SPYDER ROBOT

Project Report

Robotics Club

Designed by

Robotics Core Members

2024-2025

Under the guidance of

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Accredited by NBA

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Abstract

The Spyder robot project focuses on developing a modular, serpentine robot capable of emulating the distinct gaits of lateral undulation and sidewinding locomotion, inspired by the natural flexibility and adaptability of snakes. By utilizing lateral undulation, the robot can achieve high-speed movement on standard surfaces, while sidewinding provides stability and manoeuvrability over challenging terrains, such as slippery or uneven ground. This versatile gait-hybrid approach allows the Spyder robot to efficiently traverse complex environments with minimal power expenditure.

Designed to be compact, low-cost, and low-power, the Spyder robot has significant potential for applications in various fields. Its ability to access restricted or hard-to-reach areas makes it a valuable tool for search and rescue missions, stealth operations, and wildlife research. This project aims to harness the unique advantages of snake-like motion to create a reliable, adaptable robotic solution for environments where conventional wheeled or legged robots would struggle.

Mechanical Design

The Spyder robot's design incorporates a partitioned gait template inspired by snake locomotion, providing both flexibility and adaptability across various terrains. The robot measures 823.3 mm in length, 70 mm in width, and 68 mm in height, with a weight of 2.75 kg (excluding off-board controllers). Built for traversing uneven and three-dimensional environments, the robot consists of 12 modular segments connected by a total of 12 servo motors, arranged in alternating pitch and yaw joints to facilitate lateral and dorsoventral deformations.

To reproduce the anisotropic friction profile that is key to snake movement, each pitch segment includes a pair of one-way wheels with a 12 mm diameter and rubber O-ring. Using a ratchet mechanism, these wheels unlock when rotating forward but lock in reverse, creating low forward rolling friction and high backward sliding friction, along with substantial lateral sliding friction. Tests confirmed this frictional profile, allowing the robot to efficiently utilize lateral undulation on flat surfaces.

This careful combination of modular design, frictional mechanisms, and servo motor configuration enables the Spyder robot to adapt to complex terrains, making it effective for challenging environments and applications requiring high mobility.

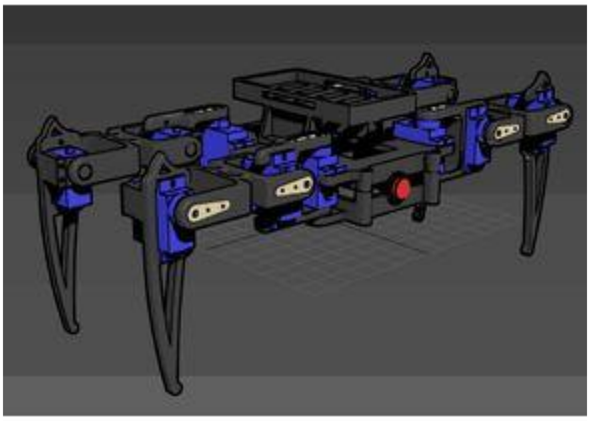
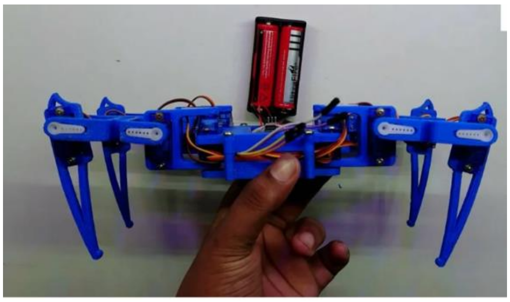


Fig.

The figure shows a CAD model of a legged robot with articulated legs, designed for stability and manoeuvrability. The frame includes mounts for electronics, and servo connections allow independent leg movement for flexible navigation.

