been put in place in 1720 allowing the entry of foreign books unconnected with Christianity, modern Western astronomical knowledge in the form of books and instruments was introduced to Japan, starting with Chinese translations of Western books made by Jesuit missionaries and later through the strictly regulated trading channel of the Dutch East-India company (for the historical background of Japanese astronomy, see Nakayama, 1969).

Octants were typical of the Western astronomical instruments imported directly from Europe to Japan, without interposing by the Chinese, and were widely welcomed among the Japanese in the Edo era because of their novelty, portability, and high performance. The present paper describes how the Japanese understood the principle and functioning of octants and sextants, and accepted and modified them in a handicapped state of seclusion. We also briefly compare the situation of accepting octants in China with ours.

2 ORIGIN AND CHARACTERISTICS OF OCTANTS

Octants were a handy and accurate navigational apparatus that was used mainly on board ships to measure the elevation of celestial bodies. They were invented nearly simultaneously by Thomas Godfrey of the US in 1730 (Hindle, 1972) and John Hadley of Britain in 1731 (Hewson, 1951). At that time, the invention was referred to as a Hadley's quadrant or simply a quadrant. However, the name often caused confusion because of the much larger astronomical quadrants used earlier by such people as Tycho Brahe, so during the reign of Queen Victoria Captain Leckey and his contemporaries assigned it the name 'octant', rather than quadrant (ibid.). Before the introduction of octants, cross staffs, back staffs, and Davis quadrants had long been used for navigational reckoning (see Waters, 1958; Wynter and Turner, 1972).

For the purposes of later discussion, we shall briefly summarize the structure and measuring principle of an octant and its superiority over the previously-used instruments mentioned in the above paragraph. Figure 1 shows the conceptual structure of an octant, which basically consists of the sector-shaped frame IAA' with two mirrors attached vertically to the plane of the frame. One mirror H (half of which is transparent glass) is fixed to the frame, while another mirror can be rotated with the mobile bar IB around the axis I. Note that the two mirrors become parallel when the bar IB coincides with IA. On the arc AA' is inscribed a precise angular scale. In practical usage, the observer's eye E first views the sea horizon through the glass part of H along the line of sight EG, and by adjusting the position of IB, places the reflected image of the Sun, for example (in the direction of C) at the same position in H as that of the horizon. Then, according to a basic theorem of optics, twice the angle of the mirror I (α) is always equal to the deflected light-ray angle CIG', namely the elevation of the Sun (β). Hence, by doubling the scale of the angle inscribed on the arc AA', one can immediately read the elevation of the Sun on AA'. This is the principle of the octant.

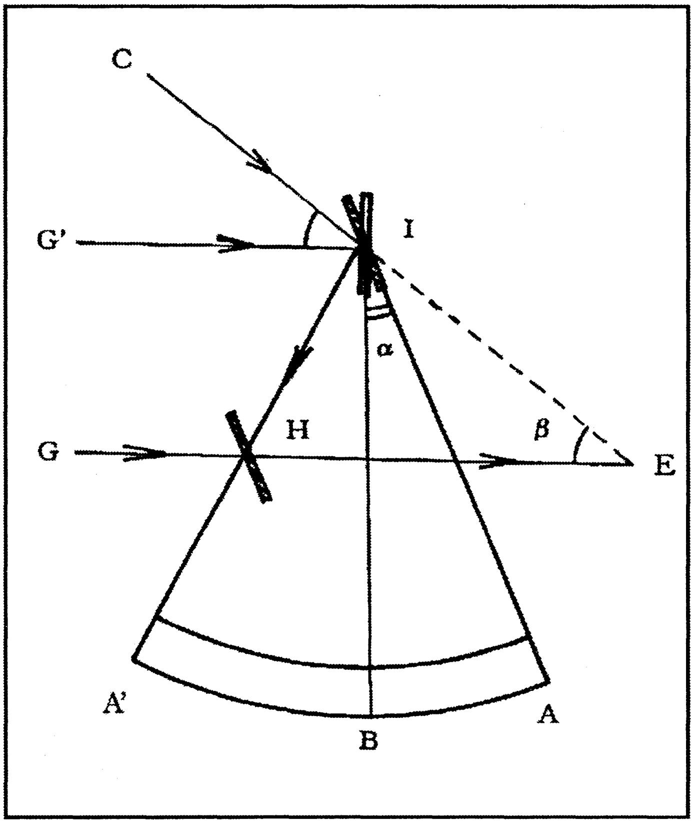

Figure1. Diagram showing the conceptual structure and functioning of an octant. Half of the mirror, H, is transparent glass in ordinary models. Note that $2\alpha = \beta$.

