Bell3D: An Audio-based Astronomy Education System for Visually-impaired Students

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This article presents a software system that allows astronomical data to be represented and analysed purely through sound. The goal is to use this for communicating astronomy to visually impaired students, as well as providing a new modality of astronomy experience for those who are sighted. The programme — known as Bell3D and developed at the University of Aberdeen — allows various stars to be selected from a database and then maps a variety of their astronomical parameters to audio parameters so that they can be analysed, compared and understood, solely through the medium of sound.

Introduction and background

The ability to experience the surrounding Universe is inherent and taken for granted by those who are sighted, but for those with a visual impairment, the night sky remains almost entirely impenetrable. Utilising sonification — the use of non-speech audio to convey information (Kramer et al., 2010) — allows those with a visual impairment to engage with data that would previously have only been accessible via visual modalities, and therefore available exclusively to sighted people. Sonification allows traditionally visually-oriented and data-driven fields such as astronomy to be explored and experienced by visually-impaired people, some of whom may never have had the opportunity to enjoy and experience these fields before. Furthermore, this technology allows a new, complementary modality to visual experience for sighted people, with potential applications across data science, science communication, art and education.

A simple example of sonification would be a kettle whistling when the water within it reaches around a hundred degrees centigrade. The data in this example being the temperature of the water and the information extracted from analysing the whistling being that the water has reached its boiling point. Another classic example is a Geiger–Müller radiation detector, which creates an audible click when particles associated with radioactivity strike the detector. However, sonification is not to be confused with audification. Audification is the direct playback of data samples (Kramer, 1993), as opposed to sonification which is the "transformation of data relations to perceived relations in an acoustic signal" (Kramer et al., 2010).

Sonification, in many situations, is better suited to analysing large datasets for patterns and anomalies than visual modalities (Kramer et al., 2010). For example, a significantly large dataset such as a genomic sequence, which would traditionally have taken a lot of time and resources to analyse for patterns and anomalies visually, may be sped up and compacted using sound, allowing it be analysed in the order of minutes.

Both sonification and audification have, until recently, only been applied sporadically throughout the history of astrophysical and astronomical research. The first use of these technologies in the literature was during the *Voyager 2* mission in the late 1970s (Scarf, 1982). These technologies have more recently been used to analyse radio plasma waves around Saturn (Gurnet, 2005), as well as examining large collections of solar wind data (Wicks et al., 2016). Furthermore, recent work into a sonification prototype for analysing satellite and radio telescope data (Candey et al., 2006; Diaz-Merced, 2013) has shown that researchers within the astronomy and astrophysics communities are hopeful of the potential of applications of sonification at the leading edge of these sciences.

The astronomy and astrophysics communication communities have experienced a surge in the use of sonification and audification in the last decade. Recent works including the European Space Agency's use of sonification as a method of public engagement with the *Rosetta* mission (European Space Agency, 2014); NASA's Earth+ system[1] and the Harvard–Smithsonian Centre for Astrophysics' Star Songs: From X-rays to Music project[2]. Furthermore, during the press coverage of the LIGO experiment's recent detection of gravitational waves (Abbot et al., 2016), the audification of the detection was used ubiquitously by the media and has become synonymous with the detection[3]. These technologies have only recently begun to be implemented as astronomy communication tools, but computing and audio technologies are now reaching a level of low cost and high performance that gives sonification the potential to be used throughout astronomy communication and education for the visually impaired.

How the system works

The Bell3D system[4] was developed after realising the potential of sonification and audio-based data displays within astronomy communication and education, not only as an essential resource for visually-impaired people, but also as a new, engaging medium of astronomy experience for those who are sighted. The programme is in its infancy and requires more work, but has so far proven to be an important step towards ubiquitous access to astronomy experience and education.

The software involves the user selecting a constellation and then specific stars within that constellation to be sonified — meaning data relating to the selected stars is transposed into audio signals. When stars are selected, their astronomical parameters such as magnitude, location, size and distance from Earth obtained from the SIMBAD database[5] (Wenger, 2000) are mapped onto audio parameters such as volume and pitch. The audio is spatialised, meaning that the user listening to the sounds perceives that these sounds are in three-dimensional space, with audio coming from particular areas around their head; the star's equatorial coordinates are used for this. This provides an engaging experience and gives the user an idea of where the star(s) reside in relation to Earth.

The sounds produced are simple and easy to analyse. For each star there are two sounds: a repeating "ping" sound and a continuous tone. Both can be turned on and off independently. The former encodes three data points within one sound — a star's distance from Earth, its location with reference to the Earth and its apparent magnitude — and the latter encodes one attribute — a star's colour index.