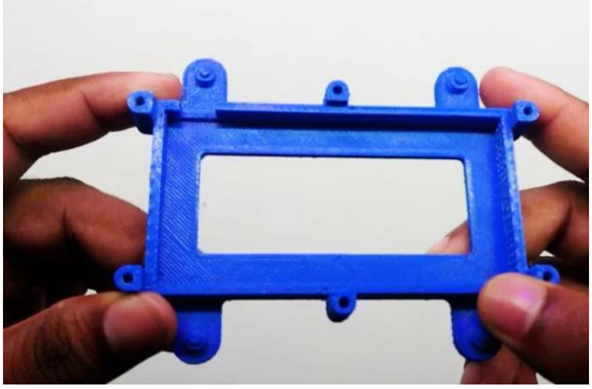
Design Inspiration

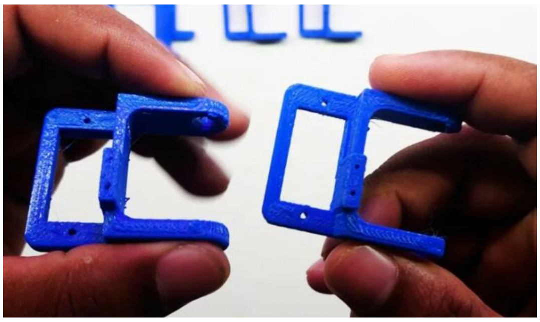
The Spyder robot is a hyper-redundant, modular robotic system designed to emulate the movement of snakes, providing high adaptability and efficiency across challenging terrains. Built with 12 servomotors and linked segments, the Spyder robot leverages both lateral undulation and sidewinding gaits for versatile mobility. This design allows the robot to move swiftly over flat surfaces with lateral undulation and navigate complex, slippery, or uneven environments through sidewinding locomotion.
Inspired by pioneering work in snake robotics, the Spyder robot incorporates bio-inspired control techniques to achieve smooth, cyclic motions. With an anisotropic friction profile facilitated by one-way wheels, it achieves low forward friction and high backward and lateral friction, ensuring stability and grip on varied surfaces. This approach makes the Spyder robot a valuable tool for applications in search and rescue, stealth operations, and wildlife research, where access to confined or hazardous areas is essential.

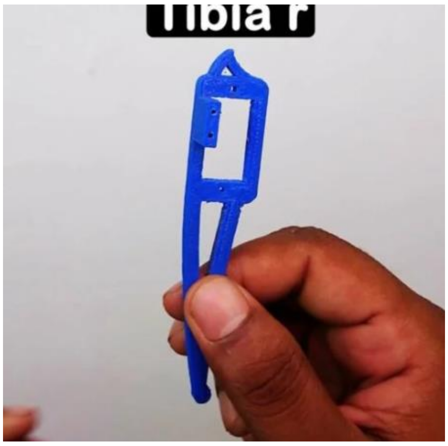


Design Process

The Spyder robot utilizes 3D printing technology for rapid prototyping and iterative design, reducing both design time and cost. The final structure is built from PETG (Polyethylene Terephthalate Glycol), chosen for its balance of structural strength and lightweight properties, which enhances the robot's flexibility and movement efficiency. For easy assembly and maintenance, the robot components are secured using socket head cap screws, simplifying disassembly.
To ensure stability, the internal circuitry and battery are mounted on the Servo Mount frame, providing resistance to shaking and movement. Each joint incorporates a "Hardy-Lock Type Mechanism," offering protection from water and debris, critical for operating in various environments. The robot’s head, made from a scratch-resistant plastic compound, is designed to be durable and wear-resistant while maintaining clear camera visibility and minimizing visual distortion, optimizing it for high compatibility with rough terrains and camera-based operations.







Materials Used

Given the tight space and weight constraints in the Spyder robot, careful material selection was essential. Materials needed to provide a balance between durability and lightweight properties, especially considering environmental exposure and operational demands. After testing thermoplastics such as PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), and PETG (Polyethylene Terephthalate Glycol), PETG emerged as the optimal choice for this application.

