KINETIC STREET FURNITURE WITH ARM-Z

ELA ZAWIDZKA & MACHI ZAWIDZKI
Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland

ABSTRACT

Arm-Z is a concept of a hyper-redundant manipulator based on linearly joined sequence of congruent units. Each unit has only one degree of freedom (1-DOF), namely a twist relative to the previous unit in the sequence. Since each module is identical, Arm-Z has a potential of being economical and robust: the modules can be mass-produced and, in case of failure, easily replaced. However, the control of Arm-Z is nonintuitive and difficult, thus it usually requires application of computational intelligence methods. This paper presents a number of concepts for kinetic street furniture based on Arm-Z: a spiral column of adjustable height, a sun-tracking shade/solar energy harvester, bio-mimicry sculpture, kinetic sprinkler/fountain. The proposed concepts are low-tech in principle. Therefore in each case, the first module in the sequence is fastened to a solid base (ground). For simplicity, the drive is applied directly to the first module and transferred to subsequent units by internal gears. Each module is equipped with a set of cylindrical and bevel gears with straight teeth with involute profile (for connecting the modules).
Keywords: Arm-Z, extremely modular system, low-tech, street furniture.

1 INTRODUCTION

Sophisticated 3D tubular shapes can be built with simple congruent modules, as presented in Fuhs and Stachel [1]. An analogous parametric design system for creating 3D mathematical knots composed of only one type of unit has been introduced in Zawidzki and Nishinari [2]. Arm-Z is a concept of robotic manipulator based on the same idea, which has been introduced in Zawidzki and Nagakura [3]. Biological snakes are extremely well-adapted for various types of environment. It is mostly due to the high redundancy of the snake mechanism. In many cases of irregular environments the bio-inspired robots outperform traditional robots equipped with wheels, legs or tracks. The research on snake-like robots is carried out for several decades. This type of locomotion has been researched already in the 1940s [4]. Fifty years later a rigorous mathematical model of this locomotion has been developed. In the late 1990s, a trunk-like locomotors and manipulators have been introduced in Hirose [5]. Snake-like motion gives this type of manipulators certain advantage over conventional robotic manipulators in various environments. They are capable of operating in geometrically complex environments which are inaccessible for conventional robots and manipulators. Such snake-like robotic manipulators can be equipped with various types of working heads for: surveillance, cleaning, welding, etc., as shown in Fig. 1.

Conventional industrial manipulators have low number of degrees of freedom (DOF). On the other hand, bionic trunk-like or snake-line robotic arms have large (redundant) number of DOF. Arm-Z has as many DOFs as the number of modules minus one. Therefore Arm-Z can be categorized as a so-called *hyper* redundant manipulator (HRM) [6]. The inverse kinematic problem of a typical industrial manipulator can be solved easily [7], therefore, its control is straightforward. Conversely, since HRMs are highly non-linear, their control is not straightforward at all, and requires application of artificial intelligence methods [8]–[10]. For more information on this type of manipulators see Chirikjian and Burdick [11].

2 THE CONCEPT OF ARM-Z

Arm-Z modules are geometrical parametric objects analogous to sectors of a circular torus. Each module is defined by the following parameters: size *r*, offset *d*, and angle between

WIT Transactions on The Built Environment, Vol 209, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/HPSU220021

Figure 1: Oliver Crispin Robotics Ltd. Snake-arm robots, series II, X125 System. On the left: sleeved and integrated manipulator with a laser cutting head. On the right: unsleeved, integrated manipulator with inspection camera and light tool. *(Source: http://www.ocrobotics.com.)*

