環境モニタリングのための多足歩行ロボットの開発
Development of Multi-legged Robots for Environmental Monitoring

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近年，様々なセンサの高精度・小型・軽量化に伴い，検査用ロボットも小型・軽量化が進んでいる．本研究では，工場やプラント内での各種モニタリングを行うための多足歩行ロボットのプラットフォームの開発を行う．具体的には，人間と共有する作業空間での移動を想定し，工場やプラント内でのはしごの昇降ができる移動機能や，3 次元距離情報を用いた環境認識機能を実装した．本稿では，各種予備実験を紹介する．

Keywords: Multi-legged robots, Environmental Monitoring, Topological Mapping, Any-field Mobility

1. Introduction

The development of mobile robots has been increasing significantly with several types of robots such as wheeled and legged robots. Only less than half of the terrain in the world can be accessible by a wheeled robot. Thus, the limitation of coverage area causes the minimal mobility. On the other hand, the mobility of humans and animals is higher and more flexible in any terrain. They can go everywhere on earth. Furthermore, the animal-like mobility can be applied to a multi-purpose robot in these environmental conditions for performing a rescue mission, space exploration, and environment mapping. This condition motivates us to involve in the research of legged type robot by imitating animal morphology. The goal of this paper is to develop legged-robot by imitating the cat morphologies for achieving cat-like mobility.

During the past 40 years, a variety of robot has developed a diverse set of intelligent and inspiring legged robots. Boston Dynamics has built Big Dog, quadruped robot that able to move on challenging terrain [1]. Then, ANYmal has a similar feature that able to move in any terrain [2]. However, it has difficulties in the climbing movement. Other researchers are focusing on the speed capabilities of the legged robot. MIT Cheetah has been developed with the 33kg of weight and can run until 22 km/h [3]. Li et al. also developed a cheetah-like robot that able to move ultra-high speed. The robot is developed using anatomical analysis and design, inspired by a biological neural mechanism [4]. Furthermore, quadruped robot is developed for climbing vertical surfaces and performing autonomous floor to wall transfer. It has a limitation on the flexibility of maneuvering [5].

According to the current situation on robot mobility, we develop a Felidae-like quadruped robot able to climb without decreasing its maneuvering capabilities.

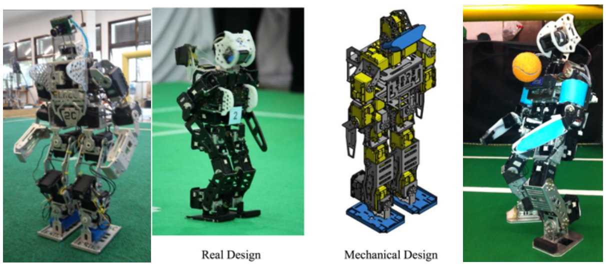
Real Design
Mechanical Design

Fig.1 Development of biped robot

2. History of Development

The present authors started in the legged robot development eight years ago, focusing on mini-size humanoid robots with its controller. We developed a series of humanoid robot for competing RoboCup 2012 – 2015 [6-7]. The robot has capabilities to highly flexible maneuvering, kicking, self-recovery from falling. However, this type of robot has a limitation of function due to the limitation coverage payload. The robot has minimum power energy and incomplete sensory system [6-7]. The appearance of the robot can be seen in Fig. 1. the robots are made of aluminum material with 50 cm of weight.

2.1 First prototype of Quadruped Robot

In order to enlarge the purposes, in 2015 we moved to developed quadruped robot. In the prototype, there are 3 degrees of freedom (hip-x, hip-y, and knee joint) in each leg. The robot's size is approximately 30 cm x 18 cm x 20 cm, and its weight is 2

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kg. The robot figures can be seen in Fig. In the hardware structure, Arduino Mega was used as the main controller, which has only 16 MHz processor frequency. For low-cost development, the robot hardware also utilized the iPhone as an inertial sensor for feedback sensor and stabilization analyzer in order to change the sensor unit. The appearance of the robot can be seen in Fig. 2.