PETG was selected due to its reliable mechanical properties, including a high specific heat capacity (2400 J/kg-K) and a stable glass transition temperature (85°C), which offers resilience in varied environmental conditions. PETG's durability, even under sunlight exposure, ensures that the robot maintains structural integrity, minimizes deformation, and resists radiation and thermal variations. Additionally, PETG’s compactness supports the robot's modular design without compromising on weight or volume, making it ideal for maintaining performance in challenging environments.

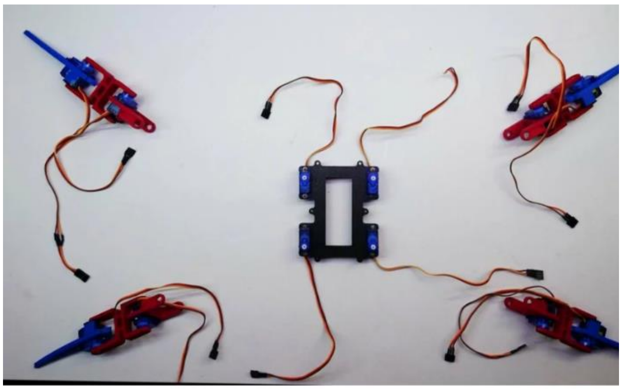


Table 1: Material Properties

Material	Specific Heat Capacity (J/kg-K)	Glass Transition Temperature (°C)
PLA	1800	60
ABS	2200	105
PETG	2400	85

ELECTRONICS

The primary purpose of the electronics in the bot is to actuate the joints of the snake in such a manner that lateral undulation and sidewinding locomotion can be emulated. To this end, we make use of the following electronic components:

Components used:

1) **SG90 Servo:**

    a) The SG90 servo is a lightweight and compact servo motor ideal for applications in small robotic projects like the Spyder robot. It offers a torque of approximately 2.5 Kgf.cm at an operating voltage of 5V, making it suitable for tasks that require moderate power without sacrificing speed and agility.

    b) This servo operates efficiently within a temperature range of -10°C to 50°C, ensuring reliable performance in various environmental conditions, from cool to moderately warm.

    c) Measuring just 22.5 x 11.5 x 31 mm, the SG90 servo is designed to fit seamlessly into tight spaces in compact robotic designs while still providing enough torque for effective motion control of joints and mechanisms.

Fig. 19: Sg90 Servo Motor

2) **LM-2596 DC-DC Converter:**
    a) The LM-2596 functions as a buck converter, to step down the resultant voltage of 7.5V from the batteries to 6.5V to prevent the servos from getting damaged.
    b) It also delivers a constant supply of voltage to the servos to prevent the windings from getting damaged.

Fig. 20: Top view of an LM-2596 DC-DC converter.

3) **FlySky - I6 Transmitter:**

   a) FlySky - i6 transmitter functions as the remote control with which we give commands to the Arduino Nano through the FlySky - r6b receiver.

   b) It has six different radio channels to allow us a wide range of customisation with regards to the commands that can be provided.

   c) It has an inbuilt display to easily calibrate and customize the radio channels, update the firmware and show the amount of charge left in the batteries.

Fig. 21: An FS-I6 transmitter module out-of-the-box

4) **FlySky - R6B Receiver:**

a) FlySky - R6B receiver module takes the commands sent by the FS - I6 transmitter and sends them to the Arduino Nano.

b) It has a range of upto 2 Km, allowing for very long range control when coupled with the video and audio feed from the camera.

c) It has an RF range of 2.405Hz - 2.475Hz with a bandwidth of 500 KHz, meaning it does not interfere with any other radio signals.

Fig. 22: Top view of FS-R6B receiver module

5) **3.7V/1950 mAH LiPo batteries:**

a) These batteries power the servo motors. We connect two 3.7V batteries in series to deliver 7.5V to the LM-2596 which steps it down to 6.5V.

b) With a capacity of 1950 mAH, the batteries can easily power the servos for more than 90 minutes, with a theoretical maximum runtime of 2.1 hours (130 minutes).