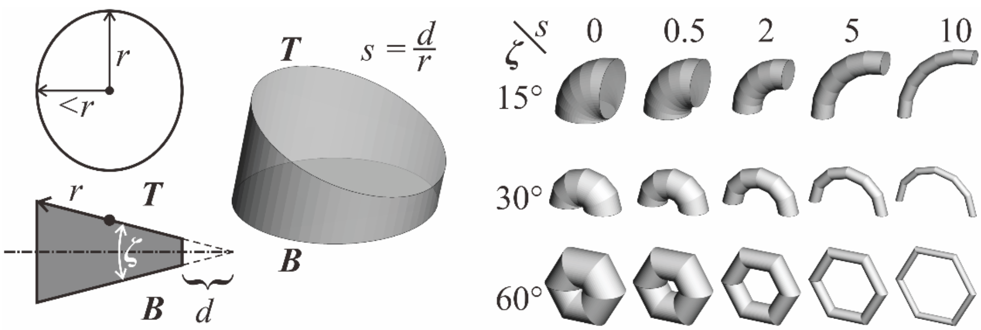

Figure 2: The geometric parameters defining Arm-Z module. On the right: a table with simple sequences of modules with various angles ζ and slenderness *s*.

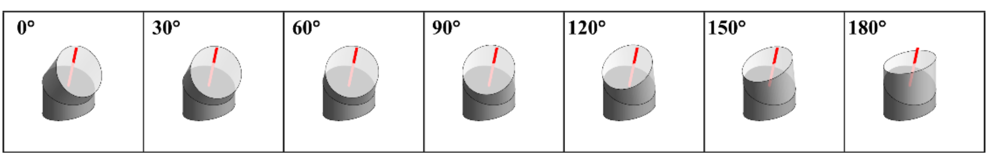

Figure 3: The bottom (dark gray) module is fixed to the base and does not rotate. The axis of rotation, which is perpendicular to the bottom face of the top module is shown in red.

bottom (**B**) and top (**T**) faces of the module – ζ, as illustrated in Fig. 2. Slenderness (s) is an additional parameter, that is a d to r ratio.

The overall shape of Arm-Z is a function of: the number of modules, the geometric parameters the module, and the sequence of relative twists between each pair of modules. Fig. 3 shows two modules at six successive twists from 0 to 180° in 30° steps.

3 STREET FURNITURE WITH ARM-Z

This section presents a few concepts of low-tech street furniture based on Arm-Z.

3.1 A spiral column of adjustable height

Columns are elements which transmit to structural members below the weight of the structure above. This architectural invention allows supporting of ceilings without the use of solid walls. Therefore the space spanned by a ceiling can increase. The first use of columns was as a single central support for the roof of relatively small buildings. More elaborated columns with aesthetic function, that is beyond mere structural support emerged since the Bronze Age (3000–1000 BC) in Minos, Assyria and Egypt.

The Solomonic column is a helical column in a form of a spiraling twisting corkscrew-like shaft. Probably the most famous Solomonic columns are Bernini's colossal bronze composite columns of the Baldachin in Saint Peter's Basilica (see Fig. 4).

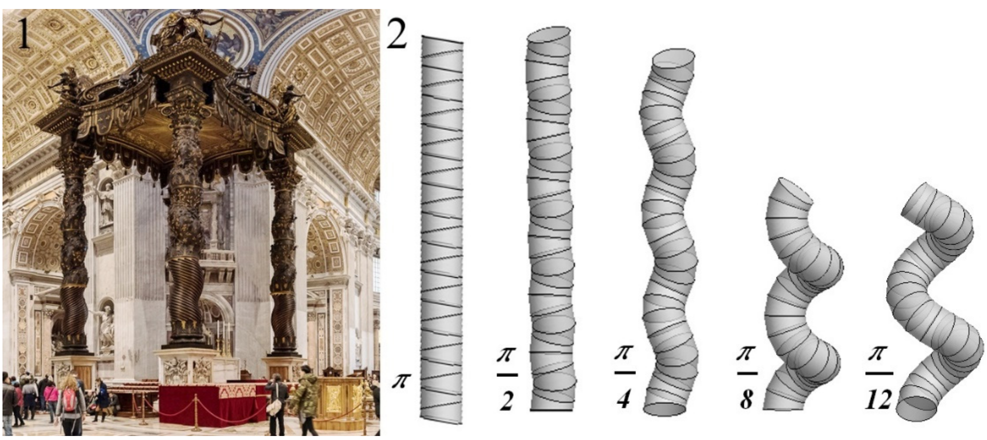

Figure 4: 1. Historical example of spiral columns: Bernini's Baldachin in St. Peter's Basilica (AD 1634). 2. Five examples of Arm-Z kinetic spiral columns controlled by relative twists (same for each unit, the values are shown for each case).

