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Memorie della

The Universe as you never sensed it.

The project of a multisensory planetarium in order to discover the beauty of the sky

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Abstract. This project is to offer a common perceptual and cognitive framework to all users, both sighted, deaf and blind or visually impaired, concerning the experience of observing the sky. The acoustic stimuli are intended to introduce a perceptual equivalent for blind and visually impaired users, while the haptic ones introduce quantitative features, which can only be known through instrumental observations.
Through the integration of these stimuli, we have given a wide range of users the opportunity to immerse themselves in a unique and shared experience of the fascinating celestial panorama. The combination of thoughtful design, focused prototyping, and a thorough preliminary assessment demonstrated the effectiveness of this innovative approach. Thanks to this multisensory planetarium, we not only make the beauty of the night sky accessible but also open new perspectives for inclusive science education, offering everyone the opportunity to explore and understand the vast Universe around us.

Key words. Inclusion, Planetarium, Multisensorial stimuli, New technology,

1. Introduction

Modern astrophysics leverages instrumental data to study objects and phenomena that are not visible in physical terms, meaning that they cannot be investigated with the naked eye or analogous optical systems. Nevertheless, the fascination of night sky observation remains one of the primary ways to access astronomical knowledge and content.

Since the dawn of time, humans have looked at the night sky and wondered about the nature of the celestial bodies they observed. This curiosity led to speculative explanations and eventually to the development of scientific methods to address these questions. People began to investigate the sky using instruments capable of observing beyond the limits of human senses. The invention of the telescope by Galileo Galilei in the early 17th century revolutionized astronomy, enabling the observation of celestial bodies in unprecedented detail and expanding our understanding of the Universe.

The celestial vault is the apparent surface of the sky, which many cultures and myths aim at as a sort of physical cover above the observer (Plug 2008). This concept, though an apparent feature, has been deeply embedded in human history. It symbolizes a powerful idea that has historically, sociologically, and culturally unified humanity. Though being an apparent feature, the existence of which has been overcome by scientific studies and modern astronomical observations, it still represents a powerful idea, historically, sociologically and culturally grouping humanity. This concept is inaccessible to blind and visually impaired (BVI) users, who cannot experience the feeling of standing below a black dome checkered with bright points, the stars. To address this, various successful projects have utilized haptic (touch-based) and acoustic (sound-based) resources to make astronomy accessible to BVI users. These efforts include tactile star maps (Bonne & Gupta & Krawczyk & Coleman & Masters (2018)), audio guides for astronomical phenomena (Pérez & Barnés et. al (2022)), and even 3D-printed models of celestial objects (Ortiz (2020)). Such multi-sensory representations have proven to be highly effective and have great potential to foster equal access to astronomy culture (Varano & Zanella 2023).

Following this approach, we created a multi-sensory planetarium, asking for hints and suggestions from possible end-users. In the following section, we present the design, prototyping and preliminary evaluation of a multi-sensory planetarium, using visual, acoustic and haptic stimuli to convey both the apparent and physical features of stars in the night sky, to offer common perceptual and cognitive frameworks to sighted and BVI users.

2. The project of the multi-sensory planetarium

The multi-sensory planetarium consists of a plexiglass hemisphere on which stars are represented by a metal bar that, when touched, activates visual, haptic and acoustic stimuli.

Among the approximately 6000 stars visible in the sky, we decided to include in our multi-sensory planetarium only the stars up to the fourth magnitude. This means that on the surface of the planetarium the users will be able to find about eighty stars. Using a fish-eye projection of the night sky, we identified, on the plexiglass dome, the position of the different stars which we decided to insert inside our planetarium. Subsequently, in correspondence with the previously identified positions, we drilled 0.8-1 cm holes to insert the metal bars. These elements, which represent the heart of the project, are made up of brass cylinders threaded on the top, so that a series of bolts can then be screwed on to act as a tactile representation of the apparent magnitude. The end parts of the bars have been adequately shaped to insert small vibrating motors similar to those used in smartphones. On the top of the bars, however, we positioned a 3 mm warm light LED. Image 1 shows the structure and dimensions of these devices. Finally, on the external surface of the dome, we have placed four speakers to provide the various users with a series of acoustic stimuli.

In order to reduce the vibrations of the bars and speakers, we have internally lined the dome with neoprene, the same material used for diving suits. The end part of the bars has also been covered in the same material, thus preventing the transmission of vibrations that could cause incorrect perceptions.