Fig. 24: A standard 3.7V/1950mAh LiPo battery.

6) **18650 batteries:**

a) These batteries are used to power the Arduino Nano and the V380 camera.

b) Their cylindrical shape means that they are the better choice for the head module, as their output can easily be boosted to the required 5V using the battery shield.

c) They have a capacity of 2200 mAh, meaning they can power the Nano for 115 hours and the camera for 2 hours.

Fig. 25: A variant of the commonly used 18650 battery

7) **Arduino Nano:**

a) The Nano is the primary processing unit of the bot, performing all the necessary computations to provide signal bits to the servo motors to replicate snake gaits at the joints of the snake.

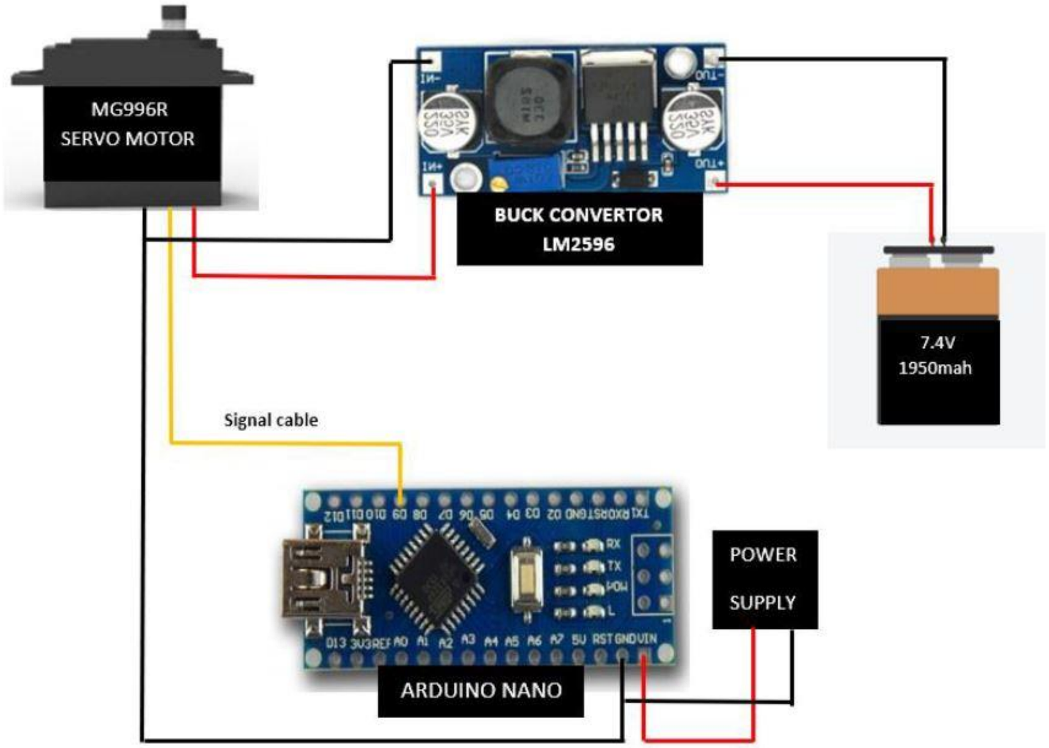
b) The Nano is powered by an ATmega 328, which has 32 KB Flash memory, 1 KB EEPROM and 2KB of SRAM which provides ample memory to write the code required.

c) It has 22 digital and 8 analog pins which are more than sufficient to connect all the MG-996R servos and the FS-R6B receiver.

d) It draws a measly 19mA of current, making it ideal for battery-driven applications such as this.

<u>Fig. 26:</u> Top view of Arduino Nano showcasing its pin layout.