The ping represents distance, location and apparent magnitude data values in the following manner: The star's distance from Earth is represented sonically by how loud the ping is, with the volume of this sound being inversely proportional to the star's distance from Earth (the closer the star, the louder the sound); the star's location (based on its equatorial coordinates) is represented by the sound's perceived location in the three-dimensional sound space; and, finally, the star's apparent magnitude or brightness is represented by the pitch of the ping sound, the pitch being proportional to the star's apparent magnitude.

The second sound — the continuous tone which represents a star's colour index — is represented sonically by the pitch of the continuous tone. The higher the pitch of the tone, the further towards the red end of the spectrum a star is, the lower the pitch, the further toward blue end.

This rather simple mapping of parameters allows the user to make basic assumptions about stars based on what they hear. For example, one can assume that Betelgeuse is a red star, based on the fact that the pitch of its tone sound is high, or that Proxima Centauri is closer to Earth than Sirius, because its "ping" sound is louder.

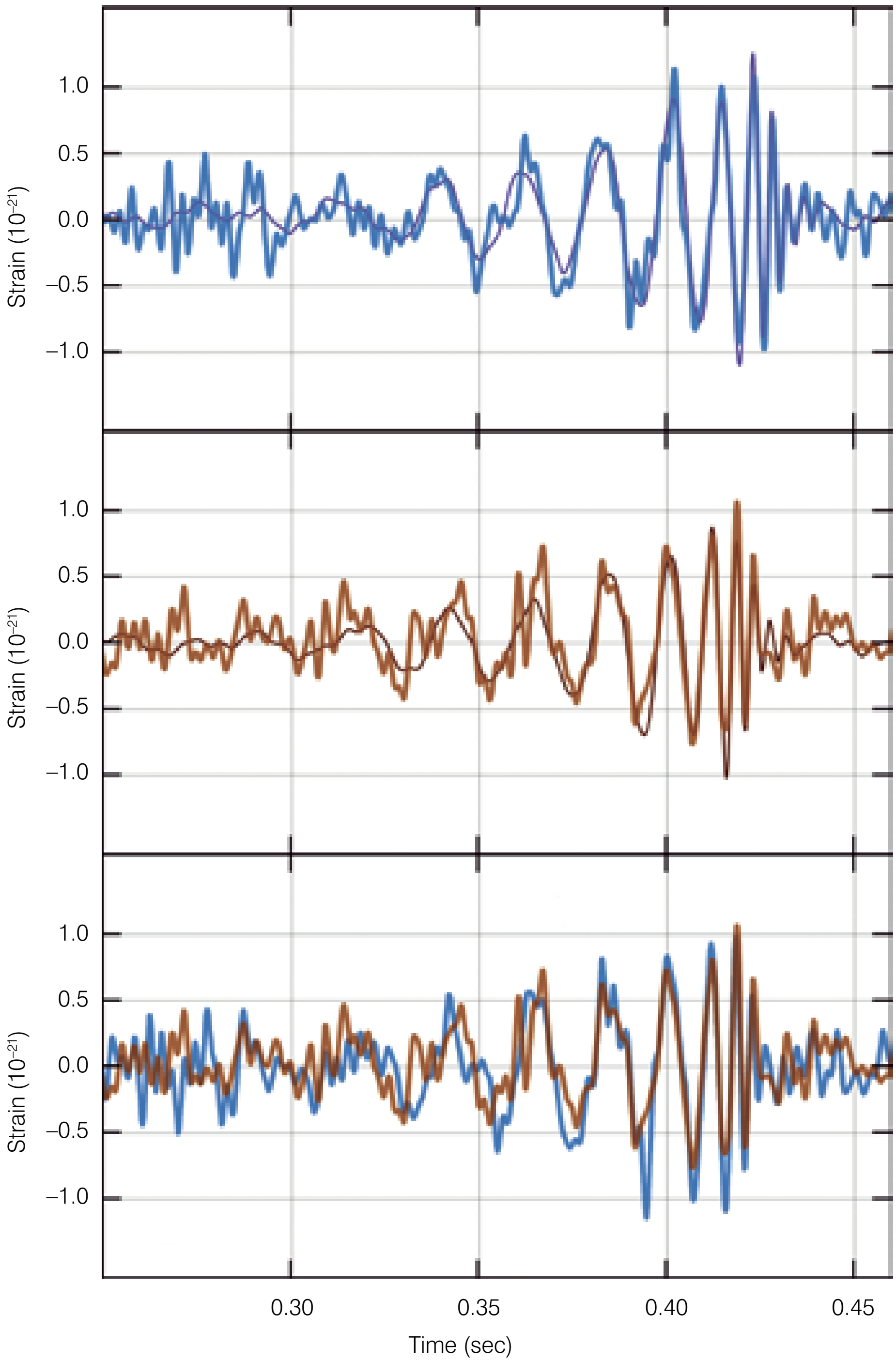

Figure 1. *The LIGO gravitational wave detection waveform, which was audified as a successful means of communicating the discovery in the media. Credit: LIGO Scientific Collaboration*

