A Review on Perception-driven Obstacle-aided Locomotion for Snake Robots

Filippo Sanfilippo[1], **Jon Azpiazu**[2], **Giancarlo Marafioti**[2], **Aksel A. Transeth**[2], **Øyvind Stavdahl**[1] and **Pål Liljebäck**[1]

[1]Dept. of Engineering Cybernetics, Norwegian University of Science and Technology, 7491 Trondheim, Norway
Email: filippo.sanfilippo@ntnu.no

[2]Dept. of Applied Cybernetics, SINTEF ICT, 7465 Trondheim, Norway
Email: see http://www.sintef.no/

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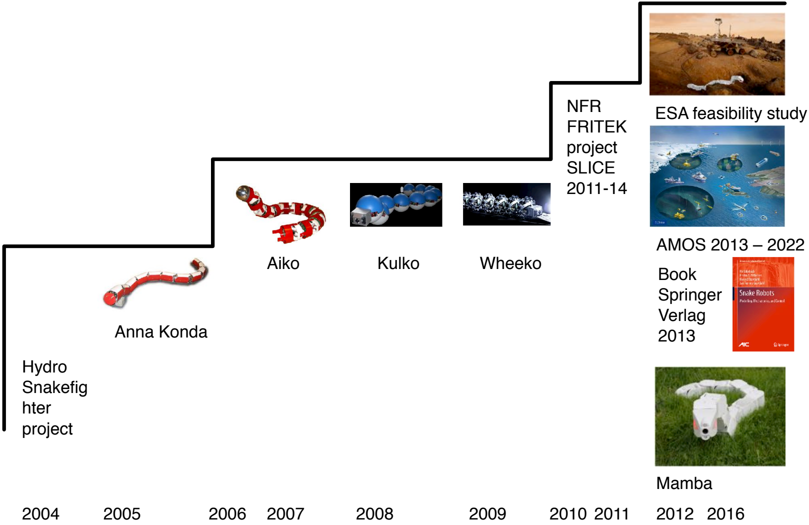
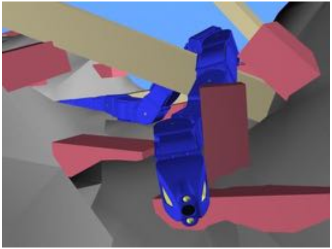
Summary

Biological snakes capabilities

Our research group



Bio-inspired robotic snakes



Building a robotic snake with such agility:

- different applications in challenging real-life operations, pipe inspection for oil and gas industry, fire-fighting operations and search-and-rescue.

***Obstacle-aided locomotion*:**

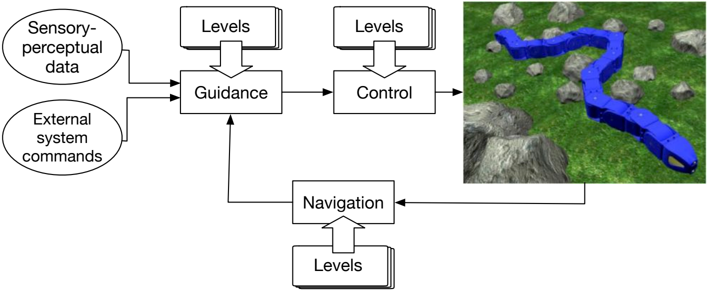
- snake robot locomotion in a cluttered environment where the snake robot utilises walls or external objects, other than the flat ground, for means of propulsion.

[1,2]

[1] A.A. Transeth et al. "Snake Robot Obstacle-Aided Locomotion: Modeling, Simulations, and Experiments". In: *IEEE Transactions on Robotics* 24.1 (Feb. 2008), pp. 88–104. ISSN: 1552-3098. DOI: 10.1109/TRO.2007.914849.

[2] Christian Holden, Øyvind Stavdahl, and Jan Tommy Gravdahl. "Optimal dynamic force mapping for obstacle-aided locomotion in 2D snake robots". In: *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Chicago, Illinois, United States*. 2014, pp. 321–328.

Perception-driven obstacle-aided locomotion



Perception-driven obstacle-aided locomotion:

- locomotion where the snake robot utilises a sensory-perceptual system to perceive the surrounding operational environment, for means of propulsion.

- Sensory-perceptual data and external system commands as input for the guidance system (decision-making, path-planning and mission planning activities).
- The navigation system achieves all the functions of perception, mapping and localisation.
- The control system is responsible for low-level adaptation and control tasks.

