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Using maritime simulation systems to present complex information in maritime museums

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Abstract

The paper presents the stages of creation of an autonomous historical navigational system simulator working both in real and accelerated time. The simulator allows performance of navigation tasks from the time of the ancient Vikings, as well as to fix a position by using the Decca system on a real Mk21 receiver recreated to cooperate with the artificial Decca system model. The Viking solar compass discovered on Wolin Island in 2013 was the trigger for creating such a simulator as part of a broader exhibition of navigational systems and tools. The main intention of the exhibition is to demonstrate the hyperbolic navigation application that links both systems.

Introduction

The National Museum of Szczecin, the Maritime University of Szczecin, and Autocomp Management Company jointly created an exhibition titled "From the solar compass to the Decca System – a History of Hyperbolae in Navigation," which was opened to the public in 2014. The main part of this exhibition is the solar compass and Decca Systems 3D Interactive Simulator, the output of a project financed by the Polish Ministry of Sciences and Higher Education.

The exhibition is a unique combination of several historical artifacts (mostly navigation systems receivers, solar compasses, etc. and the interactive navigation simulator). The navigation simulator comprises demonstrations of two different navigational systems historically separated by over a thousand years. The first is an interactive simulator of a Viking solar compass, which used the sun to determine directions. The original of a solar compass was discovered by the archeological team of Prof W. Filipowiak on Wolin Island (Poland) in 2000. This is a wooden disk from the 11^{th} century, interpreted by contemporary researchers to be solar compass (made available for the exhibition by the National Museum of Szczecin). The second part is the Decca Navigator, a now defunct navigational positioning system (the first hyperbolic land-based navigation system, developed shortly after World War II).

The original concept of the project was to present completely different systems in a uniform environment, an idea carefully chosen, joining completely different systems which were at one time milestones in navigation, and perhaps most important, both of which used hyperbolae as a reference line. Hyperbolic navigation is time based, using lines drawn up to reflect variable positions in time increments.

The solar compass also utilized the hyperbola concept. Although Vikings never knew what hyperbolae were, they of course understood relative positioning, which they could determine in terms of longitude. Actually, knowledge of hyperbolic formulae is not necessary with the Decca system either. Instead, the navigator needs to understand the procedure of graphical position fixing on a navigational chart with Decca lattices.

Historical context as trigger to simulator creation

During the creation of the new concept of a maritime museum cum science center in Szczecin, two distinct contemporary concepts of such installations were used:

1. Classically presented ancient artifacts;
2. Simulation and multimedia interactive tools available for use by spectators interested in “learning by doing”.

The latter approach provides a unique opportunity to immerse spectators in a virtual world quite like the actual historical world in question, and in this case even to practice navigation as was done at that time. The discovery of the Wolin disk was the trigger for the execution of this project, which expands the possibilities of museums using available technology and historic knowledge.

The Vikings’ solar compass

In the earliest times before deep sea voyages, navigation was based on terrestrial observations – most commonly vessels engaged in coasting. Voyages were short, conducted during daylight in sight of land. In the case of the Vikings, this meant that what is often referred to as the *Viking menace* was limited to gradual steps – that eventually led them as far as the Mediterranean, it is true, but impeded their progress and established parameters to their history that did not contain them for very long.

We know that the Vikings reached Greenland, which they colonized, and what is now the Canadian coast of North America, before the magnetic compass was developed; this had to have been done by sailing long distance via latitudinal navigation (Bernáth, et al., 2013; Jones, 1968) using wooden compass dials probably equipped with two gnomons and used to determine local noon and later on the latitude of the navigator. Knowing their latitude would have enabled the navigators to stay on course on their many east-west voyages between Greenland and Norway. It is of circumstantial interest that these hearty and fearless travelers seemed not to have sailed far from their native latitude except where coastal navigation was long established and readily possible.

Figure 1. The wooden dial dated to the 11th century found on the Island of Wolin from the Polish Institute of Archeology and Ethnography, interpreted to be a Viking solar compass. The straight line could represent the gnomonic curve of vernal equinox. The gap at the lower right rim could represent south

It has been proven in several trials and sea tests that the solar compasses was able to achieve three degrees of heading accuracy (Cowham, 2007).