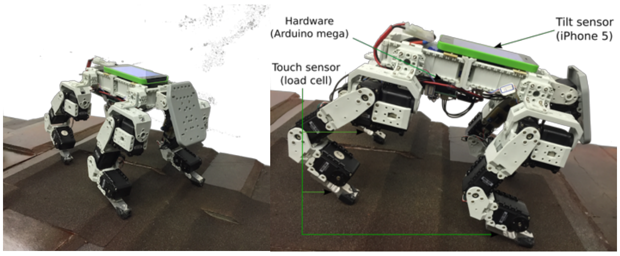

Fig.2 First prototype of Quadruped robot

Using this prototype, we implemented our neural based locomotion model. We use neural oscillator model for generating the walking pattern. The robot can move dynamically in both sloped and rough terrain [8].

2.1 Second prototype of Quadruped Robot

This prototype has more complex sensors than the first prototype. It has onboard systems that provide power, actuation, sensing, controls, and communications. The robot is equipped by Kinect camera for local area detection and dual laser range finder (LRF) for wide area detection. There are also one force sensor in every leg for measuring the touching. All the sensory input and control systems are processed in embedded PC UDOO QUAD.

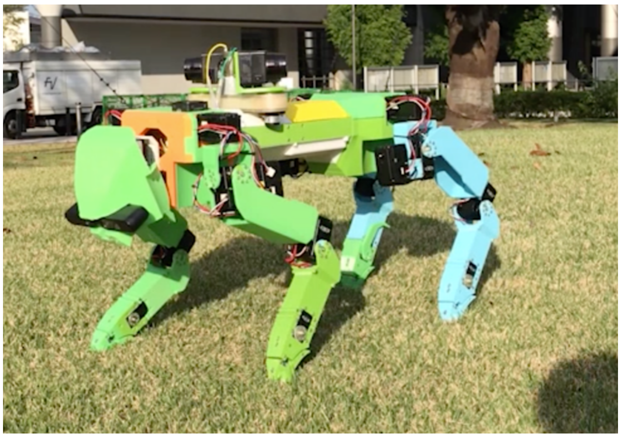

Fig.3 Second prototype of Quadruped robot

The robot has approximately 60 cm of length, 25 cm of width, and 35 cm of height. The robot is equipped by single gripper in every leg. However, due to the mechanical problem, the robot could not perform for climbing behavior.

3. Proposed Robot

Several researchers have analyzed Felidae animal morphologies. From the behavior viewpoint, the animal has higher mobility than many other animals. They have faster movement in many field conditions. Our robot is inspired by its morphology, from the dimension until the motion behavior.

3.1 Mechanical design

The proposed robot weight is about 7kg and the dimension is 25 cm (width) x 60 cm (length) x 30 cm (height). The mechanical structure of the robot can be seen in Fig. 4. The robot has 23 degree of freedoms (DoF). There are 4 DoF for joint in each leg, one gripper in every leg, 2 DoF for the dual sensor, and 1 DoF for the neck. There is a single gripper in every leg. We use servo motor Dynamixel MX-106 as the actuator of the leg, and otherwise, are using Dynamixel MX-28.

