A Study of AIS Frames Sent by CubeSats into the Ground Station

Thandiwe Promise Mnisi
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
Thandiwepromise192@gmail.com

Janvier Kamanzi
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
ORCID: 0000-0003-2119-4687

Innocent E. Davidson
French-South African Institute of Technology/Africa Space Innov. Centre
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
ORCID: 0000-0002-2336-4136

2024 32nd Southern African Universities Power Engineering Conference (SAUPEC) | 979-8-3503-7134-5/24/$31.00 ©2024 IEEE | DOI: 10.1109/SAUPEC60914.2024.10445042

***Abstract*— The automatic identification system (AIS) refers to a tracking system relying on ship-fitted transceivers; this system is indispensable in vessel traffic service (VTS). When satellites are used to receive AIS signatures, the term satellite AIS (S-AIS) is used. AIS information adds more on marine radar information, which leads the technologies for collision avoidance concerning water transportation. This paper presents an evaluation of the quality of AIS frames received at the ground station and recommends improvements on the current AIS system so that we can detect signal degradation and track vessels that go "AIS dark".**

Keywords—AIS frames, TDMA, VTS, Maritime Mobile Service Identity (MMSI), Radio triangulation, GPS

I. INTRODUCTION

The study of Automatic Identification System (AIS) frames sent by CubeSats to the ground stations involves analyzing the data transmitted by these miniature satellites as they orbit the Earth [1]. AIS is a system used for tracking ships and other vessels at sea, and CubeSats equipped with AIS transponders can provide valuable data for maritime safety [2]. An AIS transponder is a device that transmits and receives information about a ship's identity, position, course, speed, and other key parameters. It operates on very high radio frequencies and utilizes a Global Positioning System GPS receiver to determine the vessels' exact location [3]. The AIS frames are transmitted via VHF ranging between 161.975 MHz or 162.025 MHz) [3].

When a ship's AIS transponder is activated, it sends out a signal that includes the vessel's unique Maritime Mobile Service Identity (MMSI) number, its name, and its position [4]. This signal is picked up by the other vessels in the vicinity as well as by ground-based AIS receivers and satellite AIS systems. At the same time, the AIS transponder is also constantly receiving signals from other nearby vessels, which it uses to plot their position and track their movements. This allows it to constantly update the ship's position and provide critical situational awareness to the vessel's crew and other vessels in the area.

The communication system of the CubeSat is typically designed to work with ground station antennas to enable data transmission between the satellite and the Earth. The communication system of the antenna consists of a transceiver, an antenna, and an onboard computer [5], [6]. The AIS system uses a time-division multiple access (TDMA) radio access. However, the TDMA scheme is known for technical deficiencies in the form of reliability when receiving AIS messages from various transceivers coming in simultaneously [7]. This has been a major concern commercial companies have been exploring jointly with the marine industry.

Originally, the purpose of AIS system was brought on board make sailing vessel self- identification of sailing vessels and maritime traffic monitoring more accurate [8] as it captures vessels out of the radar visibility, thus eliminating the imperfections of the radar. [9]. The advantage AIS offers over the radar technology is that it solves the issues of shadow and noise that often hamper the performance of radars.

Presently, many countries bordering with coasts have adopted the AIS system with AIS chain station being built. These stations are also referred to as PSS meaning physical shore station [10]. These stations consist of insfrastructures such as servers, database servers, firewalls, and other networking devices. Countries from various regions of the world, signed cooperation agreements concerning the exchange of data from national AIS systems and the further development of these systems [10].

The purpose of this paper is to explore and propose techniques that can help improve the shortcomings of the TDMA scheme currently used in the LEO CubeSats as regards taking AIS frames and sending them to the ground stations on one hand, to mitigate signal degradation as well as tracking vessels that go "AIS dark" [11]. It is also noteworthy to mention that South Africa counts 12 CubeSats usually developed at universities of which two, namely ZACUBE-1 and ZACUBE-2 are products of the French South Africa Institute (F'SATI) and the Cape Peninsula University of Technology (CPUT) where I am a student [12], [13].