Additional applications of the system

The obvious, prevalent use for the system lies within astronomy education and communication, but uses within the arts have been discussed as potential further applications of the Bell3D software. Sonification and audification have been employed successfully within artistic endeavours attempting to explore ideas combining science and art on many occasions (Mast et al., 2015; Polli, 2005) and have been the basis of many sound artist's practice, such as Robert Alexander[6], Mélodie Fenez[7], Ryoji Ikeda[8] and Rory Viner[9]. Bell3D has the potential to be used in such a way in future either as a composition or performance tool for artists.

The system was used as an astronomy-teaching resource by Dr Wanda Diaz-Merced of the Harvard–Smithsonian Centre for Astrophysics during a recent series of lectures and workshops at South Africa's national science festival, SciFest Africa[10]. Dr Diaz-Merced used sounds from the system to explain the basic ideas of sonification and how astronomical data can be portrayed via sound.

Future work

Development of the Bell3D system and, potentially, further astronomy-related sonification tools will continue during a project that will commence in August 2016, run in collaboration with the International Astronomical Union's Office of Astronomy for Development (OAD) in Cape Town, South Africa. During this project the software will benefit from input by researchers, educators and outreach specialists at the South African Astronomical Observatory, as well as being used in OAD-led astronomy lessons with students at the Athlone School for the Blind. This will allow for preliminary evaluation of visually impaired users' responses to and perceptions of the system's sonifications.

Work on the Bell3D system will be the basis of a PhD within the Multimodal Interaction Group at the University of Glasgow, Scotland, beginning in late 2016. Plans for additions to the system include: head-tracking to provide a more engaging experience for the user; functionality for planets, galaxies and other astronomical bodies to be sonified; and a completely "visual-free" interface, so that those with a severe visual impairment can use the system without a screen via the use of haptic technologies and speech recognition. This further research will focus much more thoroughly on investigating user perception and response to sonification within astronomy in both visually-impaired and sighted groups. The prototype described here is a useful preliminary investigation into the software technology needed to facilitate such sonification interaction, however it lacks thorough empirical analysis on response and perception.

Furthermore, as the University of Glasgow played a significant role in both the recent LIGO discovery of gravitational waves (Abbot et al., 2016) and the communication of it in the media, a collaboration between the multimodal group and the astronomers and astrophysicists involved at Glasgow will be discussed in the coming years. The media presence surrounding the LIGO