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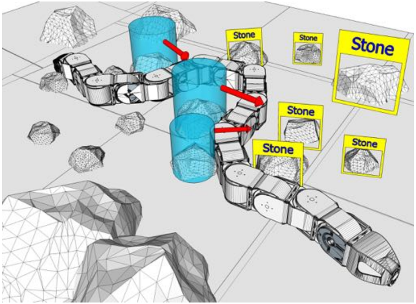
Underlying idea and contribution



Contribution:

- review and discussion of the state-of-the-art, challenges and possibilities of perception-driven obstacle-aided locomotion for snake robots.
- current strategies for snake robot locomotion in the presence of obstacles.
- overview of relevant key technologies and methods within environment perception, mapping and representation.

Motion across smooth, usually flat, surfaces

Existing literature:

- motion across smooth, usually flat, surfaces;
- various approaches to mathematical modelling of snake robot to analyse different control strategies[3].
- many of the models focus purely on kinematic aspects of locomotion[4,5], while more recent studies also include the dynamics of motion[6,7].

- However, many real-life environments are not smooth, but cluttered with obstacles and irregularities.

[3] Pål Liljebäck et al. *Snake Robots: Modelling, Mechatronics, and Control*. en. Springer Science & Business Media, June 2012. ISBN: 978-1-4471-2996-7.

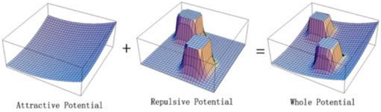
[4] G. S. Chirikjian and J. W. Burdick. "The kinematics of hyper-redundant robot locomotion". In: *IEEE Transactions on Robotics and Automation* 11.6 (Dec. 1995), pp. 781–793. ISSN: 1042-296X. DOI: 10.1109/70.478426.

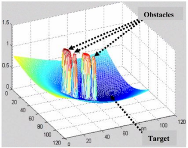
[5] Jim Ostrowski and Joel Burdick. "The Geometric Mechanics of Undulatory Robotic Locomotion". en. In: *The International Journal of Robotics Research* 17.7 (July 1998), pp. 683–701. ISSN: 0278-3649, 1741-3176. DOI: 10.1177/027836499801700701. URL: http://ijr.sagepub.com/content/17/7/683 (visited on 03/02/2016).

[6] Pavel Prautsch, Tsutomu Mita, and Tetsuya Iwasaki. "Analysis and Control of a Gait of Snake Robot". In: *IEEJ Transactions on Industry Applications* 120.3 (2000), pp. 372–381. DOI: 10.1541/ieejias.120.372.

[7] P. Liljebäck et al. "Controllability and Stability Analysis of Planar Snake Robot Locomotion". In: *IEEE Transactions on Automatic Control* 56.6 (June 2011), pp. 1365–1380. ISSN: 0018-9286. DOI: 10.1109/TAC.2010.2088830.

Obstacle avoidance





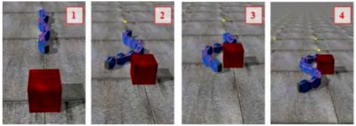
- Collisions make the robot unable to progress and cause mechanical stress or damage. Different studies have focused on obstacle avoidance locomotion.
- Artificial Potential Field (APF) theory[8] has been adopted. A controller capable of obstacle avoidance was presented in[9].
  - The standard APF approach may cause the robot to end up trapped in a local minima. To escape local minima, a hybrid control methodology using APF with a modified Simulated Annealing (SA) optimisation algorithm was proposed in[10].

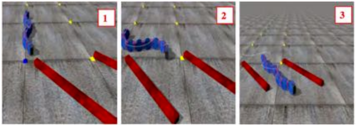
[8] Min Cheol Lee and Min Gyu Park. "Artificial potential field based path planning for mobile robots using a virtual obstacle concept". In: *2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2003. AIM 2003. Proceedings*. Vol. 2. July 2003, 735–740 vol.2. DOI: 10.1109/AIM.2003.1225434.

[9] C. Ye et al. "Motion planning of a snake-like robot based on artificial potential method". In: *2010 IEEE International Conference on Robotics and Biomimetics (ROBIO)*. Dec. 2010, pp. 1496–1501. DOI: 10.1109/ROBIO.2010.5723551.

[10] D. Yagnik, J. Ren, and R. Liscano. "Motion planning for multi-link robots using Artificial Potential Fields and modified Simulated Annealing". In: *2010 IEEE/ASME International Conference on Mechatronics and Embedded Systems and Applications (MESA)*. July 2010, pp. 421–427. DOI: 10.1109/MESA.2010.5551989.