All stimuli are managed electronically by a series of Arduino[1] boards. Developed in 2005 at the Institute of Interactive Design in Ivrea (Italy), Arduino was designed to offer a simple and accessible solution for creating interactive devices. Its main features include a programmable micro controller, an array of digital and analog input/output pins, and an extensive open-source software library. This combination makes Arduino extremely adaptable, allowing users to quickly and easily develop a wide range of projects, from simple sensors to complex automation systems. Arduino's potential extends beyond robotics to include applications in home automation, environmen-

[1] https://www.arduino.cc/

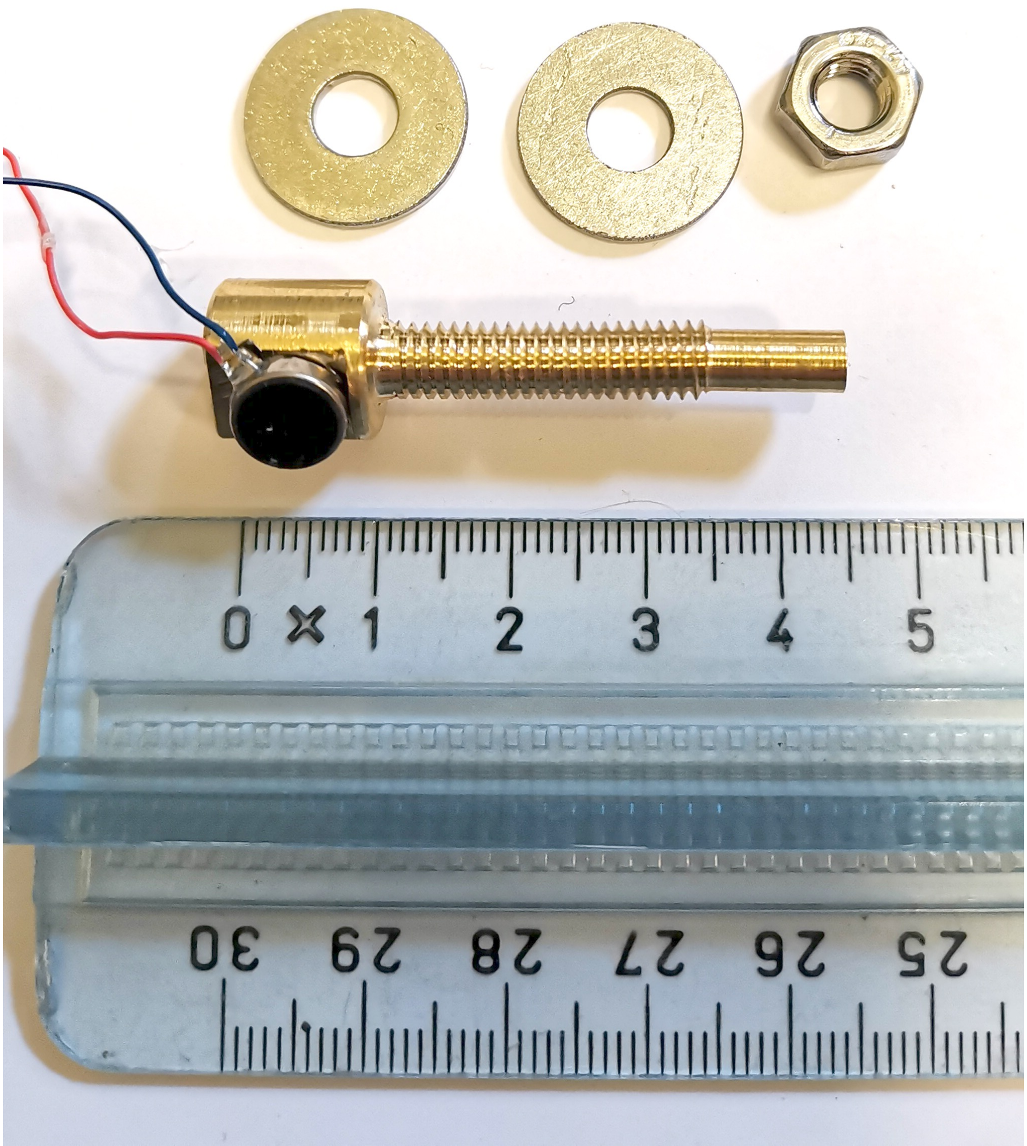

Fig. 1. Tactile elements used to represent the stars both in the prototype and in the planetarium.

tal monitoring, wearable devices, and more, thanks to its ease of use, large support community, and ability to integrate numerous sensors and actuators. In our project, Arduino was used to provide a complete perception of the celestial vault to all people regardless of their physical condition. The image on the right of Figure 2 shows the electrical connection of the ”stars” of the Cassiopeia constellation to the Arduino board.