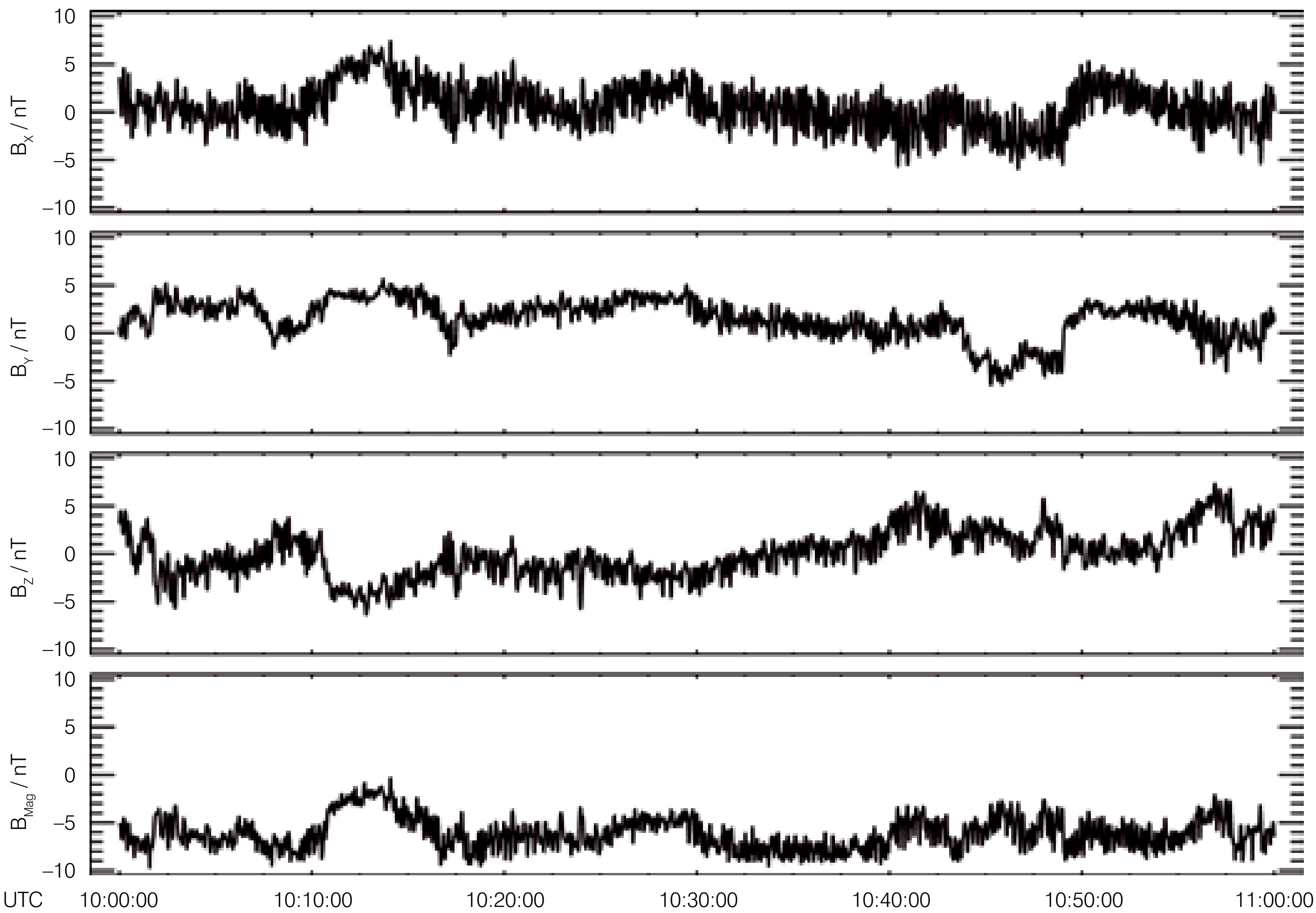

Figure 2. *The magnetic field parameters of comet 67P/Churyumov–Gerasimenko, measured by ESA's* Rosetta *spacecraft, which were sonified and the resulting audio used as the base for the highly successful blog post titled The Singing Comet[13]. Credit: Karl-Heinz Glaßmeier, Technische Universität Braunschweig, Germany*