The latest studies go father and show that it was possible that Viking navigators also used so-called sunstones (Icelandic calcite) in combination with a wooden dial. This enabled them to extend the navigation period by enabling sailing on cloudy days and during twilight, therefore making navigation possible during the summer nights at high latitudes. The use of sunstones by Vikings was just speculation until researchers found a unique calcite crystal in the wreck of an Elizabethan ship sunk off the coast of the Channel Islands in 2013.

The discovery of the wooden solar compass dial by the team of Prof. Filipowiak in Wolin (Poland) was another great step towards discovering how ancient navigation evolved. The Polish disk is now in the Museum at Wolin, Poland; it has been dated to the first half of the 11th century. Unlike the Uunartoq disk, the Wolin dial appears to be divided into 24 sections rather than 32. On its surface there are several lines, thought to be declination lines and a straight line representing the equinox (Figure 1).

Decca system

An important further stage in the development of navigation systems was stimulated by radio (the era of radio navigational systems). The reason was the major barrier of astronavigation in dynamically developed aviation where those methods were difficult to apply and the low accuracy of astronomical methods were too imprecise for marine navigation. The system of radio beacons appeared in the 1930s and, combined with reliable gyrocompasses, enabled the navigator to establish position and direction by the use of as few as two bearings.

The Decca Navigator (DNS) navigation system operating between 1947 and 2001 was a significant milestone in navigation. Before that, one's position had been determined on the basis of astronavigation techniques – by means of a sextant and chronometer, the accuracy of which had not surpassed a few nautical miles. Decca was a breakthrough at least on a par with contemporary GPS. Since that moment, with positioning accuracy up to a few dozen meters, flight and shipping have entirely changed.

The DNS is a hyperbolic radio navigation system which was established in the United Kingdom after World War II and later used in many areas around the world. The first application of Decca was during the D-Day Invasion of Normandy. Decca operates by measuring the phase differences between continuous signals from Master and Slave stations. These differences represent the differences in distance and thus relate to hyperbolic lines printed on a Decca chart. By plotting the readings from more than two pairs of hyperbolas at any particular instant, users can plot position. The system used groups of stations consisting of at least three shore based transmitter stations called chains. The combination of Master-Slave in a given chain was distinguished by the colors used (red, green and purple) to discriminate position lines in so-called "deccometers" and in the special Decca chart with displayed hyperbolas. Chains were marked with capital letters and numbers (for example 6C – North Scottish). Decca was operated in the 70–130 kHz radio band. Each chain comprised of one Master and two or three Slave stations, usually located 80 to 110 km from the Master station. The accuracy of DNS ranged from 50 meters during daytime to 200 meters at night.

Museological valorization of new technology to enhance the presentation of nautical heritage; international cooperation

All maritime museums, regardless of where they are located, have as their essential goals to collect, protect, and present to their visitors in the best possible way various material objects of maritime tradition and therefore nautical history. Museum displays vary from the static and self-explanatory to the complex that require explanation.

In the context of this paper, the musicological goal is to offer the visitor that entire range, from the Viking navigational disk as something to appreciate as a simple artifact from the past to marvel at, to a means of understanding the true value of the disk to those who actually used it. In other words, the museum offers the visitors a range of opportunities from merely observing its historic significance to participating, through simulation, in that history.

From the point of view of the museologist, who has been up against such impossible tasks as explaining how to use a sextant in fifteen minutes to students who have no navigational knowledge, the notion of intelligent simulation, which by nature demands user/visitor involvement, as an aspect of presentation within the museum is a breakthrough that will expand the possibilities of museoloical instruction immediately and in multiple unpredictable ways in the near future. This is evident in that this project accomplishes a very complicated goal, typically limited to aficionados/experts, since visitors will have the opportunity to comprehend the similarities between navigational techniques roughly a millennium apart in time.

The Department of Technical Heritage of the Maritime Museum "Sergej Mašera" in Piran, Slovenia has been closely tied to Slovenia's maritime faculty in the last decade, through research and educational cooperation. Through this, the Department came in contact with maritime researchers in Poland, and it is keen on becoming involved in the project. Next year the Maritime Museum in Piran will borrow this exhibition. During that time the museum will promote the entire range of the project within the association of Mediterranean maritime museums.