3.2 A sun-tracking shade/solar energy harvester

The prototype of the Arm-Z modular solar tracker has been described in our previous paper [12]. The purpose of such a device is to efficiently harvest solar energy or to serve as an active sun-shade. Fig. 5 on the left shows the sun direction to be followed by Arm-Z during summer (from the solstice to autumn equinox) between 10:00 and 18:00 hours. The positioning of Arm-Z in space and illustration of the tracking parameters are shown on the right.

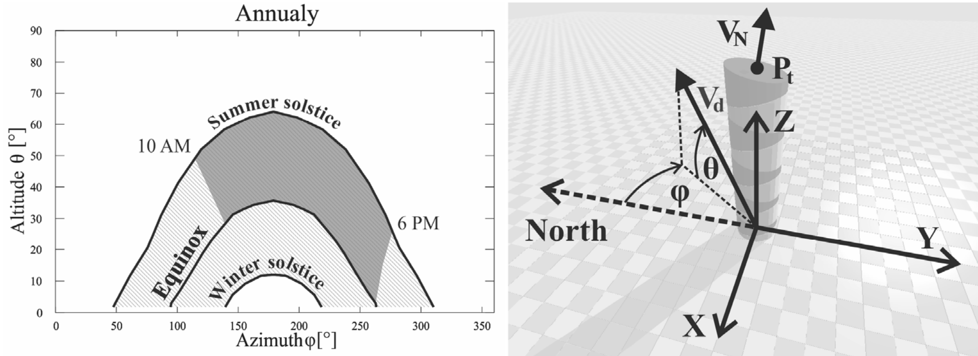

Figure 5: On the left: the sun positions during a year. Gray hatch indicates the considered tracking periods. On the right: the coordinate system, nomenclature and controlling parameters of the Arm-Z. $\mathbf{P_t}$ is the position of the tip of Arm-Z. $\mathbf{V_N}$ is the vector directing from the tip of Arm-Z. $\mathbf{V_d}$ is the sunlight direction. $\mathbf{V_d}$ (φ, θ) is a function of the azimuth angle φ and altitude θ.

The sun tracking is formulated here as minimization of the angle between vectors $\mathbf{V_N}$ and $\mathbf{V_d}$. This optimization problem has been solved in Zawidzka et al. [12] using dual annealing [13], [14]. Authors show there that Arm-Z with only four modules (three twisting and one fixed to the base) is capable of positioning its tip in almost all required directions. Fig. 6 shows more results of this optimization.

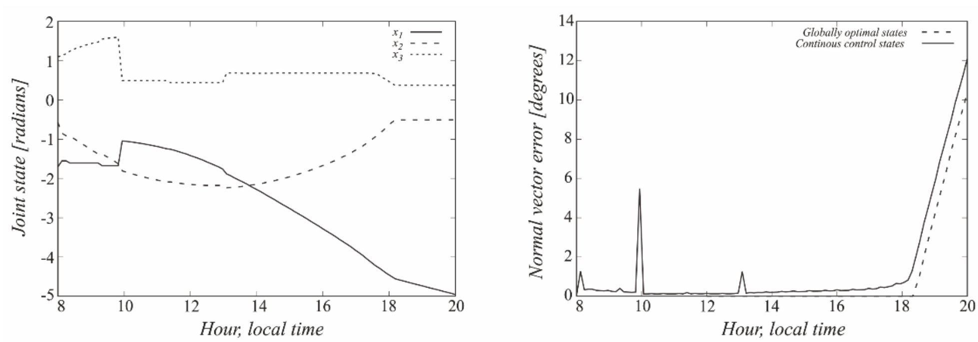

Figure 6: On the left: the relative rotations of the three twisting modules: x1, x2, x3 for a 4-unit Arm-Z following the sun on 1 July between 08:00 and 20:00. On the right: the errors, that is the differences between vector $\mathbf{V_N}$ and desired direction $\mathbf{V_d}$ for globally optimal states and for "smooth" action scenario.