A typical octant could measure elevation with an accuracy of one minute of arc by using the Vernier subscale. For solar observations, sunglasses were usually inserted in the light path (IH and GH). It sometimes happened that the sea horizon was invisible due to clouds, and to accommodate such inconvenient situations improved models were produced which could aim at the opposite horizon by adding another sighting hole near the mirror H (back-sight type). However, these became unpopular in later times (e.g. see Wynter and Turner, 1972). The name 'octant' comes from the fact that the arc AA' is $^1/_8$ (i.e. 45°) of 360° so that this allows us to measure angles up to 90 degrees. Sextants, which were invented by Captain John Campbell in 1757 (Peterson, 1997), are characterized by $^1/_6$ of a full circle for the frame angle, and gave a better measuring accuracy (up to 10 arc seconds) through the introduction of a small telescope for sighting and sometimes also a magnifying lens for reading the scale.

The octant was much superior to previous instruments like back staffs and Davis quadrants in the following respects: 1) Owing to a simultaneous viewing of the horizon and the Sun at the mirror H, measurements made with an octant could allow for the movement of the ship. 2) In addition to the Sun, an octant could also be used to observe the Moon and stars at night. 3) Because the light-paths are folded by two mirrors and a diagonal or Vernier scale was adopted, the octant was light-weight and handy so that it could even be used in stormy conditions. Because of these reasons, octants had become popular among European and US officers and seamen by the middle of the eighteenth century, and this situation continued until the beginning of the nieteenth century (Hewson, 1951).

3 INTRODUCTION OF OCTANTS INTO JAPAN

Now let us see when and how octants were introduced to Japan. The earliest description of an octant appears in the travel essay, *Kizan Roku* (Coming to the Home Mountain),[2] written in 1778 by Miura Baien, the noted natural philosopher. To learn about Western natural sciences in this year he made a trip to Nagasaki where many interpreters lived (because of the presence there of the Dutch East-India company). In Nagasaki Miura saw an octant at the home of the senior interpreter, Yoshio Kogyu, who exhibited for visitors various scientific instruments imported from Europe, such as microscopes, thermometers, and armillary spheres. However, it does not seem that Yoshio knew how to use his octant, though Miura explained in one part of the essay that octants were an indispensable apparatus for Dutch trading ships if they were to sail safely to Nagasaki. Otsuki Nyoden (1926:83) also wrote that although a certain Daimyo (warlord) purchased an octant in the 1770s, "... it had only been stored in vain at the bottom of the stock box, since nobody knew its usage." This indicates that in 1770-1780 Japanese owned at least two octants, but they had neither spoken nor written information on how to use them; they did, however, recognize the important role of octants in marine navigation.

In 1749 a Dutchman, Cornelis Douwes, published a booklet on octants, and in 1783, the famous interpreter and scholar, Motoki Ryoei, and one of his collaborators provided a translation of this titled *Shogengi Yoho* (Usage of Quadrants).[3] Strangely enough, Shizuki Tadao, one of Motoki's alleged interpreter disciples, independently translated the same Dutch booklet in 1798, giving it the title *Hachiengi Ki* (On Octants). From the translations by Motoki and Shizuki it is clear that these Japanese learned nothing about the principle of the octant from the Dutch booklet, because it exclusively described measuring techniques and how to adjust the mirror setting. Moreover, in the Douwes booklet there is no mention at all of how to use the Vernier scale, which was included in a diagram of the octant in the Dutch booklet (Figure 2). This is probably because the Vernier scale was so commonly known in Europe that its use did not need to be explained. However, as will be mentioned later, this was to cause worry to the Japanese at the initial stage of their understanding of the octant.

Figures 2 and 3 respectively show drawings of octants from Douwes' booklet and Motoki's translation, and a comparison of the two figures indicates that at the time he made the translation Motoki actually saw a different model of octant from that described by Douwes. But one can also see that both of the octants depicted are of the back-sight type, since there is a sighting hole near the fixed mirror. For a long time, this type continued to affect the design of octants used in land-surveying in Japan.

Here we shall briefly describe the career of Cornelis Douwes and the role he played in the history of Japanese astronomy. The life and works of Douwes were extensively investigated by Crone (1941). Throughout his professional career, Douwes was a leading figure in navigational and maritime education as a teacher and principal at the Naval Academy of Netherlands, as well as a member of the Dutch Science Association. He published important books on dead reckoning using octants and seamen's tables, which were widely used even after his death (e.g. Freiesleben, 1978). Among them, the booklet on octants of 1749 was the first by Douwes, and this is considered to be an important work in the maritime history of Netherlands because it was the first guidebook of this kind written in Dutch (Davids, *c*.1985).

