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Walking Navigation System of Humanoid Robot using Stereo Vision based Floor Recognition and Path Planning with Multi-Layered Body Image

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Abstract— To realize humanoid robots in unknown environment, sensor based navigation system is required as one of an essential function. This paper describes vision-based navigation system for humanoid robots, which has following features:

1) To recognize floor regions from a view of vision of a humanoid robot in unknown environment, we utilized existing technique called Plane Segment Finder, which is able to extract arbitrary planner surface regions from depth image.

2) Path planning for wheeled robots usually models a robot as a 2D ciccle, however path planning system for humanoid robot requires capable of modeling a robot as a 3D cylinder model, convex hull model, rigid model and so on, according to a situation such as a robot carries a large object or a robot opens it's arms.

Finally, we show a humanoid robot HOAP-1 with enhanced stereo vision system for navigation task and a result of path planning using generated local map through stereo vision system which uses real images as an input.

I. INTRODUCTION

Humanoid robots have been widely investigated, particularly in the field of dynamic walking control and mechanical design[1], [2], [3], [4], [5]. However current status of these humanoid robots is to walk along with pre-programmed path. To realize a humanoid robot in real-world and unknown environment, a sensor based navigation system is required.

Navigation system generates a path that a robot moves along, from a current position to a target position based on a map information around a robot. Previously, navigation techniques have been studying using wheeled robots[6], [7], [8], however there is a few researches on a navigation system for humanoid robots.

Bourgeot et al[9] proposed a method to generate footprints from a reference path. The method finds a path and footprints in terrain under robot stability and motion continuity in given a starting position and a goal position. Kuffner et al[10] developed a footprints and leg trajectory planner using global method that has ability to step over obstacles and considering global information enables to cope with local minima while other researches used local and reactive methods. Shiller et al[11] proposed motion planner for human figure that is able to finds path while changing body posture using path planning using configuration space with multi-layered grids that each grid corresponds to a single posture. These researches focus on path planning and sensor-based recognition of an environment for a path planner and it's integration beyond these researches.

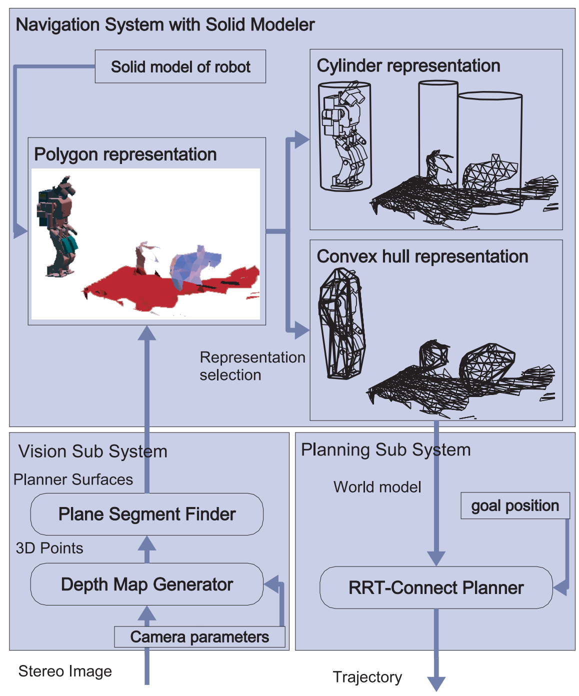

Fig. 1. An Overview of Vision-based Navigation System of Humanoid Robot

Lorch et al[12] has developed a sensor based planning system using biped robot with stereo vision sensor. They proposed footprints planner using a local environment map based on visual sensor inputs. This

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planner finds step sequence while a robot walking on a straight line. They recognized an obstacle under assumption that any object in the scene is rectangles.

In this paper, we describe the vision-based navigation system for humanoid robots with vision based floor recognition and path planning using multi-layered body image.

To recognize floor regions and detect arbitrary obstacles on a floor from a view of vision of a humanoid robot in unknown and real environment, we utilized existing technique called Plane Segment Finder[13], which is able to extract arbitrary planner surface regions from depth image.

Path planning with wheeled robots usually models a robot as a cylinder, however modeling a humanoid robot as a cylinder causes problems such as occupying too large area when a robot opens it's arms or a robot carries a large object. We developed a system that has capable of using multi-layered body image which is cylinder model, convex hull model, rigid-body model for path planning.

II. VISION-BASED NAVIGATION SYSTEM OF HUMANOID ROBOT

In this section, we describe an overview of our vision-based navigation system for humanoid robots. Our system is consists of vision based floor recognition, path planning using multi-layered body image..