A low-tech prototype of Arm-Z solar tracker has been designed and presented in Zawidzka et al. [12]. It was equipped with gears allowing for switching the spin of each unit (left/right) about its axis and transferring of the rotation to the next unit. The gear train has been equipped with so called "reverse switch". A special right/left lever switch has been placed in the side of each unit (see Fig. 7).

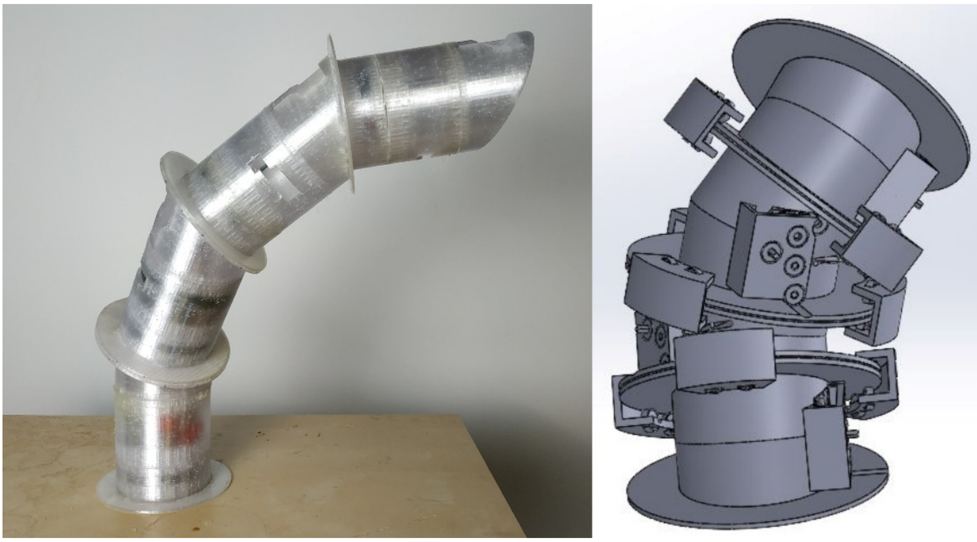

Figure 7: On the left: a photograph of preliminary 4-module Arm-Z. On the right: a computer model of a 4-module Arm-Z solar tracker.

It is would also be reasonable to install a larger Sun energy harvesting and/or shading element on the tip of Arm-Z, as shown in Fig. 8. In case of larger such elements it is also conceivable to synchronize three or more Arm-Zs as shown in the same figure.

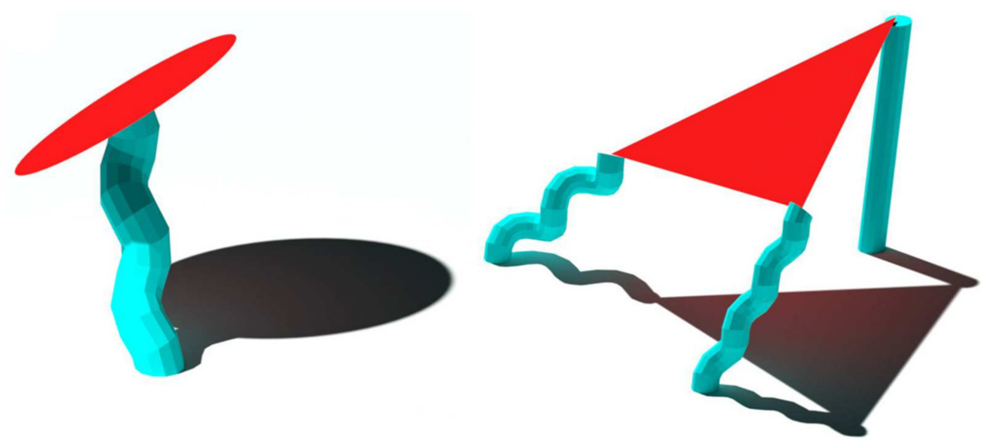

Figure 8: On the left: a single Arm-Z with larger shading/PV element. On the right (an elastic?) canopy stretched between three synchronized Arm-Zs.

