

CLAIMS

1. A robotic system comprising:

- a movement generation device;
- a tendon coupled to the movement generation device and to a robotic manipulator, the tendon being configured to move the robotic manipulator in response to the movement generation device;
- an end effector attached to the robotic manipulator, a pose of the end effector being dependent on movement of the robotic manipulator;
- a camera configured to generate an image of the end effector;
- a multi-stage neural network including:
 - a first perception block configured to receive the image and generate an image processing output representative of a state of an object within the image,
 - a policy block configured to generate command signals for movement of the end effector, the generated command signals being based on at least i) a goal for the end effector, ii) the image processing output and optionally iii) a time dependent internal state of the policy block, and
 - a compensation block configured to provide an output for control of the movement generation device based both the command signals and the image processing output; and
- control logic configured to provide the goal for the end effector to the policy block, or to select the policy block based on the goal for the end effector.

2. A robotic system comprising:

- an end effector;
- a movement generation device;

a movement coupling component coupled to the movement generation device and configured to move the end effector in response to the movement generation device;

a camera configured to generate an image of the end effector; and

a neural network configured to provide movement command signals to the movement generation device, the movement commands being configured to reach a goal in the movement of the end effector, the movement commands being compensated for variations in the movement coupling component based on the image and recurrent nodes of the neural network.

3. The system of claim 1 or 2, wherein the robotic manipulator and the movement generation device are separated by a robotic joint, the robotic joint being traversed by the tendon.
4. The system of claim 1, 2 or 3, wherein the end effector includes a gripping tool, a cutting tool, a pushing tool, a pulling tool, or a lifting tool.
5. The system of claim 1-3 or 4, wherein the robotic manipulator is a member of a plurality of robotic manipulators configured to manipulate the end effector in six degrees of freedom.
6. The system of claim 1-4 or 5, wherein the first perception block is configured to classify objects within the image.
7. The system of claim 1-5 or 6, wherein the first perception block is configured to generate the image processing output based on a stereo image.
8. The system of claim 1-6 or 7, wherein the first perception block is one of a plurality of perception blocks each associated with a different camera.
9. The system of claim 1-7 or 8, wherein the first perception block is one of a plurality of perception blocks, and further including a multiplex layer configured to pass outputs of the plurality of perception blocks to the policy block.

10. The system of claim 9, wherein the plurality of perception blocks is configured to detect different image components within an image.
11. The system of claim 9 or 10, wherein the plurality of perception blocks is configured to process images obtained from different cameras.
12. The system of claim 1-10 or 11, wherein the first perception block is further configured to determine a spatial relationship between the end effector and a target object.
13. The system of claim 1-11 or 12 wherein the first perception block and the policy block are trained separately.
14. The system of claim 1-12 or 13, wherein the perception block includes recurrent layers whose states are dependent on previously processed images.
15. The system of claim 1-13 or 14 wherein the image processing output includes a representation of the object within a three-dimensional environment including multiple objects.
16. The system of claim 1-14 or 15, wherein the image processing output includes a representation of a distance between the end effector and an object within the image, and/or a distance between two objects within the image.
17. The system of claim 1-15 or 16, wherein the image processing output includes a representation of a change in state of an object within the image.
18. The system of claim 1-16 or 17, wherein the image processing output is configured to estimate positions of occluded objects within the image.
19. The system of claim 1-17 or 18, wherein the image processing output includes a representation of an object within a three-dimensional environment.
20. The system of claim 1-18 or 19, wherein the image processing output includes a representation of a pose of an object within the image or a pose of the end effector.
21. The system of claim 1-19 or 20, wherein the first image processing layer is one of a plurality of perception blocks configured to process image data in parallel.

22. The system of claim 1-20 or 21, wherein the policy block is one of a plurality of alternative policy blocks, each of the plurality of policy blocks being configured to generate command signals for a different specific action.
23. The system of claim 1-21 or 22, wherein the policy block is one of a plurality of alternative policy blocks, each of the plurality of policy blocks being configured to generate command signals for a different class of actions.
24. The system of claim 1-22 or 23, wherein the policy block is configured to send command signals to the compensation block, the command signals being to move the end effector a specific distance.
25. The system of claim 1-23 or 24, wherein the policy block includes recurrent layers configured to make the generation of command signals dependent on prior states of the policy block.
26. The system of claim 1-24 or 25, wherein the policy block is configured to receive outputs of multiple perception blocks
27. The system of claim 1-25 or 26, wherein the command signals include a movement distance of the end effector or a force to be applied by the end effector.
28. The system of claim 1-26 or 27, wherein the policy block is configured to send command signals to the compensation block, the command signals being generated for calibration of the compensation block.
29. The system of claim 1-27 or 28, wherein policy block is configured to process output generated using the first perception block based on at least a) a prior state of the policy block and b) an output of the compensation block.
30. The system of claim 1-28 or 29, wherein the policy block is configured to receive image processing output based on images received from multiple cameras, and to generate the command signals based on the multiple images.
31. The system of claim 1-29 or 30, wherein the goal is a calibration of the compensating block.