The constellations were made visible and tactile through a red cotton thread, as shown in left image of Figure 1. In this way, blind users can identify the presence of the constellation and follow its outline by passing their hand over the surface of the dome, obtaining a mental image of it. All the stars fainter than the fourth magnitude, but still important for the creation of the constellation, were represented only in a tactile way through beads. This allows users to appreciate the entire shape of the constellation and understand how some stars are below the visible magnitude level.

3. The mapping of stimuli

The stars' physical characteristics that we decided to represent in the planetarium are: position, apparent magnitude and distance from Earth. These characteristics are mapped as described below.

Position. Information about the position of the stars in the celestial vault is provided both as tactile and as visual stimuli, corresponding to the position of the bar, representing each star on the plexiglass dome.

Apparent magnitude. The luminosity of stars has been classified in terms of apparent magnitudes, a feature introduced by Hipparchus in the II century b.C. that is related to the apparent brightness according to the following formula

$$m = -2.5 \log(F/F_0) \quad (1)$$

where F is the flux, that is, the amount of energy per unit time per unit area and F_0 is the reference flux (zero-point) for that photometric filter. Due to the presence of a minus sign and a logarithm, this means that stars of magnitude 1 are ten times brighter than stars of magnitude 2.

We set out to map the apparent magnitude of stars using both acoustic and visual stimuli. The visual stimulus is defined by the brightness of the LED, located on the upper part of the bar, whose brightness is proportional to the apparent intensity of the object represented. The acoustic stimulus (a midi sounds with a frequency of 880 Hz), on the other hand, is defined by a sound whose volume depends on the apparent luminosity of the object. We chose this acoustic mapping because the sight and hearing senses operate on a similar logarithmic scale. Indeed, the perception of light intensity by the human eye follows a logarithmic scale, according to the Weber-Fechner law, which describes how the perception of changes in intensity is proportional to the ratio between the change and the original intensity. Similarly, the human ear perceives variations in sound intensity in a logarithmic way. This approach ensures that both sighted and BVI users have a comparable approach to defining stellar magnitudes (Moore 2012).

Furthermore, the magnitude was also mapped using a tactile stimulus. In fact, on top of the metal bars we added a variable number of bolts depending on the magnitude of the star (4 bolts for magnitude 0, 3 bolts for magnitude 1, 2 bolts for magnitude 2, 1 bolt for magnitude 3). This information was described to BVI people after self-exploration.

Distance. The distance of the star from the Earth was mapped on a vibration, faster/slower for smaller/greater distances. We used a vibrating motor, such as the ones used in smartphones, with a fixed frequency of 240 Hz. In particular, we chose to increase the pulse interval by 1 millisecond every light year, as proposed byWersényi 2022.

4. Discussion

The multi-sensory planetarium was presented for the first time during the Festival "Punti di Vista" (viewpoints) held at Palazzo delle Esposizioni in Rome on 16-17 March 2024 (Varano 2024). During the event, we asked users some questions to assess the impact and the validity of the experience. From the data collected, we found that the presence of a perceptive equivalent not only of what is directly perceptible to sight (position and magnitude), but also of what can only be observed through instruments (distance), was highly appreciated by users.

The experience presents some analogies with the astronomical research world. During the first phase of exploration, acoustic and visual stimuli provide information based exclusively on the direct perception of nature, i.e. the position of objects on the celestial vault and their apparent magnitude. On the contrary, information on the intrinsic brightness or dis-