We notice that the Japanese of that time also owed much to Douwes for making available for the first time an "... advanced treatise on contemporary Western astronomy ..." (Bartholomew, 1989:17), namely *Astronomie*, which was written by J J F de Lalande (1771), the pre-eminent French astronomer of the eighteenth century. Through the Dutch translation of

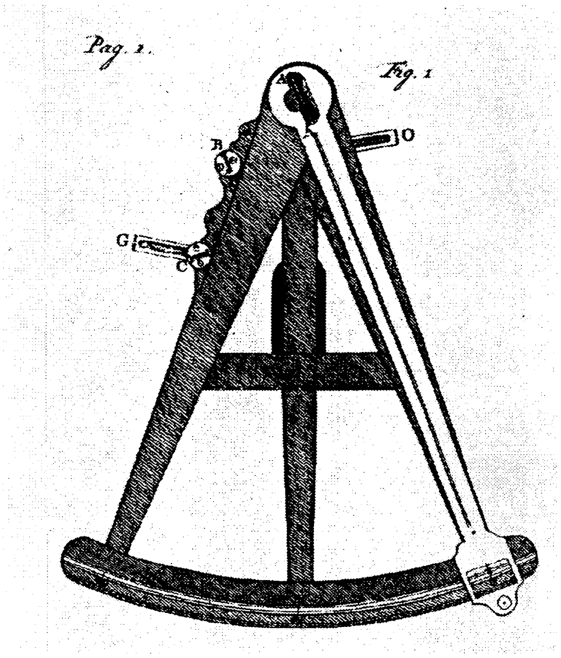

Figure 2. The drawing of an octant that appeared in the booklet *Beschryvinge van het Octant en Deszelfs Gebruik* by C. Douwes (1749).

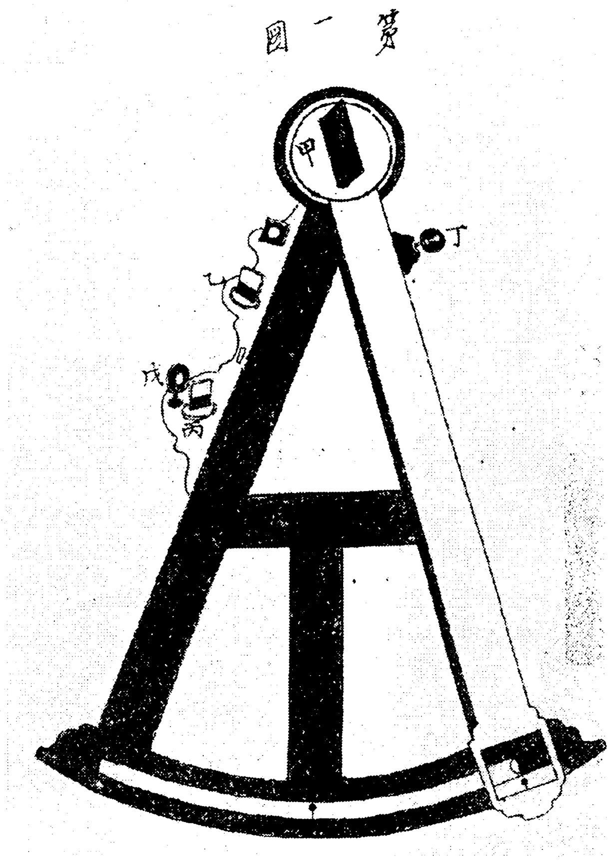

Figure 3. Drawing of an octant in *Shogengi Yoho Shogengi Yoho*,a translation of Douwes' book by Motoki Ryoei (1783).

Lalande's book (Strabbe, 1773), Japanese scholars were able to recognize the decisive superiority of Western astronomy when compared to traditional Japanese astronomy, which was of Chinese origin (Nakayama, 1969). Douwes was the organizer and supervisor of this translation enterprise (Zuidervaart, 1999); his status and career are proudly displayed on the cover page of the first volume of the Dutch edition. Therefore, we can say that Douwes made a significant contribution to Japanese society toward the end of the eighteenth century by introducing modern Western astronomy through two important books.

4 UNDERSTANDING AND MAKING OF OCTANTS IN JAPAN

Although Dutch interpreters at Nagasaki were the first to introduce new information on Western science to Japan, as represented by the Copernican system, they did not possess enough expertise in astronomy and mathematics to be able to understand the technical aspects of European scientific achievement. In Japan, the professionals in astronomy were the official astronomers of the Shogun's government. Since the establishment of the Shogunal astronomical office in the 1680s, their mandatory roles had been to devise calendars which could provide better predictions of celestial events such as the solar and lunar eclipses, a long-standing tradition of Chinese origin. Hence, they had little interest in and could not understand astronomy that was not directly connected to their purposes.

Nevertheless, they showed strong interest in the octant, probably because of the novelty and unknown principle for this instrument. In his reply letter of 1796 to the Shogunal astronomer Takahashi Yoshitoki,[4] Asada Goryu, a teacher of Takahashi, wrote: "I am grateful to hear that you could comprehend the octant that Hazama (Takahashi's colleague) acquired for you. I also feel wonderful that, with the marvellous machine allowing you to measure a very minute angle, you were too excited to sleep at night." (Arisaka, 1983:215). It is not clear from the letter itself whether Takahashi actually understood the principle and usage of the octant, including the Vernier scale. The reason for this doubt is that in a letter about a sextant that Takahashi wrote to Hazama in 1798 he confessed that he could not understand how the sextant works (Arisaka, 1983:272-273). This letter is important because it provides the first description of the sextant in Japan.