3.3 Bio-mimicry sculpture

An Arm-Z with a dozen or so modules can perform a bio-mimic underwater seed-like motion. Fig. 9 shows selected time-steps of a random motion of a 12-module Arm-Z.

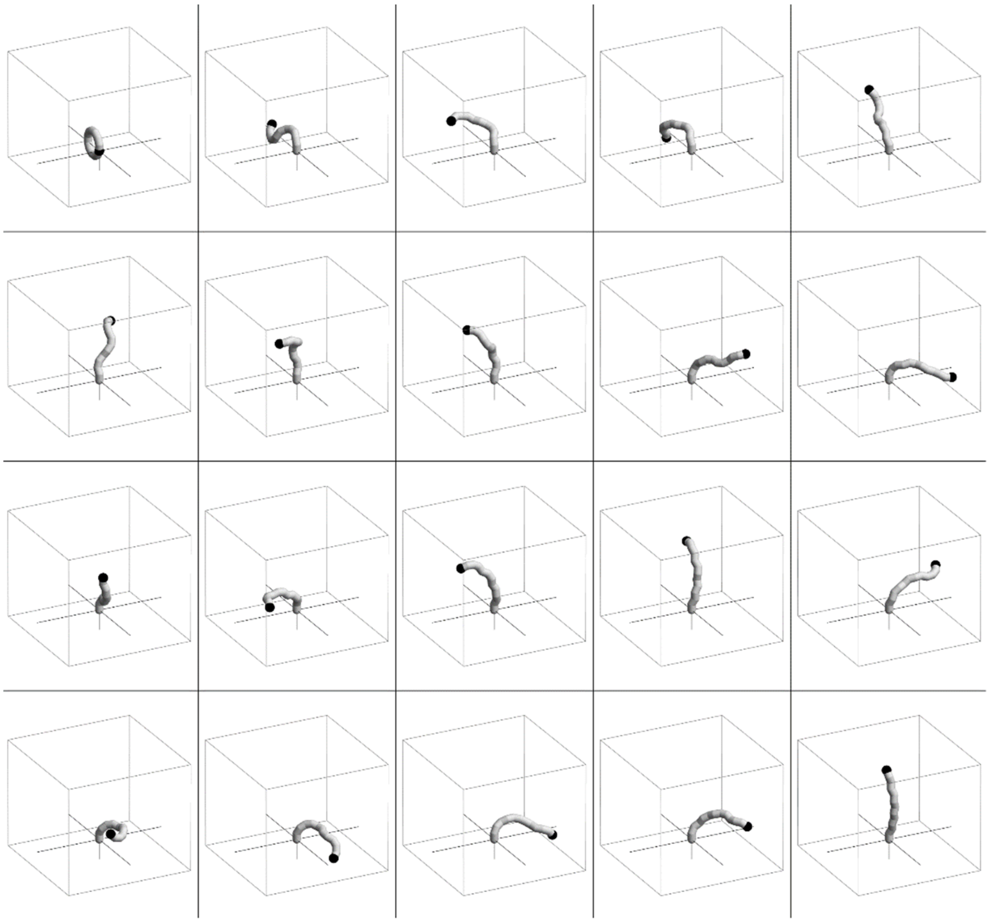

Figure 9: A 12-module Arm-Z “worm” in a random movement.

For an interactive demonstration of this Arm-Z see Zawidzki [15]. However, this concept would require either interdependent control of each module, or random (to a certain degree) rotation of each module. In any case it seems like a major challenge at this point.

