A Bio-Inspired Robotic System for Human-Like Contour Following

Introduction

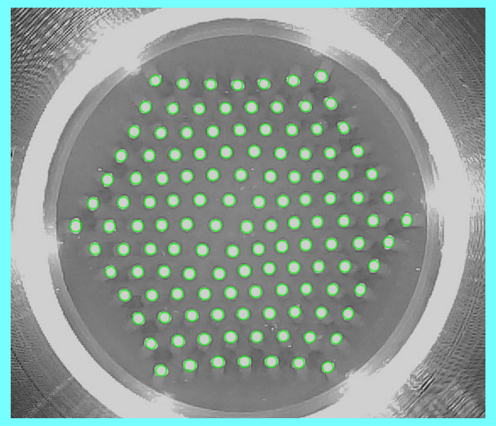
Most robots have poor tactile capabilities because no one knows how to combine tactile perception and control of action to give a robot a robust and adaptable sense of touch.

Taking inspiration from animal biology and human movement, we developed the most biologically plausible system to date that allows a robot to move a tactile sensor to explore the contours of unknown objects: a highly desirable skill - necessary for advanced manufacturing, assisted living, food production and healthcare. Our system showed robust and adaptable contour-following abilities and good potential for use in industry.

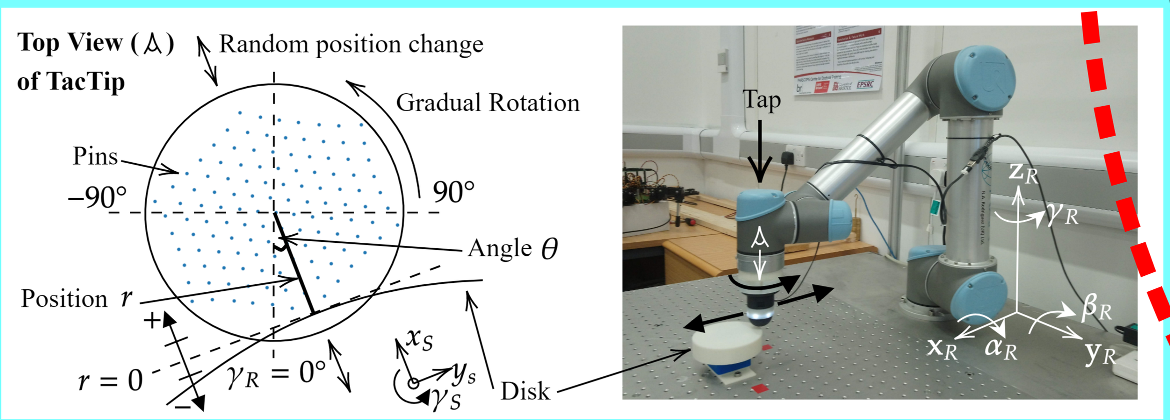
The poster is designed so that the viewer can see the different components of the system to the right, or go straight to the methodology, results and conclusions below.

Methodology

1. Tactile information, in the form of pin displacements, was extracted from a tactile sensor (TacTip) using computer vision blob-detection techniques.
2. The robot was programmed to tap the TacTip onto a disk at different angles and positions relative to the edge, and 1000 training and 500 validation samples were collected.
3. Three dendritic neural networks were trained on the training data and the network that best performed on the validation set (the PDenNN) was selected for the contour-following tasks.
4. The PDenNN was then integrated into PBTS control (see 4. right), and different objects were placed in front of the robotic arm for the system to follow.