Honda Rimei, who was a mercantile economist and ran a private school for navigation and astronomy in Edo (Tokyo), wrote *Okudanto Yohoki* (Usage of Octants) around 1799. This book was a modified version of Motoki's translation, annotated with Honda's own navigational experience. What is important about this work is that Honda later attached to his original manuscript (preserved at Tohoku University) a slip of paper saying that "Since someone asked me how to use the Vernier scale of octants, I started thinking about it and I at last realized the principle." This note, which includes some numerical examples and provides the first clear evidence that the Japanese now understood the Vernier scale, must have been written between 1799 and 1809.

Various sources indicate that by the end of the first decade of the nineteenth century, the Shogunal astronomers and others had also mastered the principles and use of the octant and sextant, including the Vernier scale. As a result, they left many writings on octants and sextants. For instance, Takahashi Yoshitoki authored *Sekutanto Sokuho* (Usage of Sextants) in around 1800. *Okutanto Genri* (Principle of Octants) was written by Hazama Shigetomi in 1809, and was later augmented by Shibukawa Kagesuke in around 1851-1852,[5] the greatest Shogunal astronomer of the nineteenth century and the second son of Yoshitoki. This is one of the earliest books in Japan to treat the correct derivation of the relation $2\alpha = \beta$ (see Figure 1) and the basis of optics. In addition, some other astronomers from the Asada school also wrote on the octant.

There were instances where octants were used in the observation of comets. At the observatory of the Shogunal astronomical office it was common at that time for positional observations of celestial bodies to be made with a meridian wire-transit, a quadrant and an astronomical pendulum clock. But in the case of comets this technique often failed because they often appeared in the eastern or western twilight sky. Hazama Shigeyoshi, the son of Shigetomi, used an octant at Osaka to measure the altitude and angular distance from selected stars of two bright comets, C/1807 R1 (Great Comet) and C/1811 F1 (Flaugergues) (see Watanabe, 1943). Considering that in general comets are shapeless and have low surface brightness, they are most inappropriate targets for viewing with an octant, and so Shigeyoshi must have had a difficult time making the positional measurements. For altitude observations, he made use of the surface of mercury in a tray as the artificial water horizon; this technique is described in *Huyo Chihei Sokukodoho* (Method for measuring altitudes without using the sea horizon) by Takahashi Kageyasu (*c.* 1807-1808), the first son of Yoshitoki, which was presented in the appendix of *Okutanto Genri*. Shigeyoshi performed various experiments with water, mercury, and some heavy oils, in a search for a surface that was unaffected by wind or vibration (Watanabe, 1943).

Octants and sextants acquired considerable popularity among dilettante intellectuals as well. Curiosity led some rich Osaka merchants who were patrons of Western learning to purchase octants, even though they were very highly priced. By the beginning of the nineteenth century, there was already a kind of network in place in Edo and Osaka for the exchange of the information on octants and related matters. Shiba Kokan, who was at the central hub of the network, was a talented painter in the Western style as well as an eager supporter of the Copernican system, though his understanding was sometimes insufficient or even wrong. Through communication with people belonging to the network, professional or non-professional, he became more and more interested in Western astronomy and published some enlightenment books on astronomy and sciences. In one of those books, *Kopperu Tenmon Zukai* (Illustrated Book on Copernican Astronomy) published in 1808, Shiba maintained that octants had never been made in Japan, and this statement should be seen as reliable given his numerous contacts with people in Edo who were interested in Western science.

So who was the first to produce an octant in Japan? It has been claimed in the literature (Ogawa Kendo, 1814) that the first octant was made in 1813 by Takamori Kanko, who served a local Daimyo as his official astronomer.[6] In 1999, however, we discovered that Kume Michikata, a low-ranking vassal of a warlord in the Shikoku island, produced an octant prior to 1806 (at least seven years before Takamori), and that this instrument still exists (see Figure 4).