Obstacle avoidance



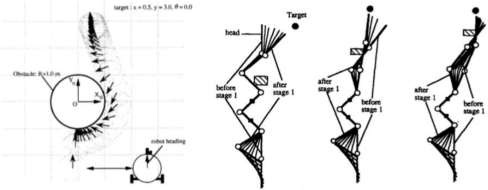


- An alternative methodology was developed in[11], where Central Pattern Generators (CPGs) were employed to allow the robot for avoid obstacles or barriers by turning the robot body from its trajectory.
- A phase transition method was presented utilising the phase difference control parameter to realise the turning motion. This methodology also provides a way to incorporate sensory feedback into the CPG model allowing for detecting possible collisions.

[11] N. M. Nor and S. Ma. "CPG-based locomotion control of a snake-like robot for obstacle avoidance". In: *2014 IEEE International Conference on Robotics and Automation (ICRA)*. May 2014, pp. 347–352. DOI: 10.1109/ICRA.2014.6906634.

Obstacle accommodation

- By using sensory feedback, a more relaxed approach to obstacle avoidance can be considered.
- The snake robot may collide with obstacles, but collisions must be controlled so that no damage to the robot occurs.
- In[12], a motion planning system was implemented to provide a snake-like robot with the possibility of accommodating environmental obstructions.
- In[13], a general formulation of the motion constraints due to contact with obstacles was presented. By using this model, a motion planning algorithm for snake robot motion in a cluttered environment was proposed.



[12] Y. Shan and Y. Koren. "Design and motion planning of a mechanical snake". In: *IEEE Transactions on Systems, Man, and Cybernetics* 23.4 (July 1993), pp. 1091–1100. ISSN: 0018-9472. DOI: 10.1109/21.247890.
[13] Yansong Shan and Y. Koren. "Obstacle accommodation motion planning". In: *IEEE Transactions on Robotics and Automation* 11.1 (Feb. 1995), pp. 36–49. ISSN: 1042-296X. DOI: 10.1109/70.345936.

Obstacle-aided locomotion

Even though obstacle avoidance or obstacle accommodation are useful features, these control approaches are not sufficient to fully exploit obstacles for means of propulsion.
A key aspect of practical snake robots is therefore obstacle-aided locomotion.
A preliminary study aimed at understanding snake-like locomotion through a novel push-point approach was presented in[14].

Remark 1. An overview of the lateral undulation as it occurs in nature was first formalised according to the following conditions:

- it occurs over irregular ground with vertical projections;
- propulsive forces are generated from the lateral interaction between the mobile body and the vertical projections of the irregular ground, called push-points;
- at least three simultaneous push-points are necessary for this type of motion to take place;
- during the motion, the mobile body slides along its contacted push-points.

[14] Zeki Y. Bayraktaroglu and Pierre Blazevic. "Understanding snakelike locomotion through a novel push-point approach". eng. In: *Journal of dynamic systems, measurement, and control* 127.1 (2005), pp. 146–152. ISSN: 0022-0434. URL: http://cat.inist.fr/?aModele=afficheN&cpsidt=16829403 (visited on 02/26/2016).

Obstacle-aided locomotion

[1]

Obstacle-aided locomotion

[15]

[15] Matt Travers et al. "Shape-Based Compliance in Locomotion". In: *Proc. of the Robotics: Science and Systems Conference*. 2016.

Obstacle-aided locomotion

Remark 2:

- most of the previous studies highlight the fact that obstacle-aided locomotion is highly dependent on the actuator torque output and environmental friction.

- In [2], the main focus was on how to use optimally the motor torque inputs, which result in obstacle forces suitable to achieve a user-defined desired path for a snake robot.
  - There are two main issues to practically use this method for obstacle-aided locomotion: (1) the definition of an automatic method for finding the desired link angles at the obstacles; (2) the automatic calculation of the desired path.