Mathematical models applied in simulation systems

Solar compass model

Mathematical problems that need to be solved during the development of the solar simulator compass come down to:

- calculation of the curve originally marked out on the wooden disk by the end of the shadow during daily movement of the sun across the sky for specific coordinates and date;
- calculation of the length and direction of the shadow for actual position of the sun and tablet orientation.

The first problem is solved by use of basic geometrical relationships and a simulator of sun position in the sky for chosen coordinates and date. It was assumed that the tablet is placed horizontally. The azimuth and the altitude of sun changing during the day defined as in Figure 2 are input data. As a result a curve marked out by the top of the shadow during the daily movement of the sun across the sky is calculated and added to the picture of the wooden disk displayed on the tablet screen.

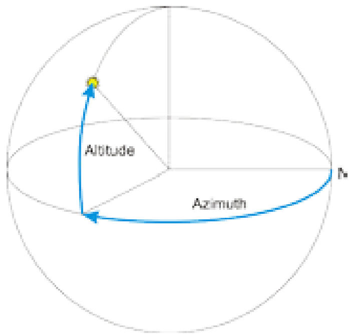

Figure 2. Position of the sun used in solar compass

The second problem is to calculate the length and direction of the shadow for the actual position of the sun and tablet orientation; this can be achieved by calculation of the coordinates of the end of the shadow for the actual position of the sun and tablet orientation. To solve this problem the following procedure is used:

- Transformation of sun's position from azimuth and altitude to Cartesian coordinates where y'-axis is the N-S line, x'-axis is the W-E line and the z'-axis is perpendicular to x'-axis and y'-axis. It was assumed that R is the average distance from sun to Earth.

$$X'_S = R\cos(\text{Alt})\sin(\text{Az})$$

$$Y'_S = R\cos(\text{Alt})\cos(\text{Az})$$

$$Z'_S = R\sin(\text{Alt})$$

- Transformation of sun's position (X'_S, Y'_S, Z'_S) to local coordinate system defined as shown in Figure 3 where α, β, and γ are angles between corresponding axes.

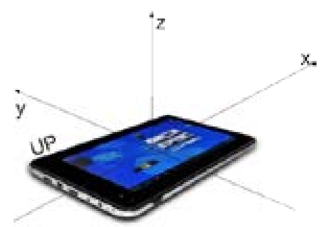

Figure 3. Local coordinate system

$$\begin{bmatrix} X_S \\ Y_S \\ Z_S \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha & 0 \\ 0 & \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha & 0 & \sin\alpha & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\alpha & 0 & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot$$
$$\cdot \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 & 0 \\ \sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} X'_S \\ Y'_S \\ Z'_S \\ 1 \end{bmatrix}$$

- Calculation of coordinates of the end of the shadow (X,Y,Z) as an intersection of the tablet surface and a line crossing position of the sun (X_S,Y_S,Z_S) and a tip of the gnomon (X_G,Y_G,Z_G).

$$\begin{cases} \dfrac{X - X_G}{X_S - X_G} = \dfrac{Y - Y_G}{Y_S - Y_G} = \dfrac{Z - Z_G}{Z_S - Z_G} \\ Z = 0 \end{cases}$$

- Calculation of distance and angle between two points (0,0) and (X_G,Y_G) – the length and the direction of the shadow.

Decca system model

The main mathematical problem in development of the Decca system is to convert a given latitude and longitude into hyperbolic coordinates according to the principles of the Decca system, which was based on comparing the phase difference of the signals from Master and Slaves (typically three in a chain red, green, and purple). This comparison resulted in a set of hyperbolic lines of position where the phase difference is constant. The interval between two adjacent hyperbolae on which the signals are in phase was called a lane. The lanes were numbered 0 to 23 for red, 30 to 47 for green, and 50 to 79 for purple. The lanes were grouped into zones, with 18 green, 24 red, or 30 purple lanes in each zone. The zones were labeled A to J, repeating after J.

The procedure of hyperbolic co-ordinate calculation is presented for one pair (Master-Slave); a similar procedure is used for all pairs. To calculate the Decca hyperbolic coordinates chain frequency, the position of the vessel and coordinates of stations have to be known.