Fig. 1 shows an overview of the developed system. In the vision sub-system, the depth map generator calculate depth map image from stereo images. From a depth map and camera parameters, it calculates 3D points for each point of an input image. PSF generate planner surface from 3D triangles generated from calculated 3D points, and segment floor surface and obstacles by using solid model of the humanoid robot.

The path planning sub-system generate a path from the current position to the given goal position while avoid obstacles. This sub-system is able to use cylinder model, convex hull model, rigid-body model for path planning. In current status, a selection of a level of robot and world representation is hand-written. RRT-Connect Planner algorithm[14] is used as a path planner

III. PATH PLANNING WITH MULTI-LAYERED BODY IMAGE

Previous researches on path planning with wheeled robots usually models a robot as a cylinder, however modeling a humanoid robot as a cylinder causes problems such as occupying too large area when a robot opens it's arms or a robot carries a large object.

Therefore a path planning system for humanoid robot requires capability of using multi-layered body

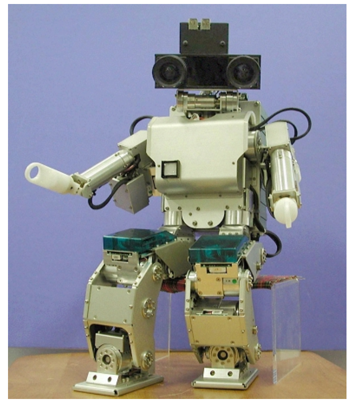


Fig. 2. HOAP-1 with Extended Head Module

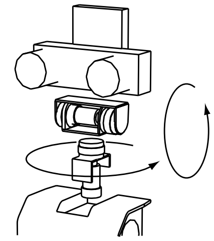


Fig. 3. 2DOF Neck Module with Yaw and Pitch Axises

image for path planning, which is cylinder model, convex hull model, rigid-body model.

This system represents an environment and a robot as a set of polygon patches, since it is able to generate cylinder model, convex hull model or rigid-body model from polygon patches. Path planning sub-system generates required an environment and a body model from polygon patches.

The implementation of this system utilize EusLisp[15], which is an extended Common Lisp implementation with a 3D solid modeler function. A solid modeler function of EusLisp manage a 3D points calculated by stereo vision system, a 3D shape model of an environment and a robot, path planning in 3D world without difficulty.

A. RRT-Connect Planner

In this paper, we utilize RRT-Connect Planner[14] as a path planning method. This method generates a path which connects from a start position to a goal position by using randomly growing trees in configuration space. Path smoothing is performed on the final path to reduce jaggedness.

IV. VISION-BASED LOCAL MAP GENERATION

Sensor based path planning system requires a local map of an environment around a robot. A map has information that which regions are occupied by obstacles or not occupied. Previous researches with wheeled robot usually modeled a robot as a 2D circle and plan a path on a 2D grid map. They use laser range sensor or stereo vision sensor to generate 2D map for planning. To cope with 3D path planning for humanoid robot, our system represents an environment and a robot requires using a set of 3D polygon patches. However, as a humanoid robot that walks on a ground, it is important to detect regions where a robot is able to move around. In this section we