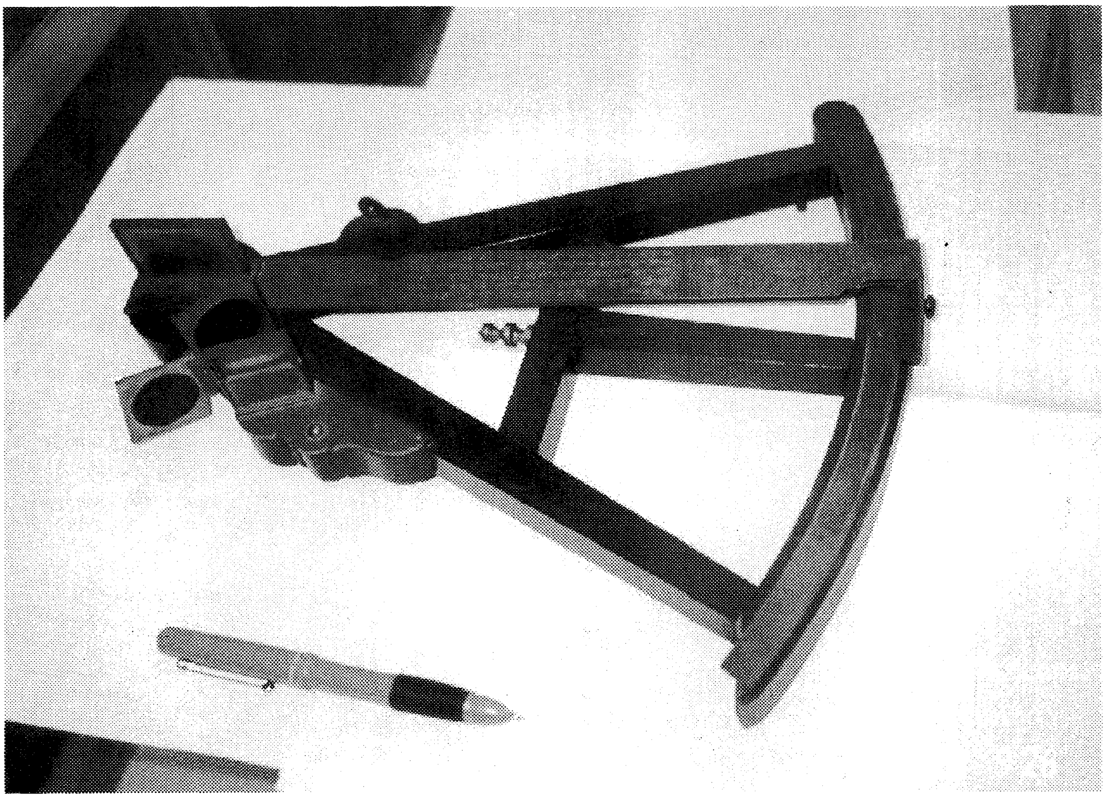

Figure4. Octant produced by Kume Michikata prior to 1806. The frame is made of hard wood, and the mobile bar and the scale-inscribed arc are of brass. The octant is equipped with two red sun-glasses of different density. The vernier is simply L-shaped and is more similar to those found on modern calipers than on traditional European octants. The minimum reading is one arc minute. (Photograph courtesy Kamada Corporation Museum).

Although it is certain that he made it by imitating an imported octant that Hazama then possessed, part of the Vernier on Kume's octant has a unique construction and is quite different from that found on European models (see Nakamura *et al*, 2000). Prior to World War II Kume had been well known as an ingenious inventor of various firearms and artillery and as the developer of the modern salt farm on Shikoku. For about four years starting from age 19, he also learned practical astronomy from Hazama Shigetomi in Osaka, and after returning home to rural Shikoku he began manufacturing telescopes, clocks, and land surveying instruments, despite his geographical and intellectual isolation.

In 1806, Kume was ordered by his Daimyo lord to construct a precision map covering the whole area that the warlord ruled over. For this purpose, Kume manufactured a Chiheigi (azimuthal circle) and a Shogengi (quadrant), and he then carried out a land survey of the region. It is interesting that he decided to adopt the Vernier scale for the two instruments since other astronomical and land surveying instruments that were in use in Japan at this time were all equipped with pre-modern diagonal scales. Considering that the Verniers on Kume's octant, Chiheigi, and Shogengi all had different spacings between the main scale and the sub-scale, and with measuring accuracies of between 1 and 2.5 arcminutes, it is obvious that he knew how to design and manufacture Vernier scales, even though he has left no written records about this. It is also apparent that Kume, like Honda Rimei, was one of the first Japanese to understand the principle of the Vernier scale.

5 ACCEPTANCE AND MODIFICATION

As the Sakoku policy had strictly prohibited people from going abroad or constructing large ships for oceanic navigation, the Japanese had no chance to use octants for their original purpose. However, octants provided measurements not only of altitudes above the horizon but also of angular distances between two targets. Under the restrictions placed by the Sakoku, the Japanese called attention to this latter function of the octant; this has already been suggested in the sentences inscribed on the mobile bar of Kume's octant (Figure 4). Murata Sajuro used to be an assistant at the Shogunal astronomical observatory, and in the preface of his book *Rokubungi Ryochi Tebikiso* (Handbook of Land-surveying with Sextants) published in 1852 he testified that his grandfather began using octants and sextants for land surveying in 1822-1823. It seems that Murata's grandfather developed a method of using a sextant to measure the distance of a battleship at sea for cannon shots from the ground, which he probably learnt from an imported Dutch book on naval gunnery.

Increased need for gunnery and land surveying in Japan at this time was motivated by growing pressure from foreign powers such as Russia and Britain for Japan to abandon its seclusion policy. As a result, many books on land surveying were published toward the 1850s. When an octant (or a sextant) was used for land surveying, the problem that worried the Japanese was the parallax inherent to these instruments. In measuring angles subtended by two target points at short distances an octant did not give correct readings, due to the parallax caused by the two mirrors being separated by 6-10 cm, which was the typical spacing in standard models. With instruments like the theodolite, which can measure azimuth and elevation angles independently, no such problem exists.