- In the first step, Δd is calculated as the difference between the distances from vessel to Master station d_{VM} and from vessel to Slave station d_{VS}:

$$\Delta d = d_{VM} - d_{VS}$$

- Next the width of lane on the baseline is calculated:

$$d_0 = \lambda_C / 2$$

where:
d_0 – width of lane on the baseline;
λ_C – wave length for the common (comparison) frequency.

- In the last step the number of lanes from Master station is calculated and named according to the given pattern (red – 0 to 23, green – 30 to 47 purple – 50 to 79, zones from A to J, repeating after J).

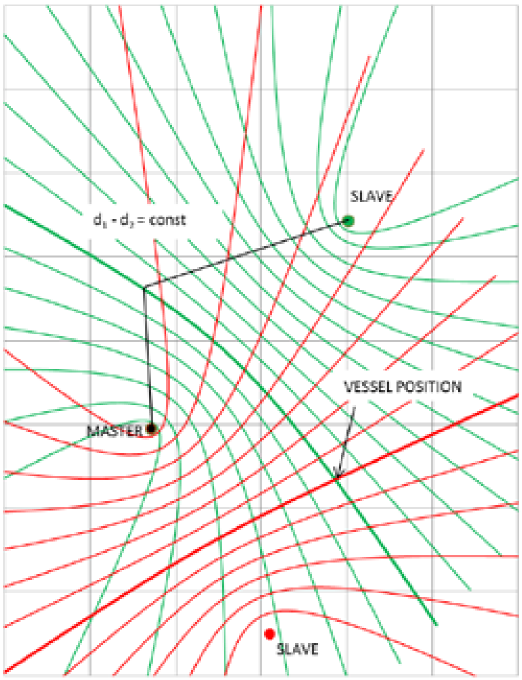

Figure 4. Example of creation of Decca hyperbolic lines

Solar Compass and Decca system Simulators

To construct the simulator, real historical devices were used that come from the collections of the National Museum and the Maritime University of Szczecin. The Decca receiver MK21 was altered and recreated so that it would be able to determine the position at sea in conjunction with the model presented above. Systems were connected to a three-dimensional ship movement simulator with graphic interface adjusted to the historical times presented, with the aim of reflecting actual conditions of a given navigational situation from the past. The chart visualizes the position of one's own ships. A virtual sailor is thus able to see the basic functioning principles of a transmitter, tune in a genuine receiver and even to get a bird's eye view of the waves rippling on the water. The bow of a Viking boat appears on a big screen together with a horizon line, while a mobile multimedia device displays a simulation of how a solar compass works. The device enables virtual navigation in the open sea with the aim of arriving at a specified place. The projects were completed by a consortium comprising the Navigation Faculty of the Maritime University of Szczecin and the National Museum of Szczecin whose teams designed the whole system – mathematical models of two main units: the solar compass and the Decca Navigator System. The hardware and software of the system was created by Autocomp Management Company.

The overall concept of the simulator is presented in Figure 5. The simulator is divided into several interconnected parts. The completely new concept here is the use of a tablet to control the simulation scenarios, the solar compass, and the speed of the model Viking boat. The 3D visualization was created using the Unity 3D graphical engine.

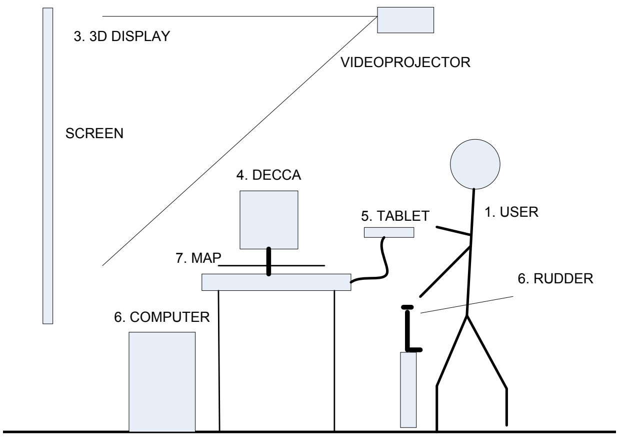

Figure 5. The general layout of the historical systems simulator

The area of navigation

The historical context of Viking sailing routes were considered and the route from east to west (i.e. from Norway to north Scotland with the Shetland and Orkney Islands) chosen as the most interesting (Figure 6). Also, Decca chains also existed in those areas and covered both Scotland and Norway. The simulator also allows scenarios to be created in other areas and routes.