The scope of this paper is as follows:

- Study and link the radio triangulation system.
- Evaluate the sensor system on the Zacube-2 and vessels.
- Analyzing and processing AIS messages

II. SATELLITE IMAGE ACCURACY TECHNIQUES

The techniques explored in this section consist of radio triangulation, satellite telecommunication interface for AIS, probability of vessel detection using satellites as well as the calculation of the vehicle's position.

A. Radio Triangulation Signal Detection

Radio triangulation signal detection is a method used to determine the location of a radio signal transmitter by measuring the strength or time difference of arrival (TDOA) of the signal at different receiving stations [14][15]. In this technique, multiple receiving stations are placed at known positions and equipped with radio receivers. When a radio signal is transmitted, it is picked up by these receiving stations. By analysing the signal strength or the time it takes for the signal to reach each station, it is possible to calculate the location of the transmitter.

Signal strength triangulation involves measuring the received signal strength indicator (RSSI) at each receiving station. The strength of the signal decreases with distance, allowing the triangulation algorithm to estimate the transmitter's position based on the signal strength measurements from multiple receiving stations. Time difference of arrival (TDOA) triangulation involves measuring the time it takes for the signal to reach each receiving station. By comparing the arrival times of the signal at multiple stations, it is possible to calculate the transmitter's location. This method requires highly accurate time synchronization between the receiving stations[16].

Radio triangulation can be used to track vessels that have technical issues of signal degradation and vessels that go AIS dark If a ship deviates from expected patterns or 'goes dark' (loss of AIS signal), this can be considered alongside other data to consider the possibility of a compliance risk, breach of sanctions, or generally illicit.

Navigation: In navigation systems, such as the Global Positioning System (GPS), radio triangulation is employed to determine the location of a receiver by calculating the distances to multiple satellites. By processing the time differences of arrival (TDOA) or phase differences of arrival (PDOA) of the satellite signals, the receiver's position can be established [17].

Search and Rescue: Radio triangulation is crucial in search and rescue operations to locate distress signals or emergency beacons. By using multiple receivers, the signal source can be pinpointed, aiding in the precise positioning of the distressed or missing vessel. See Fig. 1 illustrating this principle.

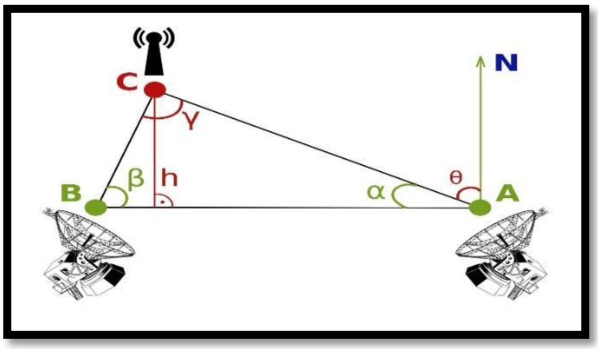

Fig. 1. Illustration of radio triangulation

In AIS, triangulation consists of measuring the radial distance of a radio transmitter from a node. Three closest nodes to the object of interests are used in the triangulation system. The three measured radial distances are overlapped and the intersect is considered. To know the direction of the radio signal we must use Doppler [18] by rotating an antenna rapidly in a circular movement. The Doppler shift helps determine the direction where a signal is coming from. The (Fig. 2).

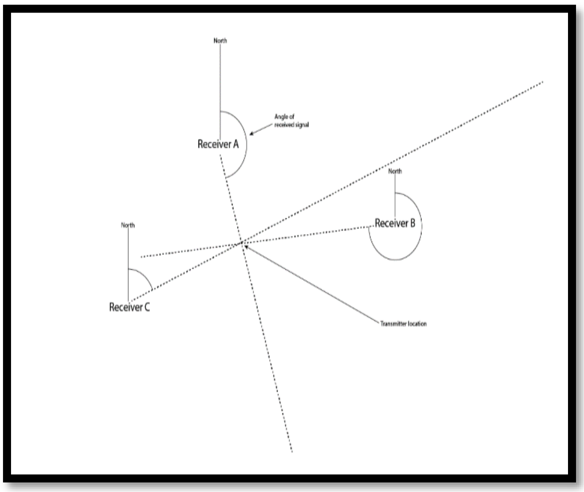

Fig. 2. Illustration of the Doppler shift when the antenna is perpendicular to the signal

B. *Satellite Communication Interface of the AIS*

According to the International Maritime Organization (IMO) regulations, every vessel covered by the International SOLAS (Safety of Life at Sea) Convention, during international voyages, is obliged to have an installed and operating AIS transponder [19]. It creates new possibilities for vessels monitoring the high seas and open oceans, not covered by the range of the land AIS base stations. To fulfill this task, it is necessary to design and build a satellite component of the AIS system.

