SOFT ROBOTICS

— The next generation of intelligent machines —

INTRODUCTION

Nowadays robotics has achieve a relevant status in society. This is proven by the extended coverage of many important international magazines, journals, newspapers, etc., about topics such as Pepper guiding people in Japan, test drives of self-driving vehicles, drones, and other robotic systems.

In this environment, Professor Pfeifer proposes the idea that the next generation of robots will be of the "soft" kind. However, at this point it is very difficult to define what soft robotics are. In a general way it can be understood as robots who have flexible/soft materials. This is very important characteristic that all robots must have in order to be able to share their living space with us.

However, is soft materials all that it is necessary? Or does soft also means touch, movement, interaction, behaviour…

WHAT IS INTELLIGENCE?

Illustrations: Shun Iwasawa, Studio Ghibli, Tokyo

In order to get soft robotics one must first understand the concept of intelligence. The classical view of intelligence, presents it always in a computational way. Certain inputs, get processed or compute, to produce a desired output. However this classical approach although it is very plausible and easy to understand, it is fundamentally flawed.

In this respect computers are very good at performing very controlled tasks. However they usually cannot entirely succeed in unorderly natural environments. On the other hand, humans and other organisms effortlessly move and interact with the natural world. So they must poses a different kind of intelligence, perhaps an embodied cognition which is more movement oriented.

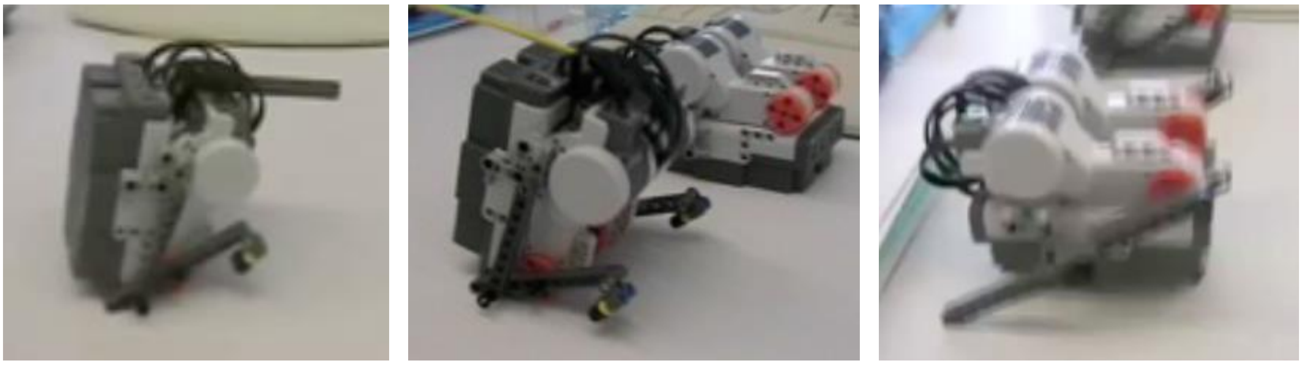
Here is important to note that the brain develop as an evolutionary necessity to cope with the complexity of movement (this maybe the reason why plants lack brains). The brain developed in order to allow the body to interact with the surrounding environment. However there is still not a clear understanding of what the roll of the brain as part of a complete organism is.

UNDERSTANDING BY BUILDING & THE SPIRIT OF EMBODIMENT

In order to understand this embodied intelligence we aim to understand what the roll of the brain as a part of a whole biological systems is. Normally this is the main goals of an artificial intelligence lab, i.e. understanding biological system, develop some principles and the theory behind it, in order to finally develop practical applications using these principles.

In this respect we use an approach called understanding by building. In this approach, we take a natural phenomenon of interest, e.g. a human walking, animals finding their nest; then we build a system that tries to mimic this phenomena, and finally we test it. If it works then it means that we understand the process. This immediate feedback about the fail or success of the system, makes it a very powerful technique for understanding biological systems.