Simulator realization

The layout of the simulator room is clean and minimalistic (Figure 7). The user is equipped with a tablet which enables them to control the simulation and to use a model of the solar compass. The "boat" is equipped with a rudder and commands can be directed to helmsmen. In front of users are three

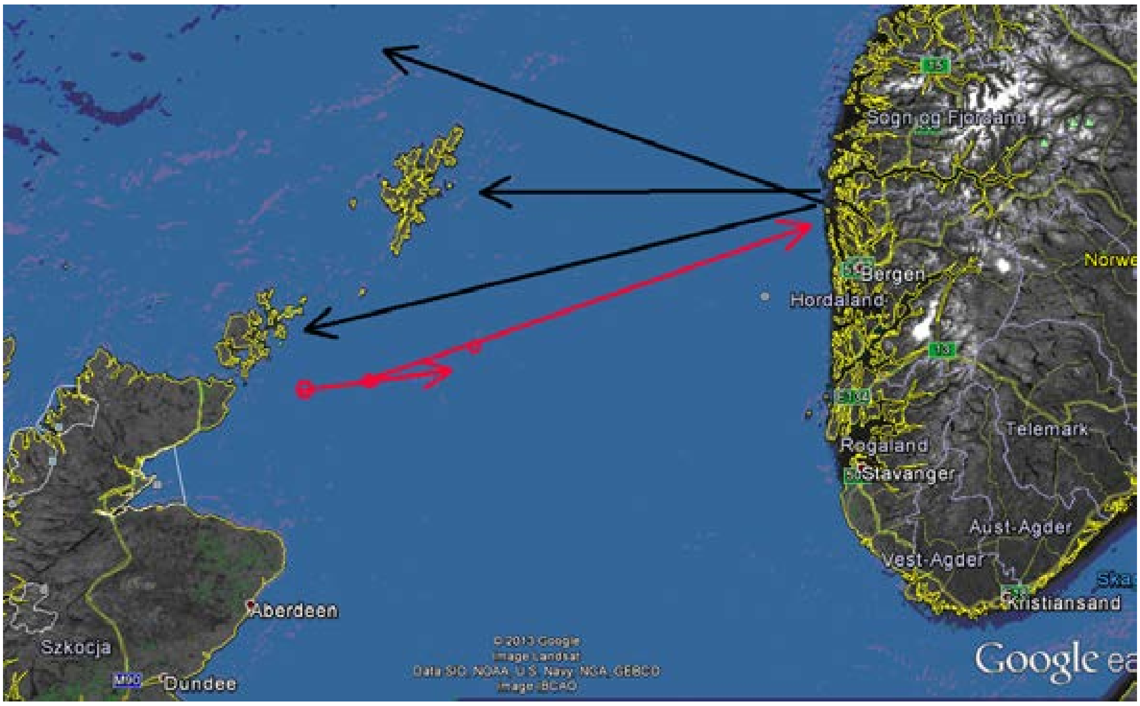

Figure 6. The sailing area of the simulator and modeled routes (black – Viking sailing, red – Decca sailing)

