A Concept of Cognitive-based Locomotion for Quadruped Robot

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1 Background

Human and animal (vertebrate) locomotion have a similar sensory-motor process. It is generated from the integration of many aspects, perceiving, reasoning, sensing, and memorizing. Currently, the development of sensory-motor coordination based locomotion is only focussing on Somatosensory and Vestibular system. Those are mainly developing the integration between internal sensory information and motor action [1, 2]. Dynamic locomotion model should integrate cognition, embodiment structure, and motion generator for developing solid methodology [3]. In human, visual input has a major effect on action behavior adaptation with environmental condition. It provides information to the brain as consideration for generating the signal to musculoskeletal system [4]. Therefore, visual information representing external input may effect to all terms adaptation instead of internal input may affect only in short term adaptation. In order to perform dynamic bio-inspired system, the model should coordinate both internal and external (cognitive) sensory information. The separation among them may limit the dynamic integration among them.

Therefore, in this paper, we propose a concept of cognitive-based locomotion which involves not only internal sensory information but also external sensory information. It implements the integration between visual information, Vestibular, and Somatosensory system.

2 System Design

Practically, human or animal is not always performing a sequential movement (walking, running, galloping, etc.). Sometimes, they need to interrupt the rhythmic movement in order to avoid unsafe grounding. This mechanism can only be triggered by involving cognition with external sensory information. The proposed cognitive based locomotion shown in Fig. 1 is inspired by Perceiving-Acting cycle of ecological psychology. 3D Point cloud data as external sensory information acts as the input. Furthermore, touching sensor and joint angle position act as the internal sensory information.

In human, visual information always cooperates with an attention mechanism. It can emphasize the important input and ignore irrelevant input. In our proposed model, selective

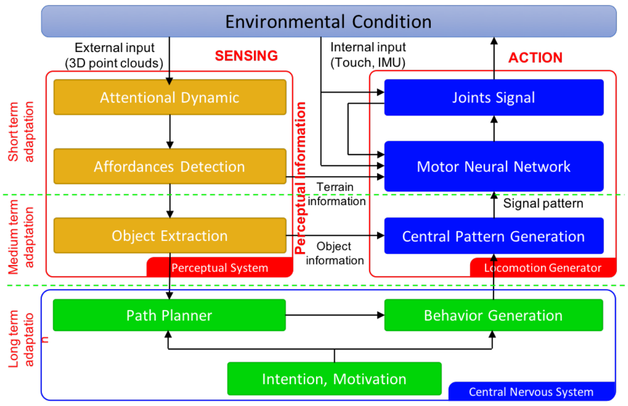


Figure 1: Overall diagram of cognitive-based locomotion

attention is modeled for processing 3D point clouds data. The attentional information is represented by the dynamic density of topological map. In medium term adaptation, the topological information is processed in a perception model for acquiring the affordance information. After that, the path planning model combined with the intention of moving is required at a higher level for generating the robot movement. The intention of movement generated from the path planner will be converted to robot moving behavior in Behavior Generation model. It sends a signal to Locomotion Generator in medium-term adaptation.

3 Locomotion generator

The neural-interconnection of locomotion generator is modeled in Fig. 2. Human locomotion generator is composed as a central pattern generator (CPG) and motor neural pools structure (MNs) [5]. In our model, CPG data will be updated in every one stepping motion (medium term), and MN structure will be updated in every time cycle (short term). CPG model has sensory feedback from MNs structure and foot touching sensors for adapting the motion pattern. MN structure also has sensory input from perceptual information (Affordance of terrain) and internal sensory information such as touching sensor, inertial sensor (Somatosensory), and heading information (vestibular). Furthermore, Perceptual information is composed of pattern interrupter and affordance-motion integrator. Pattern interrupter neurons control how big the motion pattern is interrupted to avoid an obstacle. Affordance-motion integrator generates the correction signal to motor neurons based on