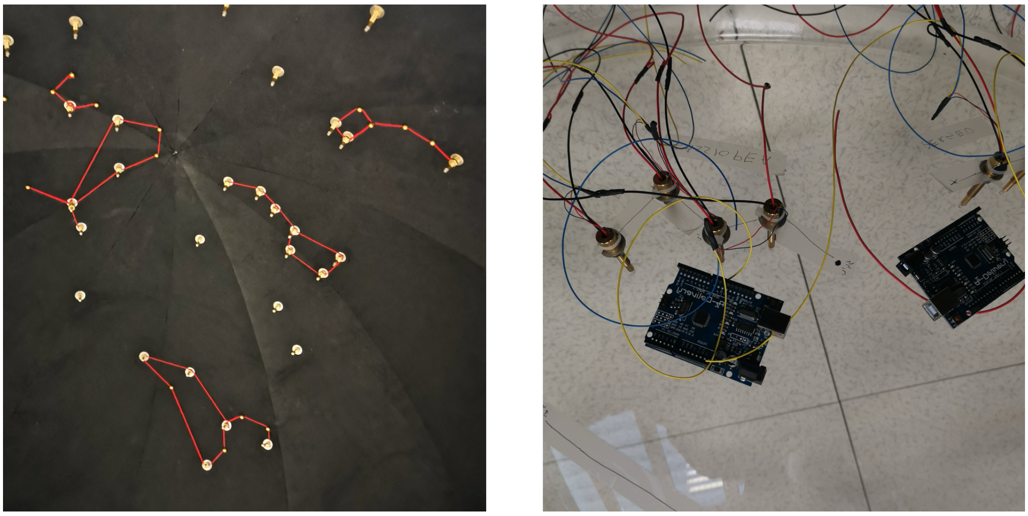

Fig. 2. The picture on the right shows the electrical connection between the different stars of the Ursa minor constellation with the Arduino board. The picture on the left shows some constellations that you can see inside the planetarium. The red cotton thread indicates the figure of the constellations, instead the black surface is the neoprene layer to avoid vibrational transmission.

tance of the various stars is precluded from direct observation of the sky. In the study of the celestial vault, to obtain a deeper perception of the sky, observation is not sufficient: various types of instruments such as telescopes are needed. Similarly, in our representation, the senses of sight and hearing are not sufficient for complete understanding; therefore, it was necessary to add an additional sense, i.e. touch.

This sense reproduces the study and observation of the celestial vault using instruments, obtaining not only detailed information on the distance but also a correct and realistic value of the magnitude of the various stars. In this way, it was possible to obtain an additional representation on a different cognitive level, providing information on distance via tactile stimuli such as vibrations and on the true magnitude of objects with the number of bolts. This approach offers a deeper cognitive picture, based on scientific data inaccessible through simple observation of the sky with the naked eye or ear. The representation, being more quantitative and objective, allows users to argue the values actually represented. This choice allows us to offer equal perceptive enjoyment of what is observable in the night sky without the aid of instruments, and a perceptive representation of astronomical data on two different cognitive levels, both accessible to everyone.

In this way, the multi-sensory planetarium manages to balance the direct perceptual experience of the night sky with a more scientific and profound understanding, allowing users to explore and understand the wonders of astronomy in an inclusive and comprehensive way (Smith & Jones 2020).

5. Conclusion

The multi-sensory planetarium represents a significant innovation in the field of accessibility and scientific education. Through the simultaneous integration of haptic, visual and acoustic stimuli, it's possible to create an exhibit capable of showing all users the beauty of the starry sky, but also providing a new way of exploring the celestial vault, making astronomy accessible to everyone, regardless of sensory abilities.

The multi-sensory planetarium demonstrated how the combined use of different stimuli can overcome the physical and perceptive barriers that traditionally exclude many people from astronomical observation. The feedback collected during the festival ”*Punti di Vista*”, where the planetarium was presented for the first time, was extremely positive. BVI users particularly appreciated the ability to perceive not only the position and apparent magnitude of stars, but also more complex information such as distance and apparent brightness through tactile stimuli. This demonstrates the effectiveness of planetarium design and the importance of using multi-sensory approaches to make science accessible. Users pointed out that despite the multiplicity of stimuli, it was possible to clearly perceive the brightness of the various stars through sound and that all stimuli – sonic, vibratory and tactile – were well orchestrated and did not create confusion. We are currently analyzing in detail all the collected data and the results will be presented in a subsequent article.

The multi-sensory planetarium not only makes the beauty of the sky accessible, but also represents a new frontier in science education. It demonstrates how multi-sensory technologies can break down sensory barriers and promote more inclusive education, allowing everyone to share in the wonder of astronomy. This project opens new perspectives for scientific dissemination, making knowledge of the universe accessible and engaging for an increasingly wider audience. The innovative use of haptic, visual and acoustic stimuli not only enriches the educational experience, but also offers a model for future applications in the field of inclusive teaching and scientific dissemination.

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