One way to avoid the parallactic problem of an octant was to prepare a table listing the corrections to be added to the measured angles. In fact, some books that dealt with land surveying using the octant were equipped with such a table as a function of distance. Another way of coping with the parallax problem was to modify the design of the octant, and Figure 5 shows an octant that was specifically intended for land surveying (after Murata, 1852). This octant has a lever on the back side of the frame so that the tilt of the fixed mirror (H in Figure 1) can be adjusted slightly to compensate for the parallax error.

Such sextants or octants have been described by Murata, and although no surviving examples have been discovered as yet their former existence seems assured because one of these octants is shown in an advertisement prepared by Osumi Genkichi (Figure 6), who produced various scientific and mathematical instruments in Edo from about the 1840s and ran a glass production factory after Japan opened the gate to the world with the Meiji restoration (1868). Although octants and sextants were featured in books on land surveying, it is doubtful that these instruments were as widely used as theodolites. After all, land-surveying carried out with an octant always required some trigonometric calculations, troublesome work for people at the time, and in drawing maps it was much easier to use the plane-table and a theodolite-like instrument.

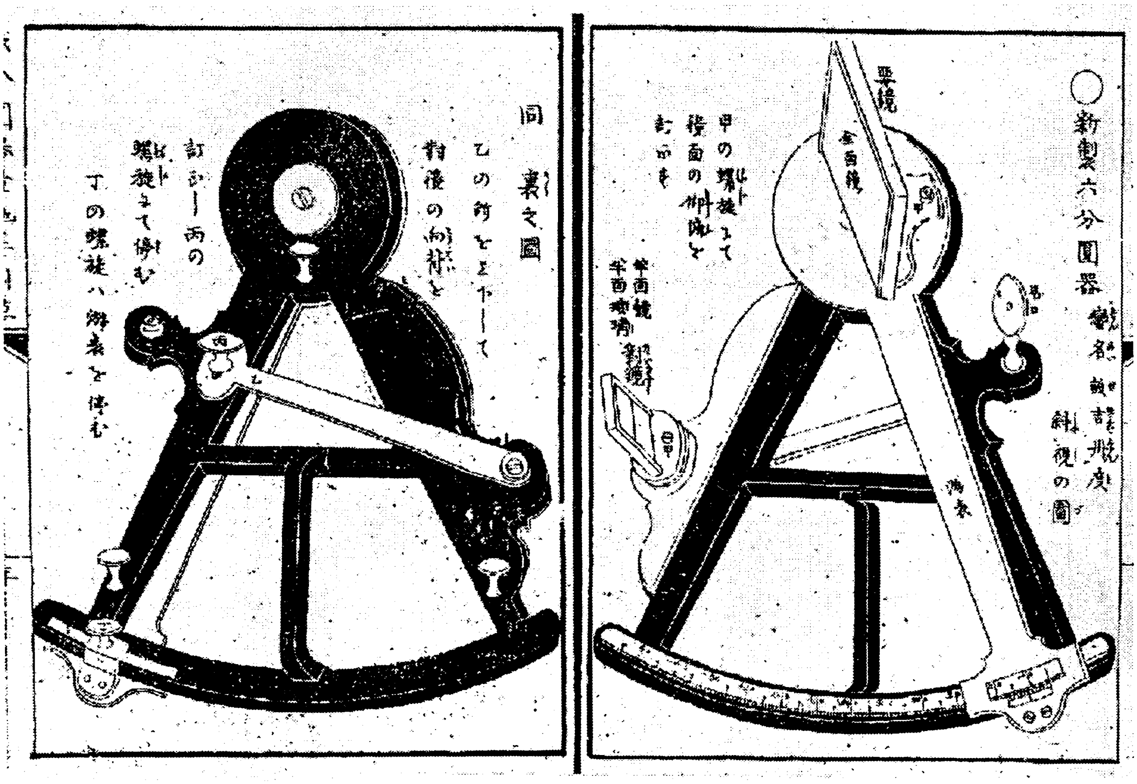

Figure 5. Diagram of a sextant designed for land-surveying (after Murata Sajuro, 1852). Front and back views are shown. The absence of sun-glasses and an adjustable lever on the rear side clearly indicate that this was intended for land surveying only, and not for observing the Sun. The height of this sextant is about 18 cm.