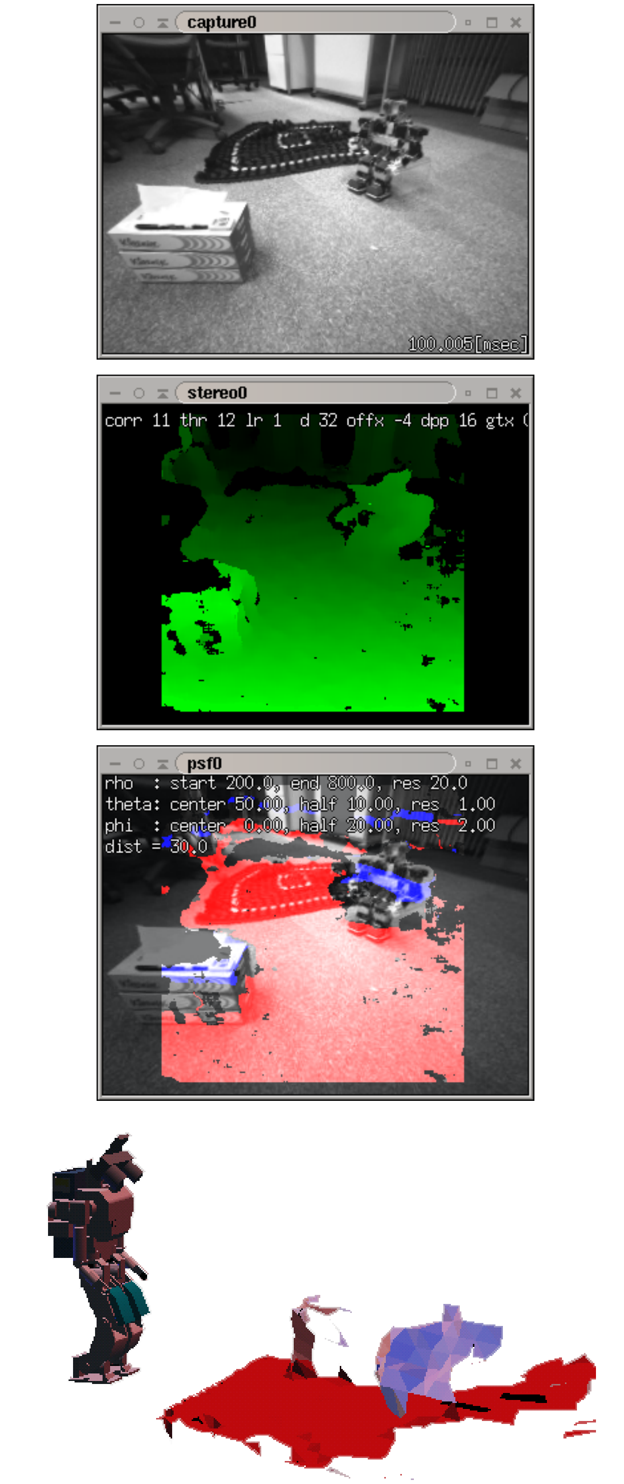


Fig. 4. An experimental result of vision based floor region recognition. From top, Stereo vision input, Depth map image, Result of Plane Segment Finder(Red regions are planner surfaces), Reconstructed environment model and the robot model

describe a method to detect floor region from visual information. We apply our Plane Segment Finder (PSF) algorithm[13] which extracts three-dimensional planner surfaces from visual input.

A. Plane Segment Finder to Extracted Planner Surfaces

We utilized the Hough transform method for extracting plane segment candidates. The Hough Transformation method is a well-known method which is robust to noise and occlusions, and generally used for extracting lines, circles or ellipses.

To apply the Hough Transform method for a plane segment extraction, we adopt the following parametric representation of a plane, where ρ is the distance between a plane and the origin, ϕ is angle against the x axis, θ is angle against y the axis. (x_0, y_0, z_0) is the point on the plane.

$$\rho = (x_0 \cos(\phi) + y_0 \sin(\phi)) \cos(\theta) + z_0 \sin(\theta)$$

Hence, to extract plane segment candidates, 1) we transform ("vote") all 3D points into the Hough space, 2)Detect peak points in the Hough space, which correspond to planner surface candidates in 3D space.

B. Fast Planner Segmentation using Randomized Hough Transform Method

The Hough Transform method has the advantage that it is robust to noise. However, the computational cost and required memory size are very high.

These disadvantages are very significant problems to develop real-time system for robotics applications. To cope with this problem, a method called Randomized or Probabilistic Hough Transform[16], [17] has been introduced. We apply this idea to our Hough Transformation for extracting planes.

This method reduces the computational cost of Hough Transform. The points to be voted in Hough array for a pixel in distance image is $S(constraint)$ points, where $\Theta - \Phi(resolution of each axis)$ points without Randomized Hough Transform method.

C. Local Map Generation based on Floor Region Detection

To detect floor regions from extracted planner surface by PSF, coordinate transformation from view coordinates to body coordinate is required , since a planner surfaces regions segmented by using PSF is represented in view coordinates.

We utilize whole body posture information for coordinates transformation under a assumption that a humanoid robot stands on a ground.

In current status, local map is represented by a set of polygon patches with information of each polygon is belongs to floor regions or not. Floor regions are considered as regions where a robot is able to move around.

V. HUMANOID ROBOT HOAP-1 WITH 2DOF HEAD MODULE WITH STEREO VISION

This section describes an extension of a humanoid robot HOAP-1, which is a commercial humanoid robot product as a behavior research platform. The purpose of this extension is to apply HOAP-1 as a research platform of vision based behavior of humanoid robot. We have developed a 2 DOF neck module and stereo vision head as shown in Fig. 2.

A. Humanoid Robot HOAP-1

HOAP-1[18] is a commercial humanoid robot from Fujitsu Automation Ltd. and Fujitsu Laboratories Ltd. for behavior research. HOAP-1 is a small-sized robot with 6[kg] weights and 480[mm] heights. It has 6 DOF for each leg, and 4 DOF for each arm as a movable joint. Sensor system of this robot is as follows: one 3-axis accelerometer sensor, one 3-axis gyro sensor, four FSR(Force Sensing Resister) cells for each foot sole, and two wireless CMOS cameras.

The robot's internal actuators and sensors except two cameras have USB interface and connected through on-body USB network. These devices is able to communicates with RT-Linux based PC through a USB interface. Real-time module (rtl_ctlmodule.o) provided by Fujitsu communicates with USB network at a 1[msec] frequency, and user written application program and real-time module are able to share information using Share Memory Space mechanism of RT-Linux.