Or in different words: If I cannot build it, I do not understand it.



To clarify this principle, prof. Pfeifer presents the crazy bird, a robot that exhibits 3 district behaviours using exactly the same control system, but different mechanical configurations. This implies that the control system, the brain of the robot, is not the only component responsible for the final outcome of the system. Therefore part of the behaviour of the robot must also be embedded in its body.

Then, it is clear that by exploiting different configurations and materials properties is possible to create different behaviours. This concept is called “emergent behaviour”, since it appears as a result of the combination of multiple factors.

However, it must be emphasize that the brain is still very important, however it is not the whole story. There is more to behaviour than just the brain.

CONTROLLED VS REAL WORLD ENVIRONMENTS

When we observe a factory environment, where robots have normally been used for decades now, it is clear that all factors are kept well under control. From the movements of the robot, to its interactions with the surrounding environment. In this way all the steps to complete a task can be perfectly planned. On the other hand, in the real world the steps to achieve a task cannot completely be plan. One can have a rough idea on how to achieve a task, however all the details are dealt with in real time, by adapting to them as they happen. Therefore the requirements for robots in factories and in the real world are completely different.

Taking this into consideration, we see that humans are built with about 85% of soft materials, so we cannot help to think that maybe this is the reason why the human body has such movement versatility. Therefore, it is fair to assume that in order to build robotic systems that perform like humans, we must build systems with soft materials.

Design and construction: Ruina, Wisse, Collins: Cornell University, Ithaca, NY

While in the control side, when we look at a task such as walking, it is clear that humans achieve it by using very little control. Simply by adjusting the body posture and the muscle tension on the legs the legs can swing forward in a very energy efficient way. On the other hand, conventional humanoids employ very complex control strategies to continuously control all the joint positions. Resulting in a very unnatural walk movement.

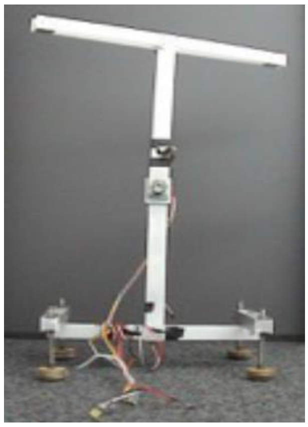
A good example of how can this be achieve through mechanical systems, is the passive dynamic walker of Cornell University. It moves passively by using no actuators. Here the control, or perhaps it can be called memory, for walking is embedded in the morphology of the system. Different what we use to think, memory does not only reside on a computer controller, but it can also be stored in the mechanical configuration of the system.

MORPHOLOGICAL COMPUTATION

However this presents another challenge from the control point of view. Since part of the control is delegated to the mechanics of the system, then the control strategy is not clearly divided as with conventional systems. A "morphological computation" is also involved in the conceptualisation of the behaviour of the whole system. Here one must try understand the mechanics acting on the system, in order to develop a suitable control strategy. As with soft robots where the functionality of dealing with impacts is outsourced to the softness of the materials. We have to start thinking about the way that the mechanical properties of the system impact the control and not the other way around.

In a different example, such as human running, we can make a case about how the morphology of our bodies influences the control strategy. When running normally we lean slightly forward in order to speed up. This causes our centre of gravity to move forward and then the legs automatically speed up in order to keep the body from falling. So here is the mechanics of the systems causing the neurons in the brain to act in order to cope with a change in the centre of gravity. In other words, the mechanics of the system are causing the controller to react.

As an example prof. Pfeifer develop "Stumpy" a two degree of freedom robot with springy materials in the feet. This robot can achieve up to 20 clear distinct ways of movement.



Design and construction: Raja Dravid, Chandana Paul, Fumiya Iida

In resume we have to stop trying to simply transfer control methods between biological and robotic systems, and start learning how to address the connection between the commands from the controller, the "morphological computation" embedded in the mechanical structure of the system and its interactions with the surrounding environment. In other words we must not control, but rather orchestrate all of its parts as a whole.