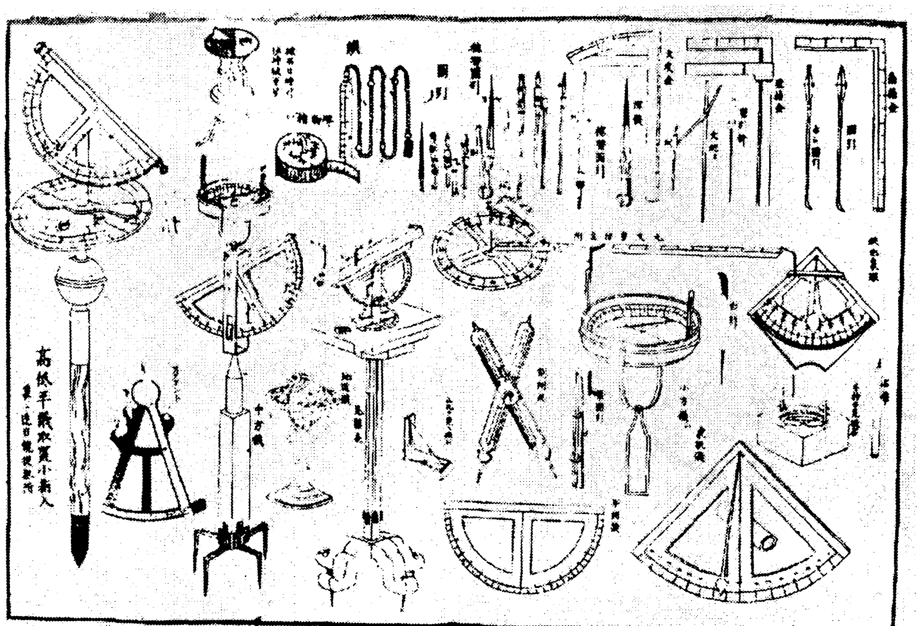

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Figure 6. An octant is included in this advertisement prepared in the 1850s by Osumi Genkichi. (Courtesy Koju-kai bunko Library).

One unusual aspect seen in Japanese books on octant-based land surveying written in the 1840s to 1860s, with a few exceptions (including the book by Murata), is that these books also explain how to use octants of the back-sight type. But as already indicated in Section 2, back-sighting was a totally unnecessary function if an octant was to be used for land surveying. In his book *Shogengi Yoho*, Motoko Ryoei (1783) clearly explained the introduction of back-sighting in a maritime context, and it seems that the conceptual structure of the octant shown in this book continued to influence authors of land surveying books in later times, even though back-sighting was no longer relevant.

Although the parallactic problem pertinent to octants was a nuisance for practitioners of land-surveying, some bright people made use of the parallax to measure distances. In his book *Rokubungi Ryochi Tebikiso*, Murata (1852) introduced a range finder called *Shakaku kangi*, and this is illustrated here in Figure 7. The structure looks fairly similar to those used on modern battleships. The book says that a standard model of this instrument had a separation of 1.8 m (baseline) between two mirrors with a small telescope at the sighting hole, and even the ones with baselines of 3.6 m and 5.4 m were also constructed. The measuring accuracy was 30 arc seconds with the scaled arc of 3.5 degrees, allowing us to measure angles up to 7 degrees. The book included a table for converting measured angles to distances, and the maximum distance in the table was about 1100 m. From Figure 7, it is apparent that this range finder was mainly used for military purposes to determine the distance of a ship at sea. It is not yet clear whether *Shakaku kangi* was a Japanese invention or an adaptation of an European model; Murata simply mentioned that this instrument was newly-produced at the time.