(a) Computer vision pin tracking

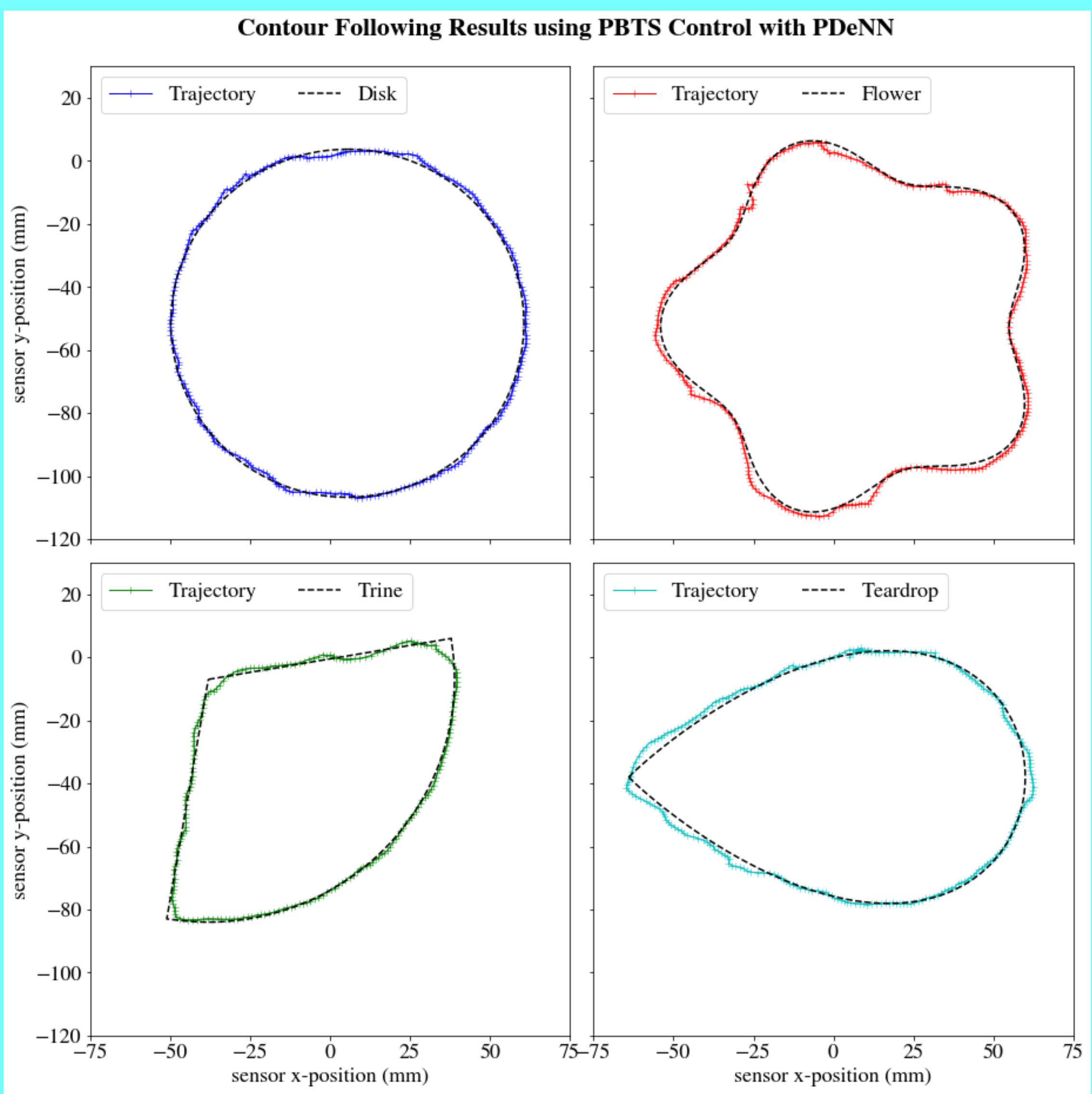


(b) Data collection by tapping sensor on 3D printed VeroWhite disk

Results and Conclusions

The system was put to the test on four different shapes. Our main findings were:

- The system was able to get the sensor to fully complete the contours, showing robustness and adaptability.
- The system struggled slightly with inflection points, sharp corners and rapid changes in gradient. Given that the PDenNN was only trained on the disk, this was as expected.
- Changes to controller gain parameters and step-size would likely improve results further.