THE POWER OF MATERIALS

design and construction: Lipson/Yaeger

There are many examples where flexible systems have infinite degrees of freedom, therefore conventional control is almost impossible to be applied. These kind of systems provide great flexibility by exploiting the properties of the materials used in them. From surgical devices that seamlessly move through obstacles to the universal coffee gripper, which automatically adapts to virtually any shape in order to grasp it, there are plenty of examples that show that with very simple control it is possible to achieve quite complicated behaviours.

On the other hand, we could also take an organic system as an example to explain the importance of the material properties when performing a task. So, if our fingertips where to be covered with hard metal, such as thimbles, it would almost be impossible to grasp a piece of glass, because we would lack the adaptive behaviour embedded in our skin, which naturally deforms when is under pressure.

GUIDED SELF ORGANISATION

Now we understand that when we design a robot, we should expand our Design Space in order to include the morphology of the system and the materials we use to build it. By moving certain aspects of the control to the morphology or materials of the design we can achieve more efficient systems. However, by doing so we usually lose flexibility in the system.

In order to coupe with this trade-off we must try to use changeable morphologies. By manipulating the materials properties or mechanical configurations we can achieve different morphologies or system properties in order to recover some of the lost flexibility. Therefore, it is important that we begin to recognise this trading spaces in order to make use of them. Unfortunately this makes the design process much more complex as the engineering design principles become much less rigid and structured.

As part of the learning process for this new design space, there are new concepts that must get our heads around, and start exploring different ways to think about what actually control means. Apart from the conventional ways of controlling the system, we must see how “guided self-organisation” can be used to manipulate the behaviour of the system. Embracing non-linearities as desirable properties that can benefit both the control and the mechanical system. Ultimately, we can achieve higher efficiency by shifting tasks to mechanical components, leaving other parts do their job independently.

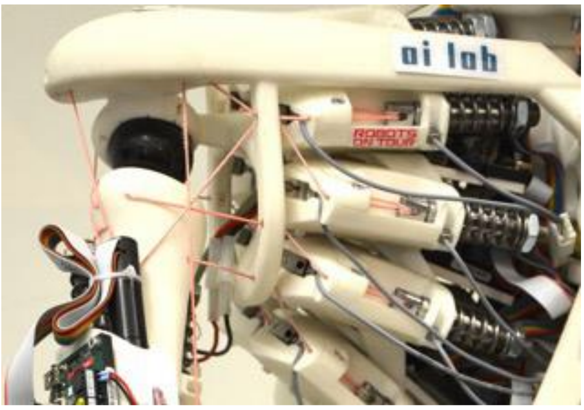
SENSORY MOTOR CONTINGENCIES

This last concept is used to explain how sensory stimulation can be stimulated, and influenced by the actions of a system. For example, while walking the field of view changes, the pressure in the feet and balance constantly change, generating a vast amount of sensory data, even though the environment is not changing.

This action driven data patterns can be used to determine the success of the tasks we are performing. Additionally, these patterns created through experience also produce expectations about the tasks we are about to perform.

All this patterns have huge implications for the control of the system. Through the correlations between different actions on a environment, and the different sensory stimulations they produce, it is possible to understand the learning process and how this affects the tasks to be performed.

Roboy Project



On the 25th anniversary of the lab, it was decided to create a new robot together with 7 universities and 40 companies. It is tendon driven system intended to be used as a research platform. It is being used to understand about the concepts mention before. Learning how to operate an over-actuated arm to achieve certain movement or mechanical properties. Also for understanding of musculo-skeletal system, brain lesions – stroke, human-robot cooperation.

Robolounge Asia Project

Since robot will fundamentally impact our lives, a space where robots and humans interact is necessary to start answering many of the questions that normal people have.

Through this interactions we can learn how to share our living spaces with robots, while also promoting exploration, discussion, experimentation, and experience.