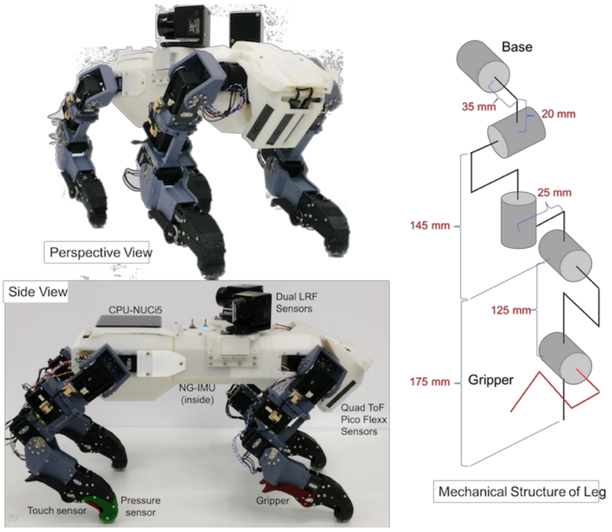

Fig.4 First prototype of Quadruped robot

3.2 Electrical system and sensors.

The robot is installed advance hardware configuration. There are two controllers for processing the system, sub-controller and main controller. Sub-controller is using AT-mega 8 for accommodating the internal sensory input. Main controller using MUC PC core i3 for processing advance systems, such as control system, communication, and interfacing. The robot also equipped with several internal and external sensory information. Inertial sensors measure the tilt angle and acceleration of the body, force sensor measures the force value of touching, and switch sensor detects the grasping position (see Figure 7). Then, in the external sensory information, there are two laser range finders (LRF) for detecting wide area of environmental condition, and quad Pico Flexx sensor (see Figure 6) for detecting the local area. The robot is powered by two 4-cell Lithium polymer battery with 3300 mAh. The hardware structure can be seen in Figure 5.