32. The system of claim 1-30 or 31, wherein the goal is to move the end effector to a position relative to an object, to grip the object and/or to move the object.
33. The system of claim 1-31 or 32, wherein the goal is to avoid contact between the end effector and a moving object.
34. The system of claim 1-32 or 33, wherein the goal includes movement of the camera.
35. The system of claim 1-33 or 34, wherein the compensation block is configured to determine a result of a prior output for control of the movement generation devices based on the image processing output.
36. The system of claim 1-34 or 35, wherein the compensation block is configured to compensate for changes in the length of the tendon or the robot manipulator, by adapting the output for control of the movement generation device.
37. The system of claim 1-35 or 36, wherein the compensation block is configured to compensate for changes in a strength of a spring or strength of the movement generation device, by adapting the output for control of the movement generation device.
38. The system of claim 1-36 or 37, wherein the compensation block is configured to compensate for weight of an object lifted by the end effector, by adapting the output for control of the movement generation device.
39. The system of claim 1-37 or 38, wherein the compensation block is configured to compensate by adapting the output for control of the movement generation device, using the image processing output.
40. The system of claim 1-38 or 39, wherein the output for control of the movement generation device includes a selected voltage or current, or a digital value.
41. The system of claim 1-39 or 40, wherein the compensation block includes a state representative of a prior response of the robotic manipulator to the output of the compensating layer.
42. The system of claim 1-40 or 41, wherein the control logic is configured to generate the goal based on a set of received instructions.

43. The system of claim 1-42 or 43, wherein the control logic is configured to generate the goal based on a task, the goal being one of a series of goals needed to complete the task.
44. A method of controlling a robot, the method comprising:
- capturing an image using a camera, the image including an end effector connected to a robotic manipulator;
 - processing the captured image to produce a representation of objects within the image;
 - applying a policy to the representation of objects to produce command signals, the production of command signals being based on at least a goal and the representation of objects;
 - compensating for a change in response to of the robotic manipulator to command signals, to produce compensated control signals, the compensation being based on prior command signals and the representation of objects; and
 - activating the robot using the compensated control signals.
45. The method of claim 44, further comprising determining if the goal has been achieved based on the representation of objects, and requesting a new goal.
46. The method of claim 44 or 45, further comprising receiving a task and dividing the task into a set of goals, the goal being a member of the set of goals.
47. The method of claim 44, 45 or 46, wherein the camera is attached to a robotic manipulator under control of the compensated control signals.
48. The method of claim 44-46 or 47, wherein the camera is a stereoscopic camera.
49. The method of claim 44-47 or 48, wherein the representation of objects within the image includes a three-dimensional representation.
50. The method of claim 44-48 or 49, wherein the representation of objects within the image includes a representation of the relative positions of the end effector and an object to be manipulated by the end effector.
51. A method of calibrating a robot, the method comprising:

generating first control signals;

providing the first control signals to a robot, the first control signals optionally being configured to generate an expected movement of an end effector attached to the robot;

capturing an image showing a response of the robot to the control signals;

generating second control signals;

changing a state of the recurrent neural network responsive to the image and the expected movement; and

generating second control signals;

compensating the second control signals to produce compensated control signals using the recurrent neural network, the compensation being responsive to the changed state of the recurrent neural network, the compensation being configured to reduce a difference between the expected movement and a movement of the end effector indicated by the image.

52. The system or method of claim 51, further comprising generating further control signals configured to train the recurrent neural network to produce compensated control signals that result in an expected movement of the end effector.
53. The system or method of claim 51 or 52, wherein the further control signals are generated over a period of at least a week, so as to adjust the recurrent neural network for changes in the robot that occur over a week or more.
54. A robotic system comprising:
- an end effector comprising:
- a digit having at least three segments separated by at least first and second joints,
- the three segments including a proximal segment, a medial segment and a distal segment, the proximal segment being attached to a robotic manipulator via a third joint,

a first transmission configured to flex the third joint,
a second transmission configured to flex both the first and second joints, wherein
the relative angles of the first and second joints are dependent on contact
between an object and the medial segment or between the object and the
distal segment, and
a first elastic element configured to extend the first joint;
one or more movement generation devices configured to move the first and second
transmission independently;
a camera configured to generate an image of the end effector; and
a neural network configured to provide movement command signals to the movement
generation device, the movement command signals being compensated for
variations in relative movements of the first and second joints, the compensation
being based on the image.

55. The system or method of claim 1-53 or 54, further comprising a second elastic element
configured to extend the third joint.
56. The system or method of claim 1-54 55, further comprising a fixed base configured to support
the end effector, the one or more movement generations devices being disposed in the
base.
57. The system or method of claim 1-55 or 56, wherein the end effector includes multiple digits,
each of the multiple digits having at least one joint.
58. The system or method of claim -56 or 57, wherein the multiple digits are each supported by the
same robotic manipulator.
59. The system or method of claim 157 or 58, wherein the neural network is configured to
compensate for contact between the medial segment and the object, by processing the
image.

60. The system or method of claim 1-58 or 59, wherein the neural network is configured to operate responsive to results of previous movement command signals using recurrent or memory enabled nodes.
61. The system or method of claim 1-59 or 60, further comprising memory storage configured to store long-term memory data, the long-term memory data including data configured to change a state of the neural network responsive to an identity of an object within the image.
62. The system or method of claim 1-60 or 61, wherein the movement command signals are configured to reach a goal for the movement of the end effector.
63. The system or method of claim 1-61 or 62, wherein the digit includes at least one pressure sensor and the neural network is further configured to provide the movement command signals based on a signal generated by the at least one pressure sensor.
64. The system or method of claim 1-62 or 63, wherein the movement command signals are compensated for variations in a length of the second transmission.
65. A method of controlling a multi-joint robotic end effector, the method comprising:
- moving a first transmission to flex a first joint;
 - capturing an image of a digit of the end effector, the first joint separating the digit of the end effector from a robotic manipulator, the digit including at least three segments separated by at least second and third joints, the three segments including a proximal segment, a medial segment and a distal segment, the proximal segment being attached to a robotic manipulator by the first joint;
 - generating command signals configured to move the distal segment to a desired location;
 - compensating the generated command signals for variation in movement of the distal segment in response to moving on the first transmission, the compensation being based on processing of the image using a neural network including recurrent or memory enabled nodes; and

moving a second transmission to flex both the second and the third joints, flexed angles of the second and third joints being dependent on contact between an object and the medial segment.

66. The system or method of claim 1-64 or 65, further comprising extending the second and third joints using an elastic element.
67. The system or method of claim 1-65 or 66, further comprising selecting long-term memory data from memory storage and changing the state of the neural network using the long-term memory data, the selection of the long-term memory data being based on a goal for movement of the end effector.
68. The system or method of claim 1-66 or 67, further comprising selecting long-term memory data from memory storage and changing the state of the neural network using the long-term memory data, the selection of the long-term memory data being based on a content of the image.
69. The system or method of claim 1-67 or 68, wherein generation of the command signals is based on long-term memory data disposed in a memory storage and compensation of the generated command signals is based on a short-term memory achieved by recurrent or memory enabled nodes in the neural network.
70. The system or method of claim 1-68 or 69, wherein generation of the command signals is dependent on detection of a person within the image.
71. The system or method of claim 1-69 or 70, herein the generated command signals are compensated for a variation in the length of the second transmission.
72. The system or method of claim 1-70 or 71, wherein the second transmission is moved using a movement generation device, the digit and the movement generation device being separated by at least two robotic joints.
73. The system or method of claim 1-71 or 72, wherein the neural network is responsive to contact between the medial segment and an object, as observed in the image.

74. The system or method of claim 1-72 or 73, wherein the neural network is responsive to an angle between the medial segment and the distal segment, as observed in the image.
75. The system or method of claim 1-73 or 74, wherein generating the command signals is responsive to classification of objects within the image.
76. The system or method of claim 1-74 or 75, wherein generating the command signals is responsive to a spatial relationship between the end effector and a target object based on the image.
77. The system or method of claim 1-75 or 76, wherein compensating the generated command signals is responsive to at least two images of the end effector taken at different times.
78. The system or method of claim 1-76 or 77, wherein the neural network includes nodes whose states are dependent on previously processed images.
79. A robotic system comprising:
- an end effector;
 - a robotic manipulator configured to support the end effector;
 - one or more movement generation devices configured to move the end effector in response to movement command signals;
 - a camera configured to generate an image of the end effector;
 - a memory storage configured to store long-term memory data; and
 - a neural network configured to provide the movement command signals to the movement generation device, the movement command signals being compensated for non-deterministic variations in movements of the end effector, the compensation being based on the image, wherein generation of the command signals is based on the long-term memory data and compensation of the generated command signals is based on a short-term memory achieved by recurrent or memory enabled nodes in the neural network.

80. The system or method of claim 1-78 or 79, wherein the long-term memory is configured to operate at a longer time period relative to the short-term memory.
81. The system or method of claim 1-79 or 80, wherein the first transmission and/or the second transmission include tendons.