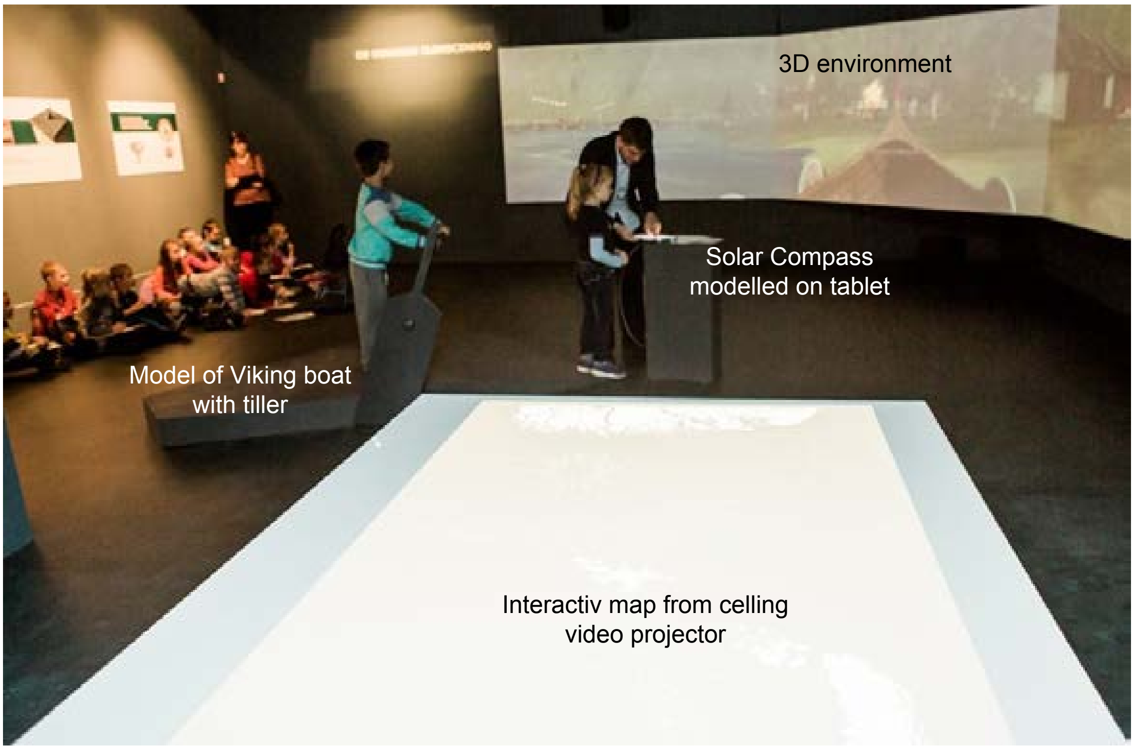

Figure 7. The simulator room (photo by M. Soja)

large screens with a 3D simulated environment. Natural voices increase the realistic feeling of the simulator. The simulation program can work in fast time after choosing the direction of sailing.

The user controls the simulation environment by means of a tablet (Figure 8). On the tablet the solar compass model is also presented after starting the simulation. The tablet also allows performing "time jumps" with chosen interval of 10, 20, and 50 Nm.

Additionally, a Decca receiver Mk21 (Figure 9) is connected to the simulator and fully operable. It enables selecting a Decca chain and reading the measurement of deccometers (red, purple,

Figure 8. The tablet used to control the simulation and to find direction by solar compass (photo by M. Soja)

Figure 9. Decca receiver MK21 used as part of the simulator (photo by T. Budzan)

green). Later on the position could be manually fixed on the chart displayed by the overhead projector.

Conclusions

The concept of an historical navigational systems simulator is a new approach in the presentation of historical context, joining together an exhibition and an interactive simulation of navigational systems and tools. The educational value of such a simulator is very high because of the interactivity, which increases the learning of the basic principles of navigational systems.

The science popularization aspect is important, and lessons are carried out smoothly and seamlessly due to immersion of the spectators in the virtual world of the simulated system. However, it must be noted here that there is a danger when this technique is introduced into a museum, for the museum must remain a high-quality learning environment that is not “dumbed down” by “user friendly” techniques. In other words, the museologist must ensure that the style of learning does not denigrate the quality of what is learned, and must ensure that the ultimate goals of the museum are met and enhanced if the new technology is to be welcomed into the building.

If the simulation is properly presented with the highest quality, the museum visitor will understand the historical context of the navigational techniques on display and how they are applied in the simulation, why they are comparable, and ultimately, one hopes, will be stimulated to further study.

In the long run, the simulation technique could perhaps lead to further historical knowledge by proving or disproving current theories.

Finally, the project’s international value must be recognized, as researchers do not work in a national vacuum but generally have some kind of relationship with museologists in their field in other countries. This natural interaction in today’s environment of extensive international cooperation should lead to the ideal of extensive exchange, as, in this particular case, the advances of the Polish researchers inspired by the discoveries of the Polish archaeologists will be shared with the Slovenian maritime museum, and, therefore, the Mediterranean maritime museum community in general.

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