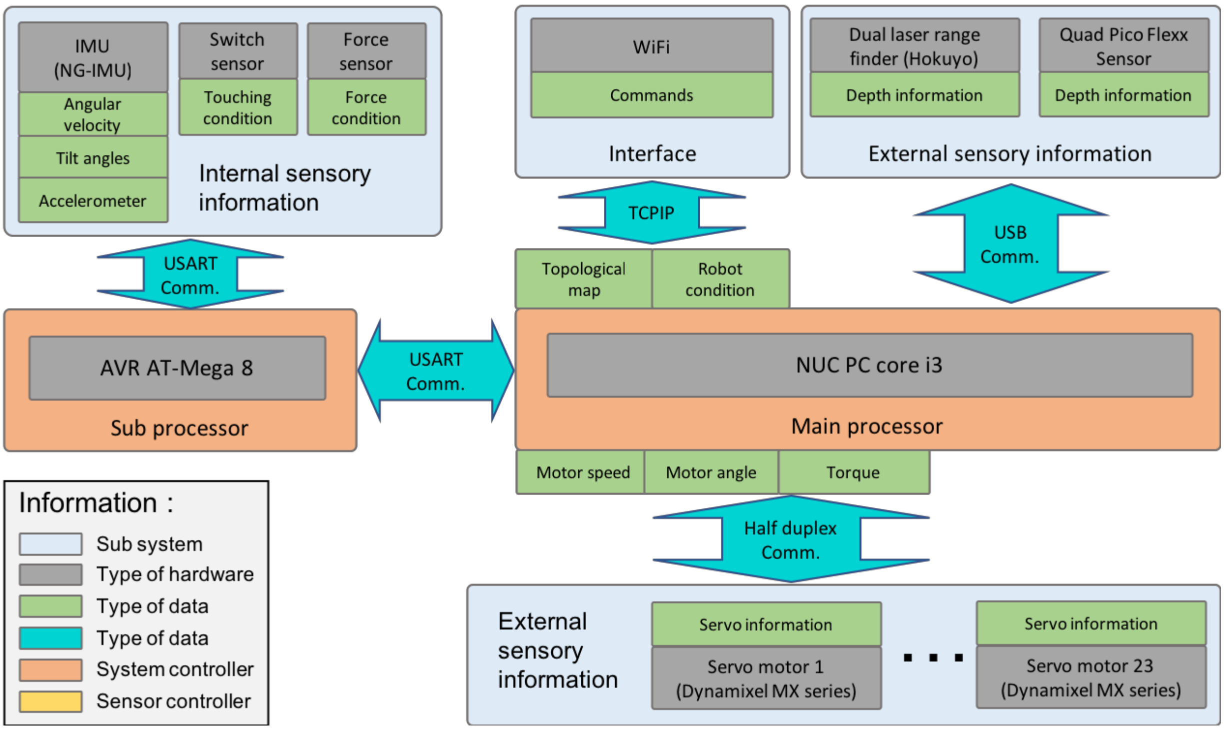

Fig.5 Hardware structure

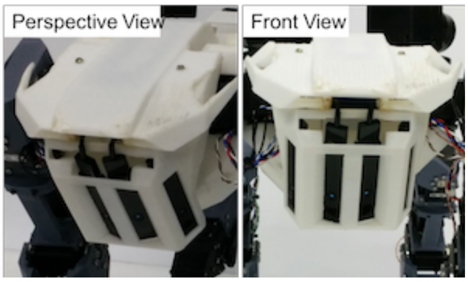

Fig.6 Design of Quad Pico Flexx sensors

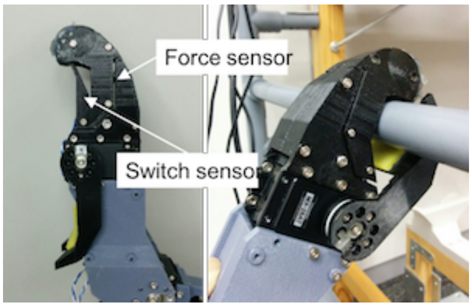

Fig.7 Design of the gripper and attached sensors

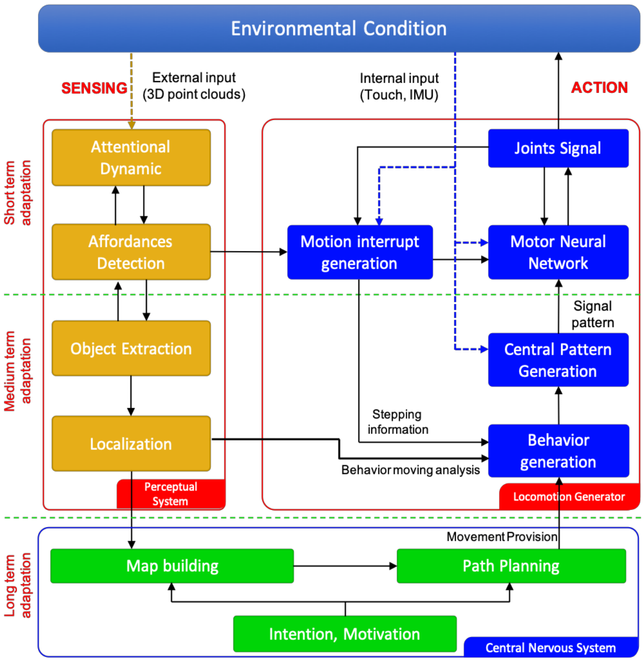

Fig.8 Design of the control systems

3.3 Control system

The system model is shown in Fig. 8 based on the perceiving-acting cycle of ecological psychology. The control system considers not only internal sensory information but also external sensory information. The system shows integration between the cognitive model and action behavior in three-term adaptations, short, medium, and long term adaptation. In short term adaptation, the perceptual information also controls the leg swinging directly.

In medium term adaptation, motion pattern will be controlled depending on the walking provision from a higher level. In long term adaptation, path planning will be generated depending on the environmental condition.

Short term adaptation implies the direct response toward changing of the condition in every time cycle. We use point cloud data generated from the time of flight sensor as the external sensory information. In order to reduce the data representation, we proposed the Attentional dynamic model represented by the topological map with dynamic density.