3.4 Kinetic Arm-Z sprinkler/fountain

One of the approaches in building the arm-Z prototype was to place the gear system close to the external casing and leaving the center of the module hollow as shown in Fig. 10.

Such a sprinkler-Arm-Z could work either as a simple watering device performing a relatively straightforward circular motion, or could perform of an “unwinding/winding” motion, as illustrated in Fig. 11.

This is particularly interesting case, as it is relatively straightforward to make. From a torus configuration, where initially each subsequent module is at 0° of relative angle to the previous one, all modules simply perform a simultaneous 360° relative rotation and the entire structure returns to the initial toric state.

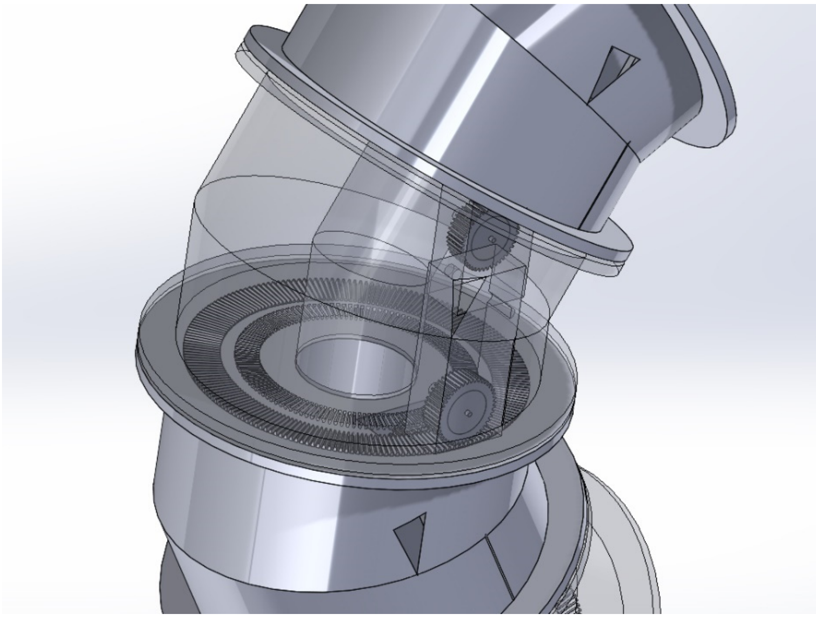

Figure 10: Hollow space inside each module of this type of Arm-Z module allows for installing a water-pipe.