<u>Circuit Diagram:</u>



Circuit diagram of a single segment connected to Master Arduino

Camera Module with Power supply

Source Code

Software Used:

The only software we use throughout the project is the Arduino IDE, which is an open-source software that provides a GUI to write code for the Arduino board, as well as allows us to upload the code to the Arduino. It also provides a single platform to download and manage all the third-party libraries that a developer might use, with easy update and downgrade functionality.

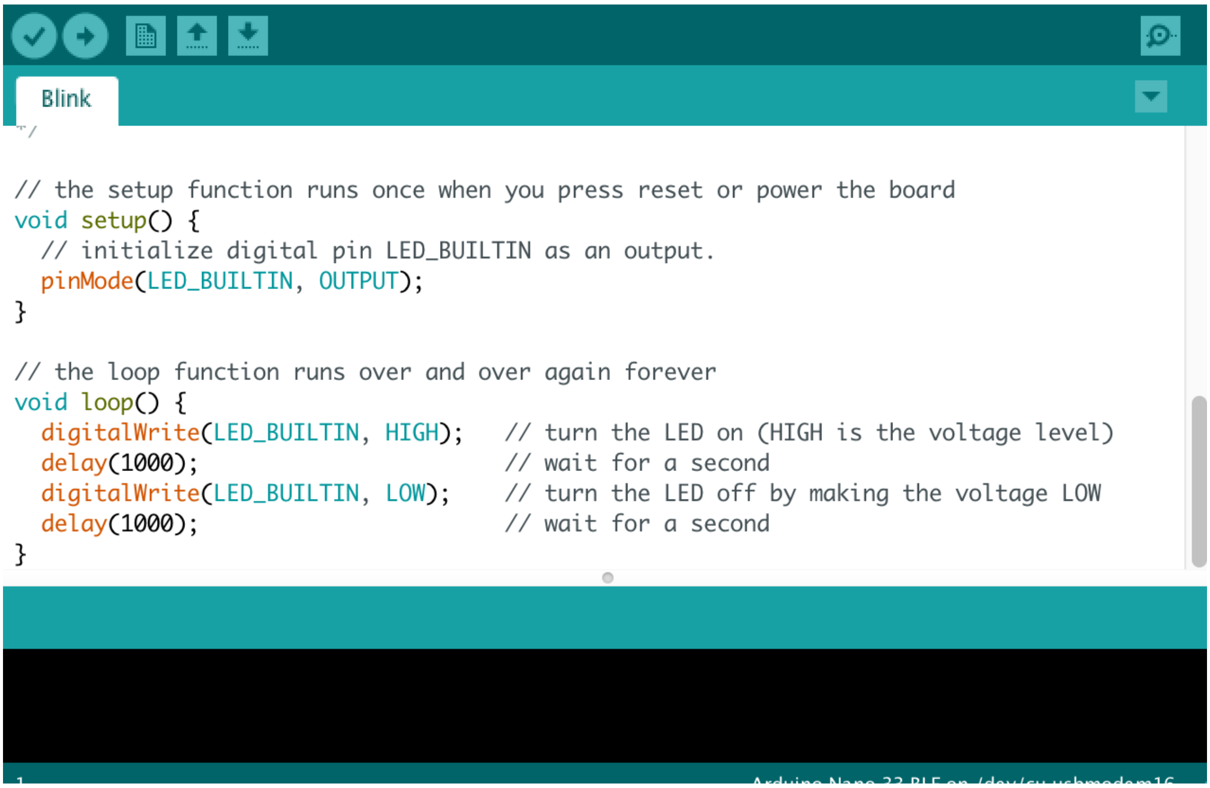


Fig. 27: Arduino IDE with code for the "blink" example.

Libraries Used:

We only make use of the Servo library, which allows us to control Servo motors using the PWM pins that are present on the Arduino Nano. No additional libraries are necessary.