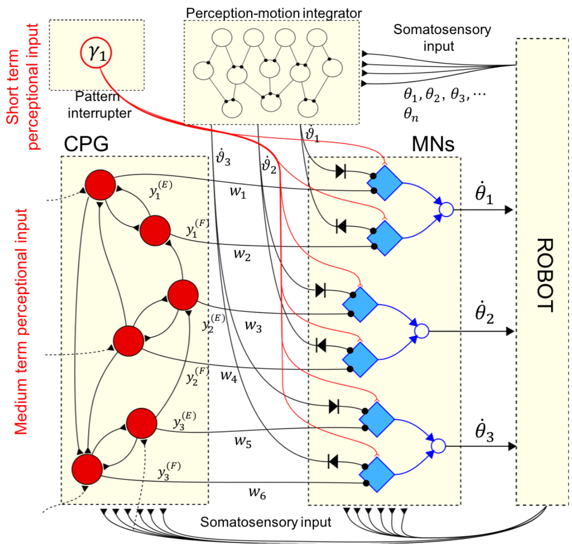
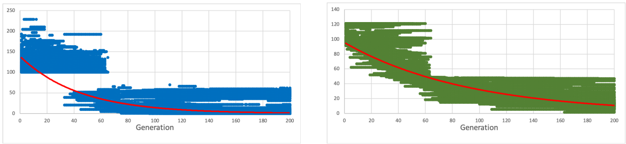


Figure 2: Neural interconnection model of proposed locomotion generator



(a) **(b)**

Figure 3: Diagram of fitness evolution. There are 128 evaluated performances in every generation. (a) first fitness is calculated by evaluating energy required and reward of passing the obstacle (b) calculated by evaluating the distance achieved

the terrain and obstacle affordances information. From the combination of the external and internal sensory information, the dynamic locomotion is generated.

4 Experimental Result

In order to implement the proposed model, the attentional dynamic and object-terrain affordance detection have built beforehand. Then, we optimized affordance-motion integrator for processing the affordance information and send the signal to MNs. In addition, the walking pattern control by CPG has been optimized in our previous work [6]. In this experiment, we employ multi-objectives evolutionary algorithm to optimize the weight parameter between CPG and MNs (**w**) and between perceptual information and MNs ($\dot{\vartheta}$) (see Fig. 2). There are 64 individuals in one population. We run the process until 200 generations through computer simulation. For calculating every evaluation, we run the robot through the obstacle with a random position. We analyze the result of passing the obstacle and its energy required. The movement distance is also analyzed. The optimization result can be seen in Fig. 3. The Red trendline of fitness evaluations decreased implies that the robot has optimized well and could perform passing the obstacle with minimum energy required and maximum distance.

After finishing the optimization, we performed the optimized system into real middle size quadruped robot. We

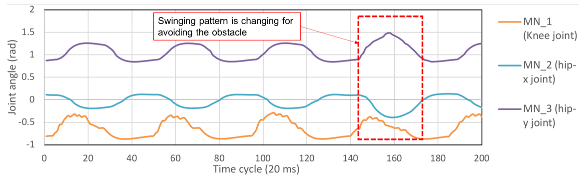


Figure 4: Signal generated by motor neurons representing one of the robot's leg. There are changing of swinging pattern in red square

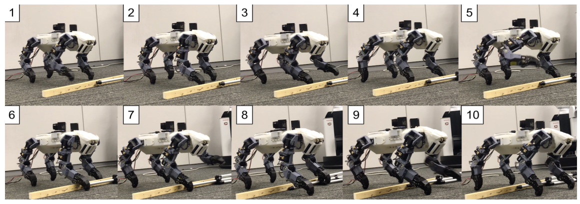


Figure 5: Snapshot of robot performance avoiding the obstacle by enabling the proposed model

run 20 performances on the carpet with a random obstacle's position. The robot succeeded in passing the obstacle 18 times autonomously. While deactivating the perceptual information, the robot always hit the obstacles. The snapshot of robot performance succeeded in passing the obstacle can be seen in Fig. 5. In 4-*th* until 7-*th* snapshots, the robot changing the swinging behavior. It lifted the leg higher than the normal pattern of swinging behavior. Shown in Fig. 4, the swinging pattern was changing and interrupted when the robot faced unsafe foothold and an obstacle. During this time, the degree of interrupter was increasing, and MNs tend to use the signal from perceptual information.

5 Conclusions

Cognitive information is essential to be involved in dynamic locomotion development. It has significant impacts not only in long term adaptation but also in short term adaptation. We use multi-objective evolutionary algorithm for optimizing the locomotion generator model. By using this model, the robot can avoid the upcoming obstacle by changing the pattern of swinging behavior. There is 10% error in the real performance due to the preciseness of sensors. However, the cognitive-based locomotion has high research prospect in order to achieve the dynamic locomotion.

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