Why perception

Interacting with the environment

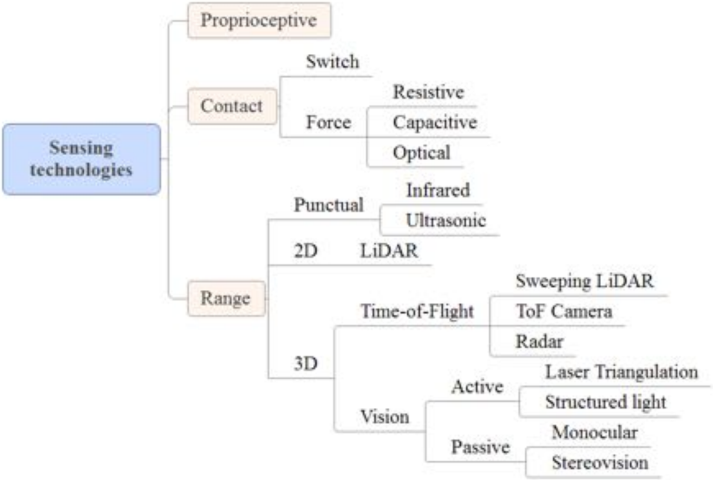
Exploiting the environment for locomotion requires being able to perceive it.

- *sensing*, on using the adequate sensor or sensor combinations to capture information about the environment;
- *mapping*, which combines and organises the sensing output in order to create a representation that can be exploited for the specific task to be performed by the robot;
- *localisation*, which estimates the robot's pose in the environment representation according to the sensor inputs.

Simultaneous localization and mapping (SLAM) in snake robots?

- SLAM: well studied in robotics (some argue even solved).
- Comparatively, there is very little work in snake robots. Even perception is very limited.

A taxonomy of sensing modalities



Some relevant examples

- Contact: already in the first snake robot back in 1972[16]; used for lateral inhibition.
- LiDAR based SLAM[17]; and rotating LIDAR for planning climbing stairs[18].
- Online localisation, offline mapping using a Time-of-flight (ToF) camera[19].
- Detection of poles for autonomous pole climbing[20]; using laser triangulation.

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

[17] M. Tanaka, K. Kon, and K. Tanaka. "Range-Sensor-Based Semiautonomous Whole-Body Collision Avoidance of a Snake Robot". In: *IEEE Transactions on Control Systems Technology* 23.5 (Sept. 2015), pp. 1927–1934. ISSN: 1063-6536. DOI: 10.1109/TCST.2014.2382578.

[18] L. Pfotzer et al. "KAIRO 3: Moving over stairs & unknown obstacles with reconfigurable snake-like robots". In: *2015 European Conference on Mobile Robots (ECMR)*. Sept. 2015, pp. 1–6. DOI: 10.1109/ECMR.2015.7324209.

[19] K. Ohno, T. Nomura, and S. Tadokoro. "Real-Time Robot Trajectory Estimation and 3D Map Construction using 3D Camera". In: *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*. Oct. 2006, pp. 5279–5285. DOI: 10.1109/IROS.2006.282027.

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Beyond SLAM

Remark 3:

Knowledge about the environment and its properties, in addition to its geometric representation, can be successfully exploited for improving locomotion performance for obstacle-aided locomotion.

Proposed in[17]: consider if the obstacles are safe for contact during the trajectory planning.
Researchers within other robot communities are already *beyond* SLAM: *semantic mapping*.

- Use knowledge to obtain a better representation of the environment.
- Use the semantics embedded in the representation to perform the task (e.g. navigation).

Conclusion and future work

Contribution:

- state-of-the-art, challenges and possibilities with perception-driven obstacle-aided locomotion;
- control strategies;
- methods and technologies for environment perception, mapping and representation.

Future work:

- perception-driven obstacle-aided locomotion is still at its infancy;
- strong results which can be used to build further upon from both the snake robot community in particular, and the robotics community in general;
- increase efforts world-wide on realising the large variety of application possibilities offered by snake robots and to provide an up-to-date reference as a stepping-stone for new research and development within this field[21,22].

[21] Filippo Sanfilippo et al. "Perception-driven obstacle-aided locomotion for snake robots: the state of the art, challenges and possibilities". In: *Journal of Intelligent & Robotic Systems, Springer* (2016). Manuscript submitted for publication.

[22] Filippo Sanfilippo et al. "Virtual functional segmentation of snake robots for perception-driven obstacle-aided locomotion". In: *Proc. of the IEEE Conference on Robotics and Biomimetics (ROBIO), Qingdao, China.* Manuscript accepted for publication. 2016.

Thank you for your attention

Contact:

- Filippo Sanfilippo, Dept. of Engineering Cybernetics, Norwegian University of Science and Technology, 7491 Trondheim, Norway.
  Email: `filippo.sanfilippo@ntnu.no`.

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