Brief explanation:

Arduino code is written in a special version of C++, with additional libraries and functions. The Arduino IDE compiles and then translates this C++ code into machine language, allowing the ATmega 328 onboard to understand the commands supplied.

a) Lateral Undulation

```
for(int i=0; i<360; i++){
   rads=i*pi/180.0;
   for(int j=0; j<8; j+=2){
      myServos[j].write(90+offset+Amplitude*sin(Speed*rads+j*Wavelengths*Shift));
     }
   delay(10);
  }
}
```

<u>Fig.28:</u> The primary logic behind lateral undulation

In order to achieve lateral undulation, we propagate a sine wave through all the laterally oriented, i.e, all the evenly numbered servos. The sine wave successfully replicates the zig-zag motion that snakes use in order to navigate from one point to another. Changing the offset variable allows us to change the direction of the snake, while the speed variable increases the rate of sine wave propagation allowing the snake to move faster.

b) Sidewinding Locomotion

```
for(int i=0; i<360; i++){
   rads=i*pi/180.0;
   for(int j=0; j<4; j++){
      myServos[2*j].write(90+offset+amplitude*sin(Speed*rads+j*Wavelengths*shift-(Multiplier-1)*pi/4));
      myServos[2*j+1].write(90+offset+amplitude*sin(Speed*rads+j*Wavelengths*shift+(Multiplier+1)*pi/4));
   }
   delay(10);
  }
}
```

<u>Fig.28:</u> The primary logic behind sidewinding locomotion

Conclusions Drawn

1. The primary objective of the Spyder robot project is to explore and enhance the locomotion capabilities of a compact, modular, snake-like robot, focusing on its performance in various challenging terrains, including slopes and uneven surfaces.
2. The Spyder robot successfully emulates serpentine locomotion through the precise control of joint angles, allowing it to navigate complex environments with agility and efficiency.
3. The implementation of both lateral undulation and sidewinding locomotion techniques has been effectively demonstrated, showcasing the robot's versatility in movement.
4. Sidewinding locomotion has proven particularly advantageous for traversing slippery and unstable surfaces, enhancing the robot's ability to maintain traction and stability.
5. The analysis of the Spyder robot's physical behaviours indicates that inclines significantly impact its locomotion by introducing gravitational forces that affect balance and movement, thereby reducing the maximum achievable frictional force and necessitating adjustments in joint actuation for optimal performance.

Future Work

The future work of this research involves collecting extensive data on the motion characteristics of the Spyder robot in combined sloped environments and irregular terrain surfaces. This data will facilitate the development of advanced control strategies that enable the robot to effectively track both position and velocity while navigating complex landscapes.

Bibliography

[1] G. Chirikjian and J. Burdick. The kinematics of hyper-redundant robot loco motion. IEEE Transactions on Robotics and Automation, 11(6):781–793, 1995. 1

[2] S. Hirose. Biologically Inspired Robots. Oxford University Press, 1993. 1,2

[3] B. Y. S. Hirose and H. Yamada. Snake-Like Robots. IEEE Robotics & Automation Magazine, (March):88–98, 2009. 1

[4] H. Ohno and S. Hirose. Design of slim slime robot and its gait of locomotion. Proceedings 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems., pages 707–715, 2001. 1,2

[5] M. Hara, S. Satomura, H. Fukushima, T. Kamegawa, H. Igarashi, and F. Matsuno. Control of a Snake-like Robot Using the Screw Drive Mechanism. Proceedings 2007 IEEE International Conference on Robotics and Automation, 28(3):541–554, Apr. 2007. 1

[6] T. Kamegawa, T. Harada, and A. Gofuku. Realization of cylinder climbing locomotion with helical form by a snake robot with passive wheels. In IEEE International Conference on Robotics and Automation (ICRA), pages 3067–3072, Kobe, Japan, 2009. 1