The first assumptions in this field were made in Norway Norwegian scientists did some simulation research, testing some possibilities of utilizing the AIS receivers installed on low Earth orbit satellites. According to the results of the Norwegian research, the present technical definition of the AIS system would provide the correct functioning of the systems in the regions with small AIS traffic density and in the polar regions. This limitation is caused by the high probability of AIS frame collision.

To minimize the probability of AIS frame collision and to maximize the probability of a vessel equipped with an AIS transponder it is necessary to make proper choices and optimize many system parameters. The most important of them are the proper choice of satellite constellation in the aspect of orbits and number of satellites, the areas of coverage and overlap areas should be carefully designed, reduction of the FOV (Field of View) of a satellite [20], Space Diversity [21]– installation of spot beams antennas onboard of a satellite, additional frequency channel for AIS transmission and the change of the vessel AIS frequency of reporting.

C. *Probability of Vessel Detection in the Satellite Field of View*

To determine the probability of detection of a certain number of vessels being in the FOV of a satellite the simulation research was done, close to the research published in the work but considering different FOVs of a satellite, different times of satellite observation, and vessels reporting period. The research was simplified only to one satellite placed in one orbit, where its linear speed was 7500 m/s. It was also assumed that FOV is square. It is visible from the simulation results that, to achieve a higher probability of detection of AIS frames in the areas of high or very high AIS traffic density, it is necessary, in this area, to implement a longer time of observation of an AIS signal. Probability detection level 0,9 can be achieved for 1200 vessels for Tobs=198s and 2500 transponders Tobs increases to 3600 s where Tobs is the observation time.

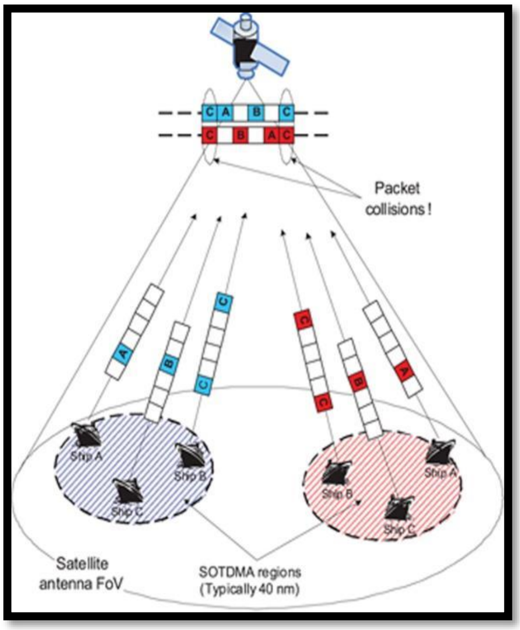

Fig. 3. Vessel detection field of view [20]

To determine the probability of vessel detection in a satellite field of view (FOV), several factors need to be taken into consideration:

Sensor Capabilities: The resolution and sensitivity of the satellite's sensor play a significant role in vessel detection probability. Higher-resolution sensors can identify smaller vessels, while more sensitive sensors can detect vessels that may be partially obscured or have low reflectance.

Vessel Characteristics: The size, shape, color, and materials used in the construction of the vessels can also impact detection probability. Vessels with larger dimensions, distinct shapes, and high reflectance are generally easier to detect.

D. AIS Vehicle Detection Calculation

To detect vessels using AIS, there is also a need for some calculations to be performed:

- **Position Calculation**: AIS transponders transmit the vessel's GPS-based position coordinates. These coordinates can be used to determine the vessel's exact location on a map.
- **Speed Calculation**: AIS also provides information about the vessel's speed over the ground. By analyzing the transmitted data over time, the speed of the vessel can be calculated.
- **Course Calculation**: AIS transponders also transmit the vessel's course over the ground. By analyzing the transmitted data, the vessel's direction of movement can be determined.

E. Access to a Particular Channel

Three techniques used to access a channel are explored.