After that, the generated topological structure is processed by Affordance Detection model. It serves Affordance of stepping legs once before performing stepping action. The result of Affordance is also processed for object detection in mid-term adaptation. Then, its result will be considered by the path planning model in the higher-level controller. Based on the intention, motivation, and goal position given by Human operator, path planner control the motion pattern which representing the (speed and direction). The motion pattern is generated by a neural model that explained in our previous research [9]. Motion pattern generation will send an analog signal to Activation network for activating stepping movement of every leg. This activation is affected by the Affordance and degree of precision in every step. This model will send the discrete signal activation, decided stepping area and its degree of precision to swinging generation model in a particular leg.

4. Implementation

The robot has a variety of locomotion behaviors. It can be dynamically generated depending on the desired speed, generating walking locomotion in slow speed and generating trot locomotion in higher speed. It has maximum speed around 0.6 m/s. This robot can be control with autonomous, semi-autonomous, and manual mode. It has remote control interface using iPad that show the current condition of the robot and its environmental condition. We have tested the robot in steep, grassy, rugged, snowy, and uneven terrain. In advance implementation, we have tested the robot for climbing the ladder.

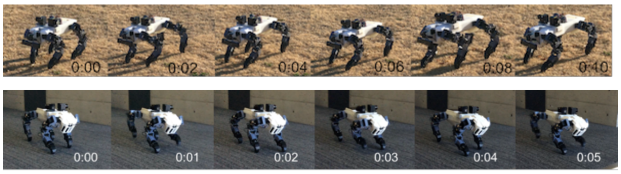

Fig.9 The robot moves on grass and flat terrain

In order to analyze the surrounding environmental condition, dynamic density topological structure generation is proposed for low-cost real-time detection. 3D point cloud data. Dynamic Density Growing Neural Gas (DD-GNG) is proposed in order to generate a dynamic density of topological structure. The result can be seen in Fig. 10. The model can specify small things while the comparator shown in Fig. 11 could not. After that, rungs of the vertical ladder detection is processed using an inlier-outlier method. Next, affordance detection is processed for detecting the feasible grasped location.

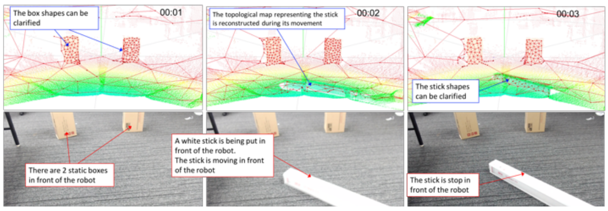

Fig.10 Topological structure generated by DD-GNG

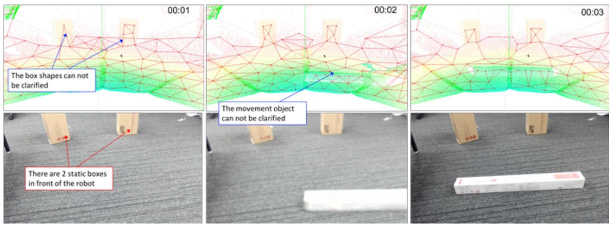

Fig.11 Topological structure generated current GNG model

A result depicted in Figure 12 shows that our proposed method able to detect and track the ladder structure in real time. The affordance of ladder provides safety information for robot grasping.