1. The Brain: Dendritic Neural Networks

To see the robot in action use this QR code

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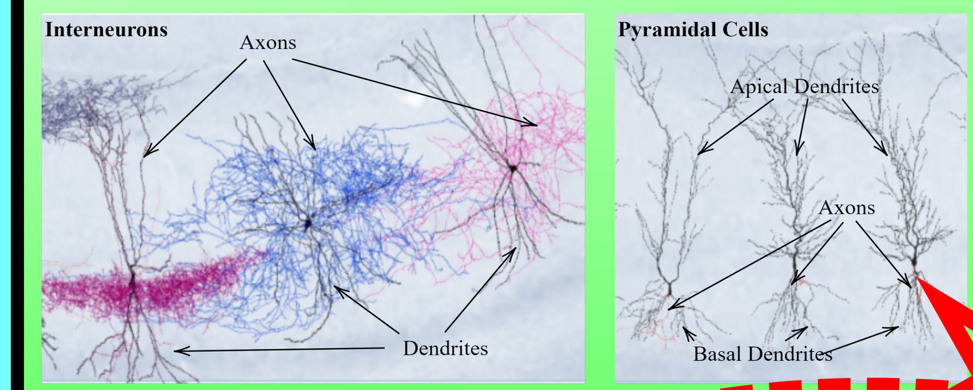
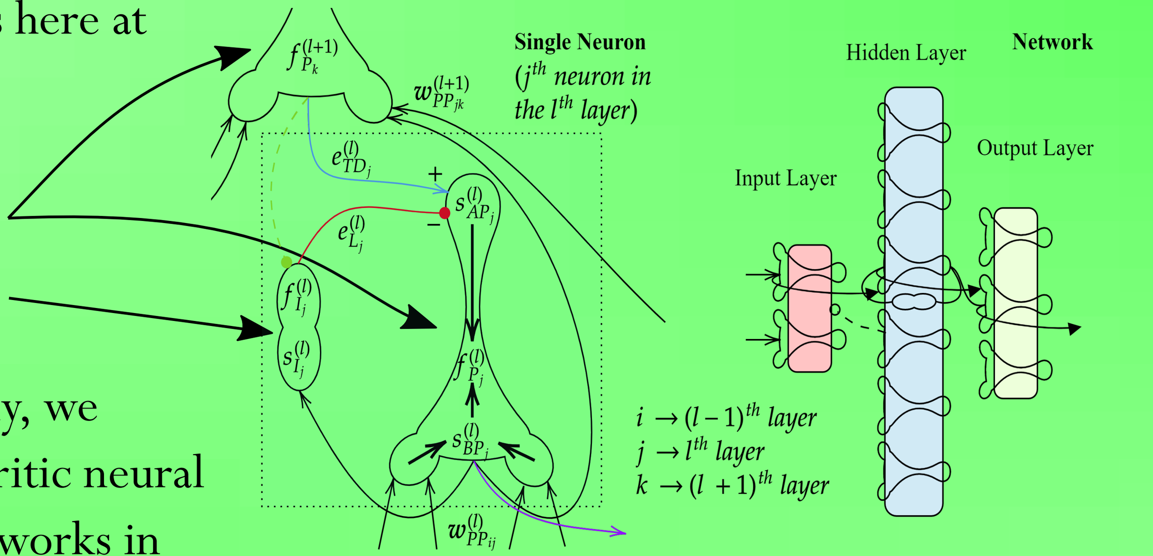
Dendritic neural networks were developed in 2017 and are based on the interaction between interneurons and pyramidal cells found in cortical micro-circuits. Rui Ponte Costa, who helped develop them, works here at Bristol University in the computational neuroscience unit.



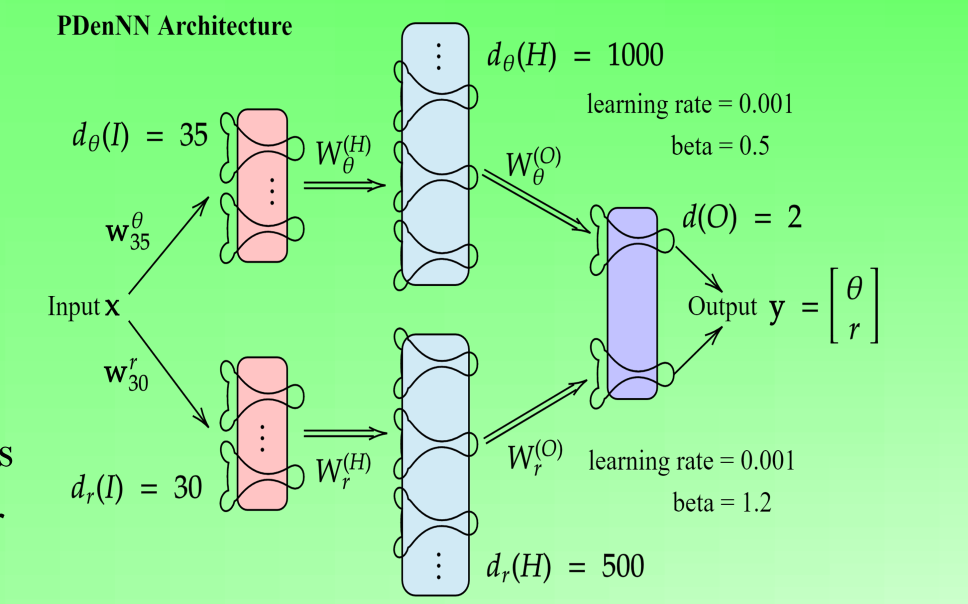
(a) Pyramidal cells and interneurons found in a rat's hippocampus.

Dendritic neural networks behave similarly to artificial neural networks (ANNs), but have added within-layer connections.



Dendritic neural networks allow for localised backpropagation, making them more biologically plausible.