Code Division Multiple Access (CDMA): in this case, a channel for satellite repeater or transponder amplifies all the carriers falling thin its passband at a time during the operational state of the channel and a code is allocated to the station [22](Fig.4).

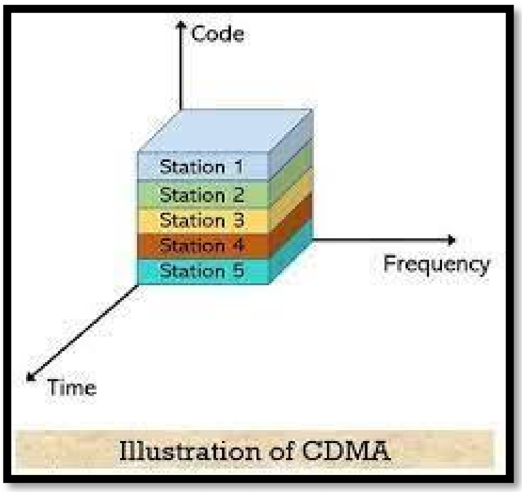

Fig. 4. CDMA illustration[22]

Frequency Division Multiple Access (FDMA): These techniques looks at the carrier in the frequency domain. If the spectra of the carrier each occupy a different sub-band, the receiver can discriminate between carriers by filtering [23]. This is the frequency division multiple access (FDMA) (Fig.5).

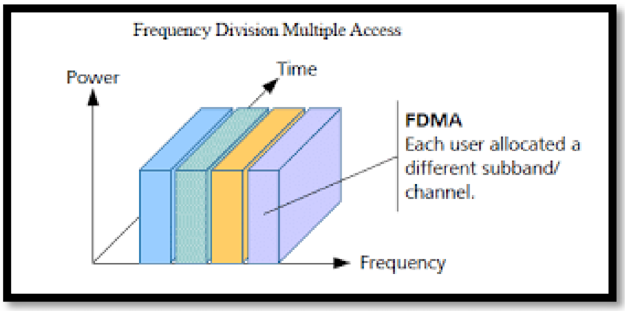

Fig. 5: FDMA principle illustration [23]

Time Division Multiple Access (TDMA): As a function of the temporal location of the carrier energies; several carriers received sequentially by the receiver can be discriminated by temporal gating even if they occupy the same frequency band. This is the principle of the Time Division Multiple Access (TDMA) [24](Fig.6).

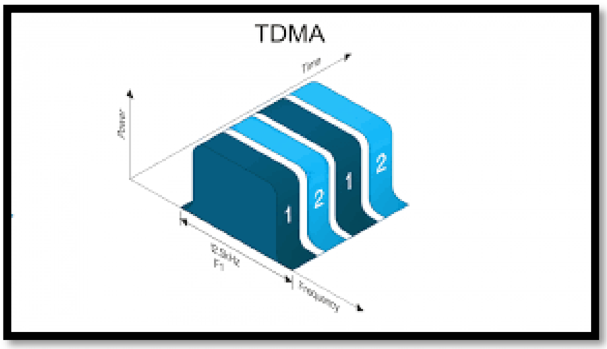

Fig.6. Figure illustrating the TDMA principle [24]

By the addition of a signature that is known to the receiver and is specific to each carrier. This ensures the identification of the carrier even when all the carriers occupy the same frequency band simultaneously. The signature is most often realized using pseudo-random code (pseudo-noise codes). The use of such codes has the effect of broadening the carrier spectrum.

III. Findings

It is noteworthy to recall that the ZACUBE-2 mission is to track vessels' activities in waters around the Southern region of Africa as well as detect fire threats in the same region. The problem at hand with the current AIS system South African satellites use experiences delays in transmitting frames to the ground stations and also that some vessels can go AIS dark.

Based on the techniques explored this study proposes the following methodology:

- (i.) Implementing triangulation techniques that will consist of using multiple receivers or ground stations. Having a second opinion would help mitigate uncertainties and possible inaccuracies. Currently, all the CubeSats that were launched under FSATI use one ground station based at the CPUT Bellville campus.
- (ii.) Avoiding AIS frames collision by carefully choosing the proper orbit for the CubeSat by considering constellations already in the orbit.
- (iii.) Increasing the detection probability using increasing the observation time.
- (iv.) Implementing the FDMA in terms of channel access instead of the TDMA that is associated with channel access delays and thus the AIS frames transmission delays.
- (v.) Implementing a system that can effectively calculate and provide information about the incident position and movement of vessels.