[7] C. Wright, A. Buchan, B. Brown, J. Geist, M. Schwerin, D. Rollinson, M. Tesch, and H. Choset. Design and Architecture of the Unified Modular Snake Robot. In IEEE International Conference on Robotics and Automation (ICRA), pages 4347–4354, St. Paul, USA, 2012. 1,2

[8] C. Wright, A. Johnson, A. Peck, Z. McCord, A. Naaktgeboren, P. Gianfortoni, M. Gonzalez-Rivero, R. L. Hatton, and H. Choset. Design of a Modular Snake Robot. Proceedings of the IEEE International Conference on Intelligent Robots and Systems, Oct. 2007. 1

[9] M. Yim, D. Duff, and K. Roufas. PolyBot: A Modular Reconfigurable Robot. In IEEE International Conference on Robotics and Automation (ICRA), pages 514–520, San Francisco, USA, 2000. 1

[10] M. Yim, W. Shen, and B. Salemi. Modular self-reconfigurable robot systems. Robotics (March), 2007. 1

[11] G. Chirikjian and J. Burdick. A modal approach to hyper-redundant manipulator kinematics. IEEE Transactions on Robotics and Automation, 10(3):343–354, June 1994. 1

[12] J. Gonzalez-Gomez, H. Zhang, E. Boemo, and J. Zhang. Locomotion capabilities of a modular robot with eight pitch-yaw-connecting modules. In 9th international conference on climbing and walking robots. Citeseer, 2006. 1

[13] H. Ohno and S. Hirose. Design of slim slime robot and its gait of locomotion. Proceedings 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems., pages 707–715, 2001. 1,2

[14] S. Hirose. Biologically Inspired Robots. Oxford University Press, 1993. 1, 2

[15] H. Yamada and S. Hirose. Approximations to continuous curves of Active Cord Mechanism made of arc-shaped joints or double joints. In IEEE International Conference on Robotics and Automation (ICRA), pages 703–708. IEEE, 2010. 1,2

[16] H. Yamada and S. Hirose. Steering of pedal wave of a snake-like robot by superposition of curvatures. In IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pages 419–424. IEEE, 2010. 1

[17] J. Gonzalez-Gomez, H. Zhang, E. Boemo, and J. Zhang. Locomotion capabilities of a modular robot with eight pitch-yaw-connecting modules. In 9th international conference on climbing and walking robots. Citeseer, 2006. 1

[18] A. Ijspeert and A. Crespi. Online trajectory generation in an amphibious snake robot using a lamprey-like central pattern generator model. In IEEE International Conference on Robotics and Automation (ICRA), pages 262–268. Ieee, Apr. 2007. 1

[19] M. Tesch, K. Lipkin, I. Brown, R. L. Hatton, A. Peck, J. Rembisz, and H. Choset. Parameterized and Scripted Gaits for Modular Snake Robots. Advanced Robotics, 23(9):1131–1158, June 2009. 1,2

[20] G. Chirikjian and J. Burdick. The kinematics of hyper-redundant robot locomotion. IEEE Transactions on Robotics and Automation, 11(6):781–793, 1995. 1

[21] G. Chirikjian and J. Burdick. A modal approach to hyper-redundant manipulator kinematics. IEEE Transactions on Robotics and Automation, 10(3):343–354, June 1994. 1

[22] A. A. Transeth. Modelling and Control of Snake Robots. PhD thesis, Norwegian University of Science and Technology (NTNU), 2007. 1

[23] A. A. Transeth, K. Y. Pettersen, and P. l. Liljebäck. A survey on snake robot modeling and locomotion. Robotica, 27(07):999, Mar. 2009. 1

[24] Gart SW, Mitchel TW, Li C. 2019 Snakes partition

their body to traverse large steps stably. J. Exp. Biol. 59, jeb185991. (Doi:10.1242/jeb.185991)