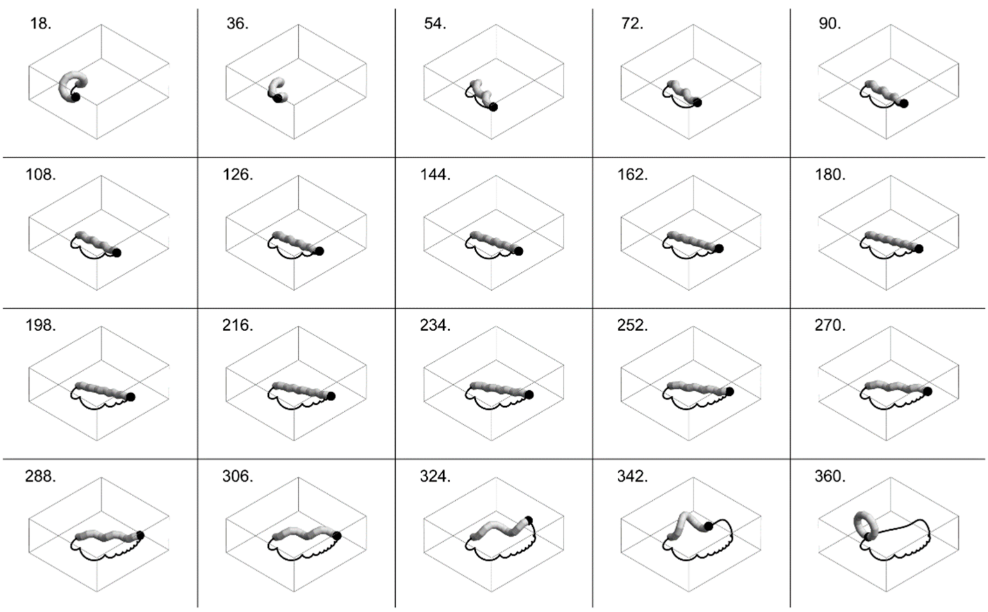

Figure 11: Selected time-steps of "unwinding" of a 12-module Arm-Z from torus into a straight pipe and back to torus. The relative twist is the same for each module and the value in degrees is shown for each frame. The trace of the tip of Arm-Z is shown as a black line.

4 CONCLUSIONS

- Arm-Z is in principle a very simple system, however, it can produce interesting behavior.
- These properties can be used for low-tech street furniture.
- Four types of such architectural elements have been presented.
- The prototypes are presently being developed.

ACKNOWLEDGEMENTS

This research is a part of the project titled "Arm-Z: an extremely modular hyper-redundant low-cost manipulator – development of control methods and efficiency analysis" and funded by OPUS 17 research grant No. 2019/33/B/ST8/02791 supported by the National Science Centre, Poland.

REFERENCES

[1] Fuhs, W. & Stachel, H., Circular pipe-connections. *Computers and Graphics*, **12**(1), pp. 53–57, 1988.

[2] Zawidzki, M. & Nishinari, K., Modular pipe-z system for three-dimensional knots. *Journal for Geometry and Graphics*, **17**(1), pp. 81–87, 2013.

[3] Zawidzki, M. & Nagakura, T., Arm-Z: A modular virtual manipulative. *Proceedings of the 16th International Conference on Geometry and Graphics*, pp. 75–80, 2014.

[4] Gray, J., The mechanism of locomotion in snakes. *Journal of Experimental Biology*, **23**(2), pp. 101–120, 1946.

[5] Hirose, S., *Biologically Inspired Robots: Snake-Like Locomotors and Manipulators*, Oxford University Press, 1993.

[6] Ning, K. & Worgotter, F., A novel concept for building a hyper-redundant chain robot. *IEEE Transactions on Robotics*, **25**(6), pp. 1237–1248, 2009.

[7] Murray, R.M., Li, Z., Shankar Sastry, S. & Shankara Sastry, S., *A Mathematical Introduction to Robotic Manipulation*, CRC Press, 1994.

[8] Rolf, M. & Steil, J.J., Efficient exploratory learning of inverse kinematics on a bionic elephant trunk. *IEEE Transactions on Neural Networks and Learning Systems*, **25**(6), pp. 1147–1160, 2014.

[9] Melingui, et al., Qualitative approach for forward kinematic modeling of a compact bionic handling assistant trunk. *IFAC Proc. Volumes*, **47**(3), pp. 9353–9358, 2014.

[10] Falkenhahn, V., Hildebrandt, A., Neumann, R. & Sawodny, O., Dynamic control of the bionic handling assistant. *IEEE/ASME Transactions on Mechatronics*, **22**(1), pp. 6–17, 2017.

[11] Chirikjian, G.S. & Burdick, J.W., A hyper-redundant manipulator. *IEEE Robotics and Automation Magazine*, **1**(4), pp. 22–29, 1994.

[12] Zawidzka, E., Szklarski, J., Kiński, W. & Zawidzki, M., Prototype of the Arm-Z modular solar tracker. *Conference on Automation*, Springer: Cham, pp. 273–282, 2022.

[13] Xiang, Y., Sun, D.Y., Fan, W. & Gong, X.G., Generalized simulated annealing algorithm and its application to the Thomson model. *Physics Letters A*, **233**(3), pp. 216–220, 1997.

[14] Virtanen, et al., SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, **17**, pp. 261–272, 2020.

[15] Zawidzki, M., Modeling of Arm-Z with AnglePath3D. Wolfram Demonstrations Project, 2020. http://demonstrations.wolfram.com/ModelingOfArmZWithAnglePath3D/.