IV. Analysis and Discussion

Based on the findings of the study, the analysis of AIS messages is expected to be accurate in terms of the following:

Position and Movements: AIS messages provide vessel position information, typically in latitude and longitude coordinates. By analysing these positions over time, the movement patterns of vessels can be determined, including speed, heading, and course changes. This analysis can be used to monitor vessel movement, identify route deviations, or detect abnormal behaviour.

Identification Information: AIS messages contain various identification information about the vessel, such as MMSI (Maritime Mobile Service Identity), vessel name, call sign, and type of ship. This data can be analysed to identify and categorize different types of vessels in a given area.

Navigation Status: AIS messages also include information about the navigation status of vessels, such as whether they are underway, at anchor, moored, or aground. Analysing this data can help identify congested areas or potential hazards to navigation.

V. Conclusion

The study of AIS frames sent by CubeSats to the ground station will provide valuable insight into the performance and effectiveness of the AIS system on CubeSats which will be used to improve maritime safety, security, and management. With radio triangulation we will be able compare the signal strengths observed by different receivers, and an estimation of the vessel's location can be made.

It is important to note that radio triangulation for tracking vessels that go AIS dark has limitations. Factors such as limited range, signal interference, and vessel mobility can affect the accuracy and reliability of the tracking. Additionally, this method may not work if the vessel completely disables its radio communication systems.

Integrating AIS data into maritime space information systems is an advantage and provides further means for delivering objective and relevant information to promote dialogue. Depending on the length of AIS darkness, tracking a vessel with no AIS positions can be challenging. The longer the outage, the more possibilities there are for where it could have gone. However, there are a few avenues to explore which may yield results when tracking dark vessels.

References

[1] A. Harati-Mokhtari, A. Wall, P. Brooks, and J. Wang, "Automatic identification system (AIS): Data reliability and human error implications," *Journal of Navigation*, vol. 60, no. 3, pp. 373–389, Sep. 2007, doi: 10.1017/S0373463307004298.

[2] D.-P. Baker, "THE SOUTH AFRICAN NAVY AND AFRICAN MARITIME SECURITY," *Source: Naval War College Review*, vol. 65, no. 2, pp. 145–166, 2012, doi: 10.2307/26397290.

[3] G. Xu and Y. Xu, *GPS: Theory, algorithms and applications, third edition*. Springer Berlin Heidelberg, 2016. doi: 10.1007/978-3-662-50367-6.

[4] K. Korcz, "The issues of maritime radiocommunication on the WRC-19," *TransNav*, vol. 13, no. 3, pp. 597–604, Sep. 2019, doi: 10.12716/1001.13.03.16.

[5] D. Dzung, M. Naedele, T. P. Von Hoff, and M. Crevatin, "Security for industrial communication systems," in *Proceedings of the IEEE*, Institute of Electrical and Electronics Engineers Inc., 2005, pp. 1152–1177. doi: 10.1109/JPROC.2005.849714.

[6] "Fundamentals of Communications Systems," 2007.

[7] A. Sgora, D. J. Vergados, and D. D. Vergados, “A survey of TDMA scheduling schemes in wireless multihop networks,” *ACM Computing Surveys*, vol. 47, no. 3. Association for Computing Machinery, Apr. 01, 2015. doi: 10.1145/2677955.

[8] E. Hart and J. Timmis, “Application areas of AIS: The past, the present and the future,” *Applied Soft Computing Journal*, vol. 8, no. 1, pp. 191–201, Jan. 2008, doi: 10.1016/j.asoc.2006.12.004.

[9] M. Marabelli, S. Zaza, S. Masiero, J. Li, and K. Chudoba, “Diversity, Equity and Inclusion in the AIS: Challenges and opportunities of remote conferences,” *Information Systems Journal*, vol. 33, no. 6, pp. 1370–1395, Nov. 2023, doi: 10.1111/isj.12458.