[25] Hu DL, Nirody J, Scott T, Shelley MJ. 2009 The mechanics of slithering locomotion. Proc. Natl Acad. Sci. USA 106, 10 081–10 085. (Doi:10.1073/pnas.0812533106)

[26] Chirikjian GS, Burdick JW. 1995 The kinematics of hyper-redundant robot locomotion. IEEE Trans. Robot. Autom. 11, 781–793. (Doi:10.1109/70.478426)

[26] Gart SW, Mitchel TW, Li C. 2019 Snakes partition their body to traverse large steps stably. J. Exp. Biol. 59, jeb185991. (Doi:10.1242/jeb.185991)

[27] Fr´ed´eric Boyer and AymanBelkhiri, “Reduced Locomotion Dynamics with Passive Internal DoFs: Application to Nonholonomic and Soft Robotics”, IEEE Transactions on Robotics, vol. 30, no. 3, pp. 578-592, June 2014.

[28] Fr´ed´eric Boyer, Shaukat Ali, and Mathieu Porez, “Macrocontinuous Dynamics for Hyperredundant Robots: Application to Kinematic Locomotion Bioinspired by Elongated Body Animals”, vol. 28, no. 2, pp. 303-316, IEEE Transactions on Robotics, April 2012.

[29] Aksel Andreas Transeth, Remco I. Leine, ChristophGlocker, Kristin Ytterstad Pettersen and P°alLiljeb¨ack, “Snake Robot Obstacle-Aided Locomotion: Modeling, Simulations, and Experiments”, IEEE Transactions on Robotics, vol. 24, no. 1, pp. 88-104, February 2008.

[30] Rollinson, D.; Bilgen, Y.; Brown, B.; Enner, F.; Ford, S.; Layton, C.; Rembisz, J.; Schwerin, M.; Willig, A.; Velagapudi, P. Design and architecture of a series elastic snake robot. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots & Systems, Chicago, IL, USA, 14–18 September 2014.

[31] Bing, Z.; Cheng, L.; Chen, G.; RaHrbein, F.; Huang, K.; Knoll, A. Towards autonomous locomotion: CPG-based control of smooth 3D slithering gait transition of a snake-like robot. Bioinspire. Biomimetics 2017, 12, 035001.

[32] Melo, K. Modular snake robot velocity for side-winding gaits. In Proceedings of the 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, USA, 26–30 May 2015; pp. 3716 3722.

[33] Kajita, S.; Hirukawa, H.; Harada, K.; Yokoi, K. Introduction to Humanoid Robotics; Springer: Berlin, Germany, 2014; Volume 101.

[34] Yamada, H.; Hirose, S. Approximations to continuous curves of Active Cord Mechanism made of arc-shaped joints or double joints. In Proceedings of the IEEE International Conference on Robotics & Automation, Anchorage, AK, USA, 3–7 May 2010.

[35] Oprea, J. Differential Geometry and Its Applications; American Mathematical Soc.: Providence, RI, USA, 2019; Volume 59.

[36] S. Hirose and H. Yamada, “Snake-like robots,” IEEE Robotics Automation Magazine, vol. 16, no. 1, pp. 88–98, 2009.

[37] S. Ma, N. Tadokoro, B. Li, and K. Inoue, “Analysis of creeping locomotion of a snake robot on a slope,” 2003 IEEE International Conference on Robotics and Automation, pp. 15–23.

[38] S. Ma, “Analysis of creeping locomotion of a snake-like robot,” Advanced Robotics, vol. 15, no. 2, pp. 205–224, 2001.

[39] A. Saha, R. P. Chatterjee, and U. Dutta, “Motion control of snake robot by lead-lag compensator designed with frequency domain approach.” World Scientific and Engineering Academy and Society (WSEAS), 2009, pp. 13–20.

[40] S. Ma, N. Tadokoro, B. Li, and K. Inoue, “Analysis of creeping locomotion of a snake robot on a slope,” 2003 IEEE International Conference on Robotics and Automation, pp. 15–23.