Future Trends of Mobiligence: Adaptive Motor Function through Dynamic Interactions among the Body, Brain and Environment

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I. Introduction

Human and Animals can behave adaptively even for diverse and complex environments in various types of behaviors, such as locomotive behaviors in the form of swimming, flying and walking, manipulation behaviors such as reaching, capturing and grasping, social behaviors to the other subjects, etc. Such an adaptive function is considered to emerge from the interaction of the body, brain, and environment, which is induced by the active mobility of the cognitive subject. We call this mobiligence. Namely, the mobiligence can be defined as intelligence for generating adaptive motor function which is emerged by mobility.

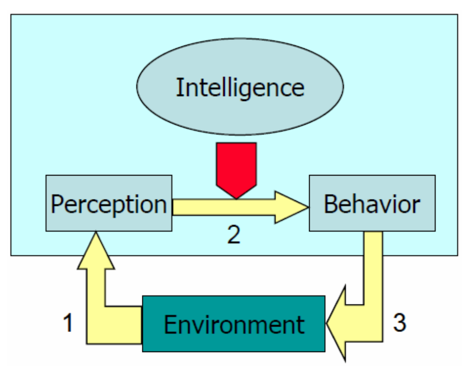
This half day workshop focuses on the adaptation mechanism of locomotion, which is one of the important functions of mobility. We are planning to treat various types of locomotion: bipedal/quadrupedal, walking, running, jumping, crawling, swimming, flying. etc. We are going to discuss the capability of adaptation of the locomotion in such various types of locomotion under various situations or environment. The issues provided on this workshop are adaptive control architecture for locomotion from the stand point of neurophysiologic approach, robotic approach, dynamic systems approach, and so on. And we are expecting to figure out a new control architecture and measurement methodologies

II. Concept of Mobiligence

Adaptive function is considered to emerge by the active mobility of the cognitive subject. In the subject is in the stationary state, there is not so much interaction among body, brain, and environment. However, once the subject starts to move, the signals to move the body are transmitted from the brain to the body. As the result of the motion of the body, the physical interaction between the body and environment are made, and due to the interaction, the information from environment is input to the brain directly or fed back to the brain via the body as somatosensory signals. Namely, the motion of the subject accelerates the interaction among body, brain, and environment, which is considered essential for the subject to behave adaptively. Based on the consideration, we built up a working hypothesis that the adaptive function emerge from the interaction among the body, brain and environment, which requires actions or motions of the subject, and defined *mobiligence* as intelligence for generating adaptive motor function which emerges by mobility. The information which can be acquired by mobility can be listed as follows:

1. Diverse information by changing location of the subject
2. Dynamical information by motion
3. Experience accumulated in the subject

There is difference in the concept of the conventional robotics and *mobiligence*, which are compared in fig. 1. In the conventional robotics, which discusses intelligence for mobility, the first step is perception and cognition. The subject recognizes the environment based on the information perceived by sensors, then plans the motions by applying knowledge which should be implemented in advance, and behaves by controlling the actuators, namely, moves the body, which causes the interaction to the environment, as shown in fig. 1-(a). On the other hand, in the concept of *mobiligence* which investigates intelligence emerged by mobility, the first step is behavior as shown in fig. 1-(b). The perception is initiated by the behavior. As a result of the behavior, rich information can be acquired by the interaction between the body and the environment, and input to the brain. The information can be accumulated in the brain, and utilized concurrently to generate adaptive behaviors in real time. The combination of the two concepts derives the tight and continuous loop between cognition and behavior or among body, brain, and environment, which is considered quite important to understand the intelligence of living systems that behave adaptively or to design the intelligence of the autonomous artificial robots.



(a) Concept of conventional robotics

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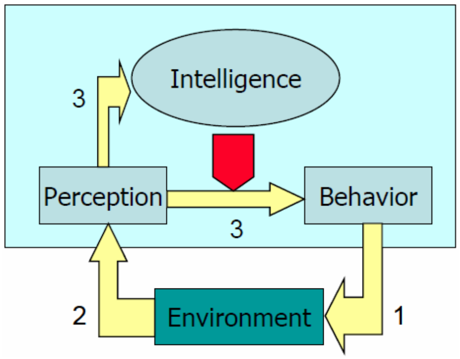

(b) Concept of Mobiligence

Fig. 1. Comparison of the concepts of conventional robotics and mobiligence

III. OBJECTIVES AND ISSUES OF THIS WORKSHOP

Locomotion is an important function of mobility. Human and animals has a real-time adaptability to a changing environment or unidentified situations. However, the mechanism from which the adaptive motion pattern emerges is not clear.

This workshop focuses on the adaptation mechanism of locomotion, which is one of the important functions of mobility and intelligent behaviors. We are planning to treat various types of locomotion. The objectives of this workshop are to bring together researchers from diverse fields of robotics and biological systems, discuss the capability of adaptation of the locomotion in various situations or environment, figure out new control architecture and measurement methodologies, which is not only from the viewpoint of robotics but also biology or biomimetic engineering.

This workshop consists of following issues.

First, Dr. Mori and his group's work is introduced from the standpoint of biomechanical, neuroanatomical and neurophysiological analysis of the adaptation mechanisms of locomotion using monkey. The results clearly demonstrated that the bipedal walking monkey could adapt its locomotion to an inclined treadmill by coupling trunk and lower-limb movements. The strategies employed were quite similar to those in the human.

Second, Dr. Christophe and his group's work is shown. The work is on development and analysis of dynamic waking of quadrupedal locomotion. The controller is based on CPG model and reflexes. They realized dynamic walk using a simple mechanical structure with a distributed control system, made of four independent leg controllers whose swing and stance phase durations are modulated based on leg loading information. Leg coordination was achieved without explicit coordination mechanism, and emerged due to the entrainment between the stepping motions of the legs, the body rolling motion and the lateral transfer of leg loading, relayed by the phase modulations.

The third is Dr. Ijspeert's work on how he modeled CPGs of lower vertebrates such as lamprey and salamander, using systems of coupled oscillators, and how they test the CPG models on board of amphibious robots, in particular a new salamander-like robot capable of swimming and walking according to the variance of the surrounding environment.

The fourth is Dr. Senda's work on analysis of butterfly's flight mechanism. This study has modeled a butterfly and implemented numerical simulation to analyze stability of the posture motion. The results show the flapping-of-wings flight obtained from the trajectory search has been unstable. The flight instability has been decreased by the wake-induced flow and/or the wing torsion of structural flexibility, which can be observed in living butterflies.

The fifth is Dr. Takuma and his group's work on design of physical bipedal robot whose joints are driven by McKibben pneumatic actuators as artificial muscles and a feed forward controller that realize multi-modal locomotion. Investigation of the robot's behavior shows that proper joint compliance achieves a walking from standing and a sequential jumping, and the result utilizing the simulation shows that proper muscle configuration provides stable landing for sequential jumping. These results suggest that tunable leg compliance with appropriate muscle configuration is powerful mechanism for bipedal robot to provide human-like multi-modal locomotion.

The last is Dr. Shimizu and his group's work on development of two-dimensional modular robot called "Slimebot." This talk discusses experimental verifications of the robot consisting of many identical modules, each of which has simple motile functions. They have so far investigated a fully decentralized algorithm able to control the morphology of the modular robot in real-time according to the environment encountered. They insist that one of the most significant features of their approach is that they explicitly exploit "emergent phenomena" stemming from the interplay between control and mechanical systems.