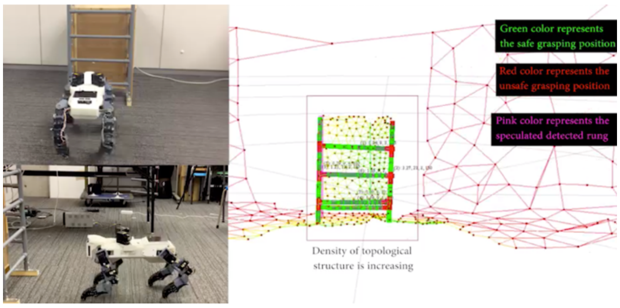

Fig.12 Robot can detect and approach the vertical ladder

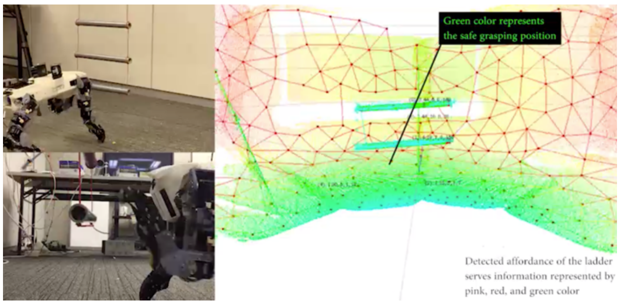

Fig.13 Robot can detect and grasp a moving ladder

After ladder detection has been achieved, we applied advanced capabilities of the robot performing horizontal-vertical-horizontal movement transition through vertical ladder without handrailing supporter. To overcome the proposed problem, we propose a multi-behavior generation model using independent stepping and pose control in the robot. Posture condition, safe movement area, possible touch point, grasping possibility, and target movement are the information that is analyzed from the sensors. There are four options developed in behavior generation, which are, Approaching, Body Placing, Stepping, and Grasping behavior. Before being applied in the real robot, the proposed model is optimized in the computer simulation. As a result depicted in Figs. 13 and 14, the robot succeeded to move through the ladder without handrail from lower stair to upper stair.

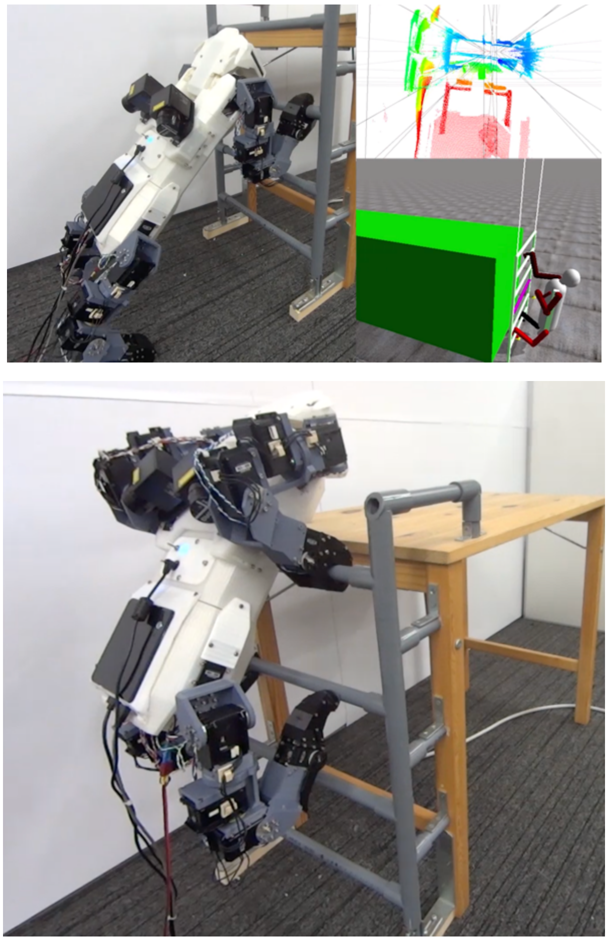

Fig.14 The robot performance on climbing the ladder

5. Future Plans

That is the current development of our quadruped robot. The robot has been implemented in many environmental conditions. With the low-cost budget, we can conduct sophisticated performances. However, there are still practical problems remain to be solved. We will improve by focusing on these three areas:

Improving stability: Although the motion system has been built, however, the stability is required to be improved. We will improve from the preciseness of the inertial sensor and manipulating the current stability model.

Soften the foothold: the robot stepping currently results in hard foothold movement. From the mechanical viewpoint, we will put the damper mechanism in the robot footprints inspired by the leg of cat morphology.

Improving durability: increasing the battery capacity is required to be applied. However, the body's efficiency will also be considered for decreasing the body weight.

Advance Experiments: further experiments are required with various environmental condition. We will make artificial ruins of the building for advanced experiments

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