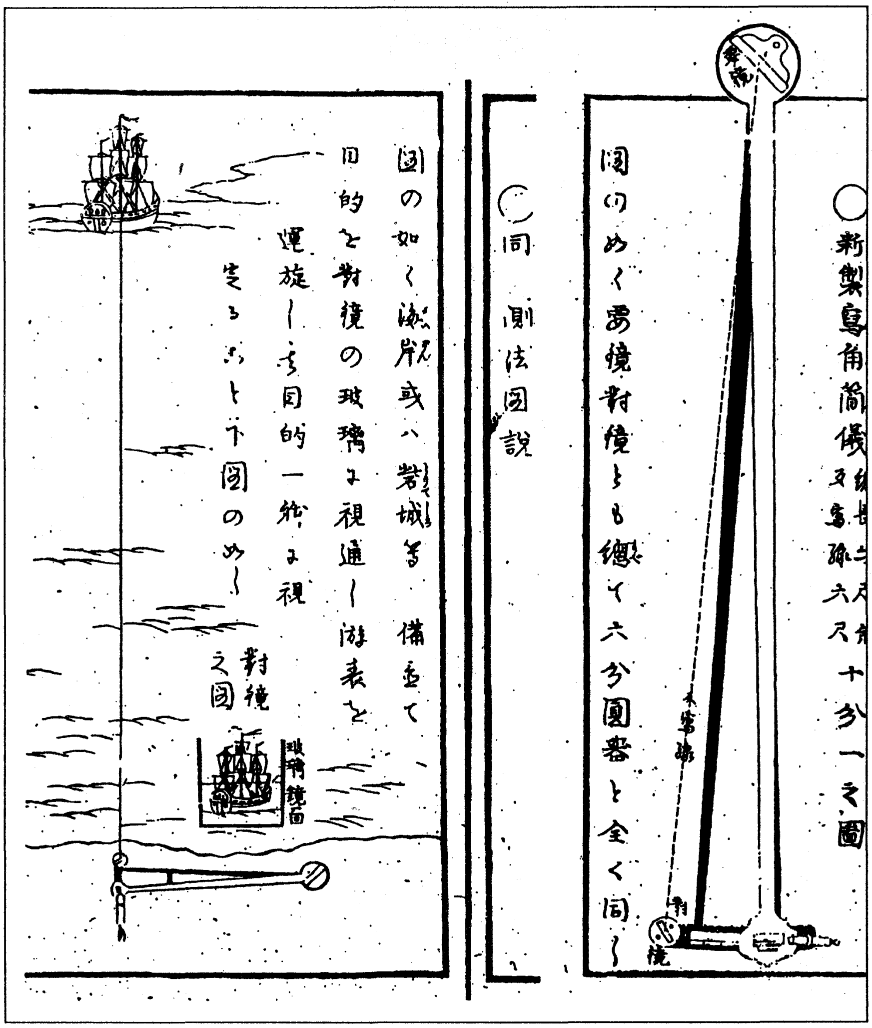

Figure 7. Drawing of a *Shakaku Kangi*, or range finder (after Murata, 1852).

In 1860, the Shogunal government sent a delegation to the United States for the first time as a prelude to opening the country to foreign influences and joining the international community. The frigate *Kanrin-maru* of only 300 tons and with a Japanese crew crossed the Pacific Ocean to San Francisco, and octants and sextants were used for the first time during this voyage (although maritime education had started three years earlier at the Naval Training School, which was established by the Shogunal government). Then from 1872 the first Japanese textbook about navigational techniques, including the use of the sextant, was published. This nine volume work, titled *Kokai Kyojusho* (Naval Ministry of Japan, 1872), was prepared for students at the Meiji government's Naval Academy.

6 CONCLUDING REMARKS

From the above discussion, one may understand how the Japanese responded to novel navigational instruments imported from Europe. The introduction of octants into Japan could be regarded as an appropriate case study of east-west cultural transfer, seen through a channel of astronomy. Hence, it may be worthwhile to compare the case in China, for instance, with ours.

Wan (2000) recently wrote a paper on the introduction of octants into China, where the first possible description of an octant is suggested by the term *Liangtian-chi* (instrument to measure the heaven), which appeared in the book *Haidao yizhi* (Sea-Island Unofficial History) published in 1806. Wan is not certain that this actually refers to an octant, but it is likely that imported octants would have attracted Chinese attention early in the nineteenth century. In 1843, Ding Gongchen published the book *Yanpao Ttushuo Jiyao*, (Illustrated Summary of Gunnery), where he explained the principle and use of the octant for the first time in China. One of Ding's contemporaries, Zheng Fuguang also wrote the book *Jingjing Lingchi* (Questions on Mirrors) in 1847, saying that "For 20 years since I got an octant, I had been thinking about how to use it. But I at last understood it by looking at an illustration shown in Ding's book." This indicates that the Chinese started to master octants during the 1840s.

Therefore, one can see that although there was a time lag of about four decades between Japan and China, scholars in both the nations were initially challenged by the appearance of this unknown European instrument. But eventually they managed to understand the principles involved and to use octants for marine navigation and for land-surveying.[7]

7 ACKNOWLEDGEMENTS

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8 NOTES

1 This paper is based on a paper written in Japanese by Nakamura in 2001 (see references). In the text, the Japanese and Chinese names were expressed in order of family and given names.

2 *Kizan Roku*, Volume 1, p.753, in *Collected Works of Miura Baien*, reprint version from Nippon Tosho Center (1979).

3 Shogengi literally means a quadrant in the Chinese terminology. Motoki used the word in his translation probably because the original Dutch book bore a drawing of an octant (Figure 2) in which the scale up to 90 degrees was inscribed on its arc. It is noted that the subtitle of *Shogengi yoho* (MS.) is *Okutanto* (octant) *yoho*.

4 Asada Goryu (1734-1799), after abandoning the position as a medical vassal of a certain Daimyo, fled to Osaka and opened a private school for medicine and astronomy in 1772, and started studying Western astronomy through Chinese translations. His excellent students such as Takahashi Yoshitoki and Hazama Shigetomi later became Shogunal astronomers, and the people from the Asada school played a leading role in nineteenth-century Japanese astronomy (Arisaka, 1968).

5 The augmentation by Shibukawa Kagesuke was probably made sometime after 1850, because he mentions in the preface of *Okutanto Genri* that for detail of the optics readers should refer to the Dutch book by Jacob Swart (1850).

6 Ogawa Kendo, who documented Takamori's octant, was the medical doctor of a Shogunal clinic. In 1998 we located one of Takamori's descendant in Tokyo, and he reported that in his childhood he actually used to see the octant in the warehouse, but it was destroyed by a US bombardment during World War II.

7 In Japan, writings and researches on astronomy, land surveying, and mathematics in particular were much less distributed as printed matter than in China and the West, but mainly communicated in the form of hand-copying. One reason for this inefficiency was that factionalism in each discipline kept its achievements secret from other factions. In addition, the market for such publications was small and premature.

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Note: in the following references, (J) and (C) indicate books and texts that were written in Japanese and Chinese respectively.

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