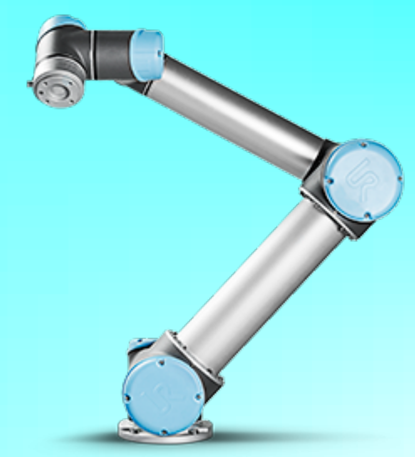
In this study, we used dendritic neural networks in combination with equilibrium propagation - a learning framework for energy-based neural networks. This meant that only a single computational circuit was needed (unlike two for ANNs), adding another layer of biological plausibility to the system.



(c) The dendritic neural network used for the contour following tasks

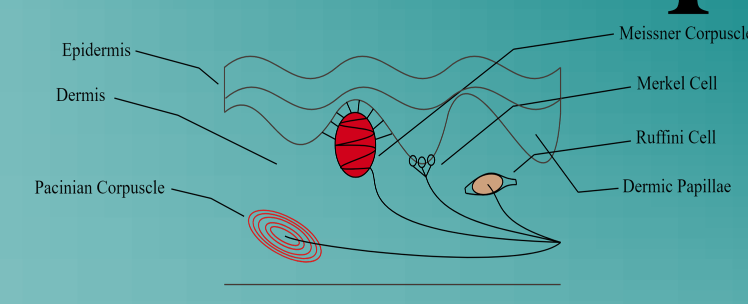
2. The Arm: UR5 Robot

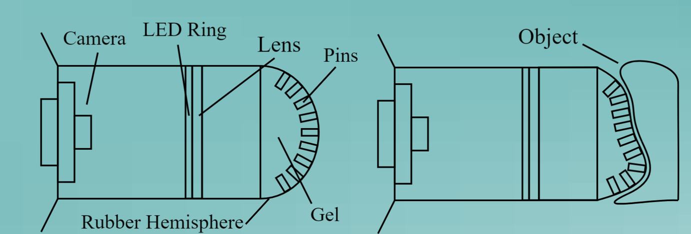
The tactile sensor (see below) was attached as an end effector to a UR5 robotic arm. The six-degree-of-freedom robotic arm was able to work at high speeds while maintaining extremely high accuracies, perfect for large data collection and contour following.



3. The Finger: The TacTip

Bristol researchers have developed a bio-mimetic tactile sensor called the TacTip. The TacTip mimics dermal papillae (found in human and animal skin), which displace when skin comes into contact with an object.

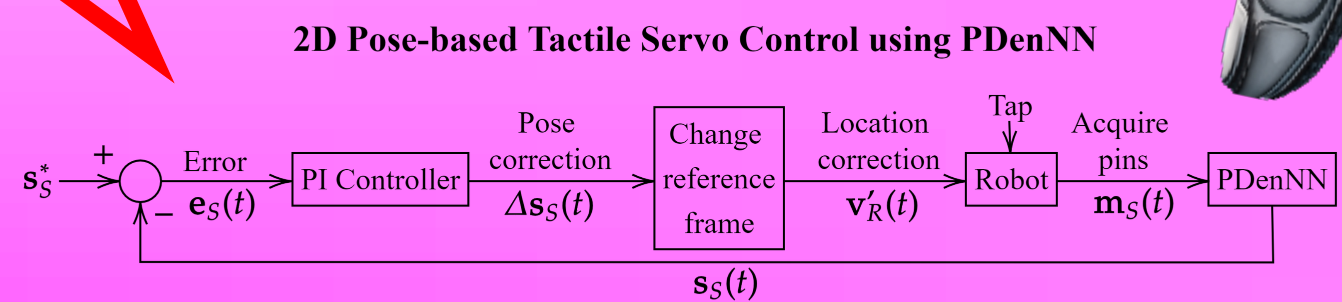




A simplified diagram of the TacTip: the camera captures displaced pins, conveying distribution of force.

(The 'contour' is the combined path of all the edges around an object. In this study, we looked at 2D contours, i.e. the edges of flat, 3D objects.)

4. The CNS*: PBTS Control



The control system acts like the central nervous system: it combines the tactile information it receives from the TacTip (finger) with the dendritic neural network's (brain's) interpretation of this information to make a controlled move along a contour.

The PBTS control works by forcing the sensor to move along an object's edge by creating a non-minimizable error tangential to that edge while at the same time minimizing the displacement and axial angle of the sensor on that same edge - thereby keeping the sensor on the edge and moving it around the contour.

* Central Nervous System

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