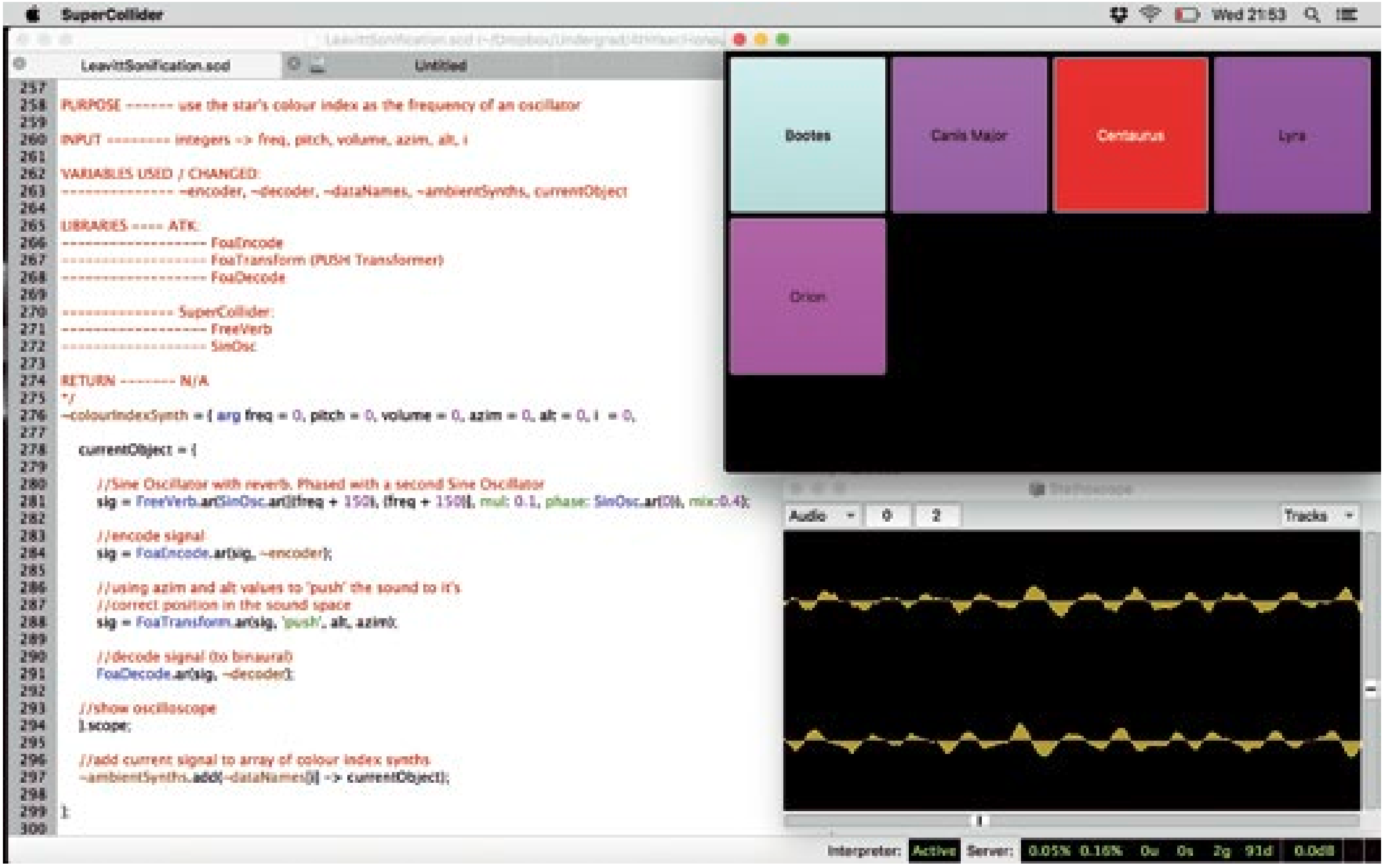

***Figure 3.** Bell3D prototype running on OSX. Credit: Jamie Ferguson, University of Aberdeen*

discovery was a major win for sonification and audification as a science communication tool, therefore taking advantage of having both teams being based at the same university will allow us to capitalise on this success.

Discussions have also taken place with the Glasgow Science Centre Planetarium — one of the UK's foremost establishments for science communication — to potentially include sounds from the Bell3D system in exhibitions and presentations within the planetarium and science centre.

Conclusion

This system provides the opportunity for people of all ages with a visual impairment to access, experience and learn about basic astronomy and the night sky; an opportunity that should be accessible to everyone. With a wealth of new astronomical instruments becoming operational in the coming years, such as the James Webb Space Telescope[11] and the Square Kilometre Array[12], and the ever-increasing ubiquity and accessibility of computing devices there have never been more opportunities to communicate astronomy to as many people as possible, regardless of disability.

As our telescopes, probes and satellites continue to provide an ever-increasing volume of data to be analysed, research into utilising more senses than the eye for data analysis is becoming increasingly vital. A more multimodal approach to data analysis will not only allow vast amounts of astronomical data to be analysed more efficiently, it will also begin to open the discoveries made, and the opportunity to make them, to people who mere decades ago would have had little opportunity to be involved with astronomy.

Notes

1. NASA's Earth+ system: http://prime.jsc.nasa.gov/earthplus/
2. The Harvard–Smithsonian Centre for Astrophysics' Star Songs: From X-rays to Music project: https://www.cfa.harvard.edu/sed/projects/star_songs/
3. Audifications of LIGO gravitational wave detection: https://losc.ligo.org/events/GW150914/
4. Further details and sounds from Bell3D: http://jfergusoncompsci.co.uk/research
5. SIMBAD database: http://simbad.u-strasbg.fr/simbad/
6. Article by Michael Byrne, 2013 on Robert Alexander *Spaced Out: 'The Space Composer' is Making Music With the Sun*: http://motherboard.vice.com/read/spaced-out-making-music-with-the-sun
7. Sound artist Mélodie Fenez: http://www.a-melodie.com/
8. Sound artist Ryoji Ikeda: http://www.ryojiikeda.com/
9. Sound artist Rory Viner: http://rory-viner.tumblr.com/
10. Video of SciFest lecture: https://www.youtube.com/watch?v=QilOFTvCTzA
11. James Webb Space Telescope: http://www.jwst.nasa.gov/

[12] Square Kilometre Array: https://www.skatelescope.org/

[13] European Space Agency, *The Singing Comet*, 2014, available http://blogs.esa.int/rosetta/2014/11/11/the-singing-comet/, (accessed 9 January 2016).

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Biography

Jamie Ferguson completed his undergraduate studies in computing science at the University of Aberdeen earlier in 2016. He is beginning a PhD at the University of Glasgow later this year on multimodal computer applications within astronomy and astrophysics.