[10] R. P. Argüelles, J. A. G. Maza, F. M. Martín, and M. Bartolomé, “Ship-to-ship dialogues and agreements for collision risk reduction,” *Journal of Navigation*, vol. 74, no. 5, pp. 1039–1056, Sep. 2021, doi: 10.1017/S0373463321000448.

[11] M. Rodger and R. Guida, “Mapping Dark Shipping Zones Using Multi-Temporal SAR and AIS Data for Maritime Domain Awareness,” in *International Geoscience and Remote Sensing Symposium (IGARSS)*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 3672–3675. doi: 10.1109/IGARSS46834.2022.9883797.

[12] F. Visser, F. Sagouo Minko, and R. R. van Zyl, “CUBESAT MISSION DESIGN FOR CHARACTERISING THE DUAL AURORAL RADAR NETWORK (SUPERDARN) FIELD OF VIEW,” 2011. [Online]. Available: https://www.researchgate.net/publication/305681733

[13] Institute of Electrical and Electronics Engineers and IEEE Geoscience and Remote Sensing Society, *2013 IEEE International Geoscience & Remote Sensing Symposium : proceedings : July 21-26, 2013, Melbourne, Australia*.

[14] D. Saltz, “Reporting Error Measures in Radio Location by Triangulation: A Review,” 1994. [Online]. Available: https://www.jstor.org/stable/3809567

[15] H. Liu, H. Darabi, P. Banerjee, and J. Liu, “Survey of wireless indoor positioning techniques and systems,” *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, vol. 37, no. 6. pp. 1067–1080, Nov. 2007. doi: 10.1109/TSMCC.2007.905750.

[16] *2011 International Conference on Information Fusion.* IEEE, 2011.

[17] A. Naz, H. M. Asif, T. Umer, and B. S. Kim, “PDOA Based Indoor Positioning Using Visible Light Communication,” *IEEE Access*, vol. 6, pp. 7557–7564, Jan. 2018, doi: 10.1109/ACCESS.2018.2796623.

[18] R. Yamasaki, A. Ogino, T. Tamaki, T. Uta, N. Matsuzawa, and T. Kato, “TDOA Location System for IEEE 802.11b WLAN,” 2005.

[19] G. K. Silber *et al.*, “The role of the International Maritime Organization in reducing vessel threat to whales: Process, options, action and effectiveness,” *Mar Policy*, vol. 36, no. 6, pp. 1221–1233, Nov. 2012, doi: 10.1016/j.marpol.2012.03.008.

[20] A. Yamazaki *et al.*, “Field-of-View Guiding Camera on the HISAKI (SPRINT-A) Satellite,” *Space Science Reviews*, vol. 184, no. 1–4. Kluwer Academic Publishers, pp. 259–274, Nov. 19, 2014. doi: 10.1007/s11214-014-0106-y.

[21] “A Comparison of Specific Space Diversity Techniques for Reduction of Fast Fading in UHF Mobile Radio Systems.”

[22] R. Prasadt and S. Harat, “An Overview of Multi-Carrier CDMA.”

[23] H. G. Myung, J. Lim, and D. J. Goodman, “Single Carrier FDMA for Uplink Wireless Transmission.”

[24] A. Sgora, D. J. Vergados, and D. D. Vergados, “A survey of TDMA scheduling schemes in wireless multihop networks,” *ACM Computing Surveys*, vol. 47, no. 3. Association for Computing Machinery, Apr. 01, 2015. doi: 10.1145/2677955.

First author:

Thandiwe Mnisi is a student at the Cape Peninsula University of Technology in the Department of Electrical Engineering in the program of Bachelor of Engineering Technology: Electrical Engineering (BET-EE). She is expected to graduate in Autumn 2024 and pursue her Honours studies in the same field. Her research interests lie in the Space Engineering she conducts under the hospices of the French South African Institute of Technology (FSATI).

Second author:

Janvier Kamanzi holds the degrees of Bachelor of Technology, a Master of Technology, and a Doctor of Engineering in Electrical, Electronic and Computer Engineering respectively obtained in 2012, 2014 and 2017 at the Cape Peninsula University of Technology (CPUT), Cape Town, South Africa. His research has focused on improving the yielding of solar systems of which one of the outcomes is a statically- sun-tracking technology applied in this paper.

Dr Kamanzi has been working as an academic at the CPUT since 2013.

Third author: