Embodied Intelligence

Deepak Jowel

University of Lincoln, School of Computer Science

28097543@students.lincoln.ac.uk

1 Introduction

Major challenges in developing or encompassing the full strength of AI are related to the need to combine algorithmic (brain) and physical (body) capabilities. Thus, raises the need to build agents with ‘Embodied Intelligence’, where the physical system and design offer some physical intelligence (PI) [Sitti, 2021]. As the new generation of robots are extensively being integrated into daily human lives it is essential for these agents to possess abilities to perceive, control, act and learn. They must perform complex and unstructured tasks in the real-world while in the presence of humans [Sitti, 2021]. Today's robots are prone to errors in unforeseen situations and lack versatility. They can only perform tasks specific to a well-known environment.

Embodied intelligence is associated with parallel but closely linked development in robotics. The areas of study focus on morphological computation and sensory–motor coordination as part of developmental robotics, and neuroscience and cognitive science with focus on embodied cognition [Cangelosi et al, 2008]. Thus, facilitating a tight coupling between an agent's body and brain [Sitti, 2021].

Whereas, embodied physical intelligence can be defined as the capability of an agent to possess ‘cognitive abilities’ encoded in their bodies [Sitti, 2021]. The abilities are not just limited to physical sensing and actuation but also encompass logical and reasoning competence. For an embodied system these abilities can be partially outsourced to the physical laws and features in the immediate environment [Hughes et al, 2021].

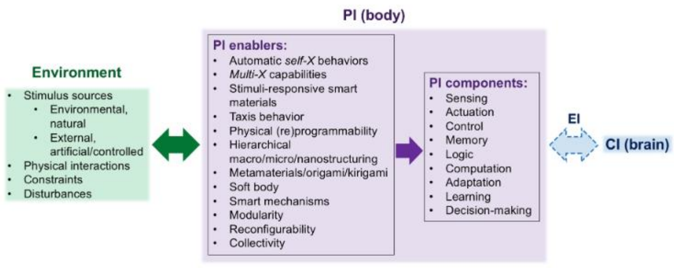


Fig. 1. Physical intelligence (PI) components and enablers on a physical agent body interacting with its environment. Such body PI is also coupled to the computational intelligence (CI) in the brain, where the embodied intelligence (EI) field investigates the tight coupling between the body and brain. [Sitti, 2021]

Both the domain of study complements each other to decipher how bodies can create intelligence and interact with their environment.

There can be two general approaches by which an agent can sense, interpret and act upon stimuli received from its surroundings. The first approach can be to possess the complete and precise knowledge of the environment including all known variables in it and then use a pre-build model to accomplish a given goal. The second approach is to select and associate simple sensory cues with sequences of actions that will lead from one to the next cue in-order to accomplish a task [Hughes et al, 2021].

This field acquires inspiration from nature to create robots that can use sensory data to interpret their immediate surroundings and with motor control, perform maneuvers like animals, insects, or humans. These robots must be sophisticated to learn and adapt as living beings.

1.1 Governing Principles

The section summaries key principles that can be introduced in-order for intelligence to be embodied in an agent. As discussed above these principles are morphological computing, sensory –motor coordination and cognition.

1.1.1 Morphological Computing

In the domain of embodied systems, the term morphological computing can be defined as the ability of the body plan of an agent to make logical and reasoning decisions in-order to compensate for the simpler control policies implemented by the computation system controlling the agent [Cangelosi et al, 2021].

1.1.2 Sensory-Motor Coordination

As the sub-topic suggests, it is the ability of an agent to sense stimuli and generate an ideal or set of ideal actions that will modify the agent-environment relation and/or alter the environment. This helps the agent generate critical sensory information through action and active perception and scrutinize control policies [Cangelosi et al, 2021].

1.1.3 Cognitive Capabilities

Cognitive capability such as those of living organisms have honed over years of evolution to make the organisms thrive in the environment that house them. It is important for an agent to distinguish features that are observed in its environment and categorize and represent this information. Also, it must be capable of processing natural language to understand and convey verbal or textual information [Cangelosi et al, 2021].

These agents can be deployed in multiple domains as mentioned below but are not limited to those.

Industrial Robots: Embodied Intelligence can be utilized to create smart robots that can perform complex tasks in industries. Modification in the overall structure to introduce more dexterity and structural equilibrium inspired from nature will make these robots more efficient. For example, the tusk of elephants can lift heavy loads of all shapes and sizes and precisely engineered locomotive wheels or legs like those of living beings will allow the robot to traverse difficult terrain.

Autonomous Systems: There are unmanned vehicles equipped with arrays of sensory devices, which navigate both on land and air. These vehicles are utilized for transporting goods, for daily commute by humans, and terrain exploration and surveillance. Underwater unmanned vehicles have evolved in recent years but still hold propulsion techniques from the past. Introducing intelligence within those vehicles using A.I and biomimicry will make them more agile in the unexplored underwater environment. And advanced perception will provide data gathering and interpretation skills just like humans.

Service Robots: The purpose of these robots is to assist humans within their household environment or any other indoor/outdoor environment. They can be considered as caregivers/assistants. These robots are supposed to, but necessarily look like humans and have cognitive and physical capabilities at par with humans to co-work with them in the real world. Such are the kind of robots that are known as humanoids. Extensive research in body planning and cognitive capabilities will make them blend well in the real world.

Healthcare: The robots in healthcare can provide critical life support to humans in cases of medical emergency and assist in disaster stuck environment where a human rescuer may have to endanger their lives. With physical intelligence these robots will become more aware about their surrounding and can perform difficult task which may even be life-threatening for humans.

2 Aims and Objectives

The primary objective of this study is the in-depth analysis of physical intelligence in biological systems. The focus will be on the realization and function of sense-think-act paradigm in real world as observed in biological agents and embed them in new robotic components.

The study will incorporate the phenomenon of action and reaction in different scenarios. And making them energy efficient while understanding the memory principles governing them. This will alter the traditional practices currently being implemented to interact with the environment. Further, attempts shall be made to look at the potential electro-mechanical solutions that can harness the observed principle, this may include devising a new sensory or actuation tool to revolutionise the present state of perception and manipulation techniques with the goal of embedding them in agents for tackling real world challenges. Focus shall be on the realization and functioning of the entire sense-think-act robotic paradigm in hte biologicl systems

The major objective of the project, that is ‘Physical Intelligence’, will lead to the study of motion primitives existent in nature across all the organisms that have honed the skills because of evolution happened over eons, for specific behaviors. This will help in introducing dexterity in current body plans of robots making them capable to trade–off computation power with physical intelligence embodied in them. Thus, enabling the agent to perform fewer computations for any given control policy governing their behaviour within the environment in which they have been deployed.

Further, methods shall be deciphered to integrate these paradigms within agents. Scaled on the software level as well as hardware level in pursuit of transferring them to robotic components.

This project will help us in understand or more precisely fabricate methods, paradigm and policies for the robot of the future that may possess ‘Artificial General Intelligence’ bring them closer to the intellectual capability equal to humans or even surpass those in some cases.

3 Literature Survey

For years engineers, researchers and scientists have taken inspiration from biology to create solutions in technology that resemble traits of living organisms. These traits are encompassed in control systems, morphologies, actuators or electronics. Robots designed using such solutions have better agility and flexibility for functionality and are more adaptive and intelligent. The goal is to understand, upscale and replicate the mechanisms that provide better performance for solving a given problem. In the following subsection some cases to bioinspired robots have been described.

3.1 Vision-Based Flying Robot

Robots that can fly in obscured environments pose great usability in main domains and these robots can challenge their human counterparts by performing tasks in hazardous and chaotic environments with greater efficiency [Floreano et al, 2008]. But traditional practices to sense the environment and control these robots have been under scrutiny because of their energy consumption and size.

Vision representation is an ideal modality, and it does not require much energy to acquire information. But the challenge lies in real-time image processing. Thus, research pioneers have over the years taken inspiration from insects, specifically from flies. The flies two compound eyes provide an omnidirectional field of view with coarse resolution. They have many neurons sensitive to optic flow, also known as elementary motion detectors (EMD) [Floreano et al, 2008].

D.Franceschini in 1992 built a physical model of the fly's visual system map visual system into motor. He replicated the visual system using 100EDMs around the circular body of the robot. The output of the EDM measured the distance to object according to the principle of motion parallax [Floreano et al, 2008].

J.Zuffery and D.Floreano developled an indoor flying robot in the year 2006 that relied on optical flow to steer away from walls.

3.2 Wheeled Robot

Robots with wheels can travel at high speeds, but only on flat surfaces. Whereas a robot with pedal body plan can move on rugged terrain.

Researchers were fascinated by the remarkable mobility and speed of cockroaches in rugged terrains. Cockroaches have six legs and display tripod gaits. They bounce and collide with ground and obstacles, but the legs coupled with gait allow the animal to automatically recover without explicit control.

In 2001 U.Saranli with his team designed 'RHex' a hexapod robot that mimics the gait properties of cockroach with simple mechanics and control. The robot can easily navigate rugged terrain. Also, in 2002 R.D Quinn and his team designed a simpler hexapod inspired by cockroaches They 'Whegs' which are rimless wheelsthus harness the locomotion system which is combination of both wheels and legs. The spoke in the wheels allowed the robot to get a foothold on higher obstacles.

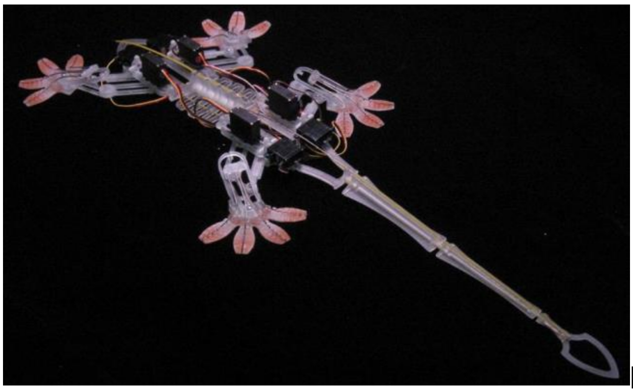

[7]

3.3 Wall Climbing Robot

Walking on vertical surfaces would be very useful. Many prototypes have been built that use vacuum suction, magnetic attraction or grasping. This makes the robot suitable for tasks such as surveillance and inspection and cleaning [Floreano et al, 2008].

In 2007 M.Murphyy and M.Sitti designed ‘Wallbot’ , a robot with two three-footed wheels. It utilizes the principle of dry adhesive. This allowed the pad to conform to surfaces as the robot moves on walls. This robot was inspired by clinging mechanism of filaments called setae found in feet of gecko [Floreano et al, 2008].

In 2006 a team lead by Mark Cutkosky at Stanford University took different approach while designing Stickybot, a robot morphological similar to gecko that uses four legs and a long tail. They utilized artificial setae to exploit shear force and the control systems is based active force distribution. The robot can walk on perfectly flat surfaces and moves by lifting and repositioning one leg at a time [Floreano et al, 2008].


[6]

3.4 Robotic Roots

Plant root systems perform many essential adaptive functions including water and nutrient uptake, and anchorage to the soil. Evidently, roots monitor a wide spectrum of physical and chemical parameters and then integrate the signals obtained to perform appropriate and often complex growth responses to cope with the immediate environmental circumstances. The more acute sensitivity of roots to various types of signals is related to the apical part of the plant root, the apex.

In the 2001, Barbara Mazzolai and her team at the Italian Institue of technology developed a prototype of the mechatronic apex system, which embeds gravity sensors, moisture gradient detectors, and a microcontroller that implements the gravitropic and hydrotropic behaviors of the plant roots. This artificial apex system can steer following gravity and moisture stimuli and its performances were tested in air and soil. The design of the osmotic actuator is also presented, together with some preliminary experimental trials to validate its working principle.

4 Research Methods

This research will use qualitative methods to find solutions for existing problems in the domain of embodied intelligence. Existing simulation tools will be used to create environments for testing different biomechanical principles. The motion primitives inspired by biological organisms will be at focus. This knowledge will be attained from video-graphical sources and in-depth study of the physiological and control mechanisms will take place.

If along the course of study, the need arises to use gait dataset then they will be acquired from open-source platforms

Evolutionary reinforcement learning to study relations between environment complexity, morphological intelligence and the learnability of control. This will help in making an evolved kinesthetic mechanism that will be tested in different simulated environments.

An attempt shall be made to replicate the knowledge into software and hardware so for the electromechanical realisation of the model that can support the studied principle, the study will investigate sensory and actuation solution as well.

5 Ethical Considerations

I hereby solemnly declare that my submission for MSc Research Project CMP9140-2324, that will investigate the research topic ‘Embodied intelligence’ will not incorporate the involvement of humans or animals. Further, neither any data deemed as sensitive information shall be collected nor any work understood as ‘ethically challenging’ will be practiced.

6 Project Plan and Risk Analysis

Below is a brief overview of the time scale over which an attempt shall be made to accomplish certain tasks as indicated in this project proposal. The achievements of tasks as proposed are subjected to uncertainty due to strict time constraints. There risks as foreseen for certain task have been mentioned in the table below:

Task	Start	End	Milestone	Risk

Literature review	3/06/2024	9/06/2024	Knowledge of existing practices	NIL
Literature review	10/06/2024	16/06/2024	Knowledge of existing practices	NIL
Study of biomechanical systems	17/06/2024	23/06/2024	Bioinspired robot	NIL
Study of intelligence in physical systems	24/06/2024	30/06/2024	Kinesthetic and physiological knowledge of a specific gait	NIL
Implementing methods in simulation	01/07/2024	7/07/2024	Morphologically stable body plan	Mimic ideal condition may not be feasible
Test the durability of the mechanics and improvise	08/07/2024	14/07/2024	Strong base for a physical system	Testing the rigid body dynamics may force to make changes
Study devising possible software solution to control the mechanics in simulation	15/07/2024	21/07/2024	Computational intelligence for control system	dynamics may not be compatible with the Sim world model
Testing the software with simulation	22/07/2024	28//07/2024	Established control system	Building a control system will be challenges

Study devising possible hardware solution	29/07/2024	04/07/2024	Electromechanical system	Resource expensive task
Integrating software and hardware	05/08/2024	11/08/2024	Agent for real world phase	Both the domain by not be adaptable
Testing the in real-world	12/08/2024	18/08/2024	observing the sim2real transfer issues	Model my fail do to unknown variables
Debugging issues for real-world implementation	19/08/2024	24/08/2024	Resolving the sim2real transfer issues	Time expensive task

References

1. Sitti, M. (2021) Physical intelligence as a new paradigm. Extreme Mechanics Letters, 46 101340. Available from https://www.sciencedirect.com/science/article/pii/S2352431621001012.
2. Josie Hughes, Arsen Abdulali, Ryman Hashem & Fumiya Iida, Embodied Artificial Intelligence: Enabling the Next Intelligence Revolution, International Workshop on Embodied Intelligence 2021, 1261012001, Available from https://iopscience.iop.org/article/10.1088/1757-899X/1261/1/012001
3. Cangelosi A., Bongard J. Fischer N.H, Nolfi S. (2015). Embodied Intelligence. In J Kacprzyk & W. Pedrycz (Eds.), Springer Handbook of Computational Intelligence. Springer, p. 697-714
4. Dario Floreano, Francesco Mondada, Andres Perez-Uribe, and Daniel Roggen, Evolution of Embodied Intelligence, Embodied Artificial Intelligence (2004) pp293-311
5. Dario Floreano, Claudio Mattiussi, Bio-Inspired Artificial intelligence, (The MIT Press, 2008), pp419- 437
6. http://bdml.stanford.edu/twiki/bin/view/Rise/StickyBot
7. https://en.wikipedia.org/wiki/Rhex

Word Count: 2543