B. Extended HOAP-1 Head Module with 2 DOF Neck Mechanism and Stereo Vision Head

From the hardware point of view, there are three problems when one utilize original version of HOAP-1 as a research platform of stereo-vision based behaviors.

The first problem is a wireless nose problem. Since original two wireless CMOS cameras use 1.2GHz microwave as wireless communication, there is a considerable noise on communication which disturbs view images of the robot.

The Second problem is unstable baseline mechanism. Since attached mechanism between head module and each CMOS cameras is very unstable so that easily change baseline between two cameras while experiment.

The last problem is restricted field of vision. Since there is no DOF on neck so that to execute behaviors such as "look around" or "gaze a target", the robot needs to control both legs to archive these behaviors. However rotating waist by controlling both legs causes self contact between legs, and it only rotate the body around 15[degree].

1) Hardware Design of Extended Head Module: To overcome above problems, we developed Extended Head Module with 2 DOF neck mechanism and stereo vision head. The 2DOF of the neck module are yaw axis and pitch axis as shown in Fig. 3.

Two Servo Module for each yaw and pitch axis of the neck module are Smart Geared Motor (TYPE-1) from Fujitsu Automation Ltd. Neck mechanism is design and developed by authors. We utilize a MEGA-D Digital Stereo Head from Videre Design Inc. as a stereo vision head.

2) Software Design of Extended Head Module: On-body USB network of HOAP-1 is easily expands new motors and sensors according to researcher's needs. The Smart Geared Motor which we used in Extended Head Module includes motor control circuit has USB interface. By connecting this circuit to on-body USB network which other motors and sensors are already connected to, these additional motors are recognized in initialization process of HOAP-1 system software implemented as a real-time module and are able to accesses as 21st and 22nd motors from control PC. We note that no firmware update of motor circuit and sensor circuit that already connected to on-body USB network required. An additional code required for user written application program is to control extended neck module, is to access 21st and 22nd motors. We believe that design of our Extended Head Module ride on the strength of expandability of HOAP-1.

VI. VISION BASED FLOOR REGION RECOGNITION AND PATH PLANNING EXPERIMENT

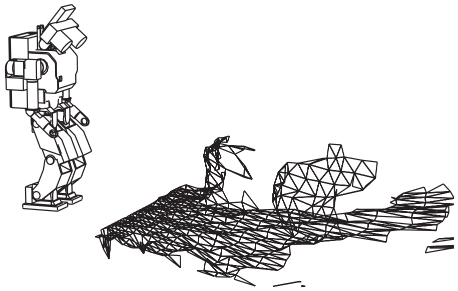
The result of path planning using generated local map through stereo vision system which from real images inputs are shown.

Fig. 4 shows an vision based floor region recognition. Top images are a stereo vision input and it's output. In output image, brighter regions are closest to the camera. Middle image is the result of Plane Segment Finder. Red regions are planner surfaces. Bottom image shows reconstructed environment model and the robot model.

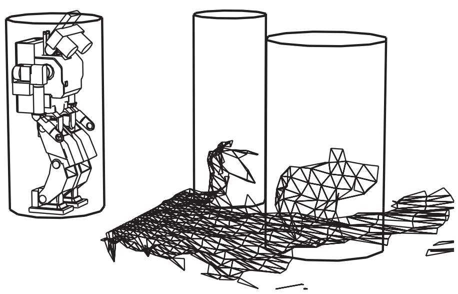
Fig. 5 and Fig. 6 shows the result of path planning when the robot its self, and the robot carries an object.

VII. CONCLUSIONS

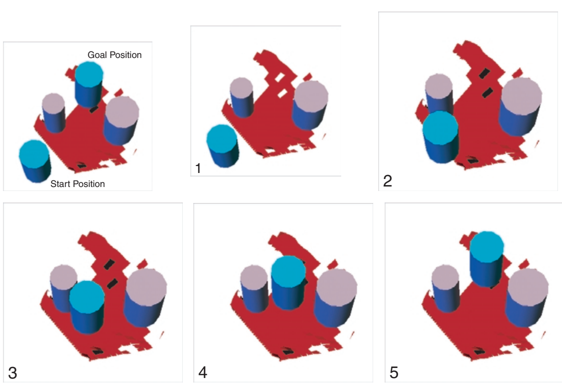
We described vision-based navigation system for humanoid robots with vision based floor recognition and path planning using multi-layered body image. A extended humanoid robot HOAP-1 with stereo vision system for navigation task was also shown and a result of path planning using generated local map through stereo vision system which uses real images as an input ware presented.



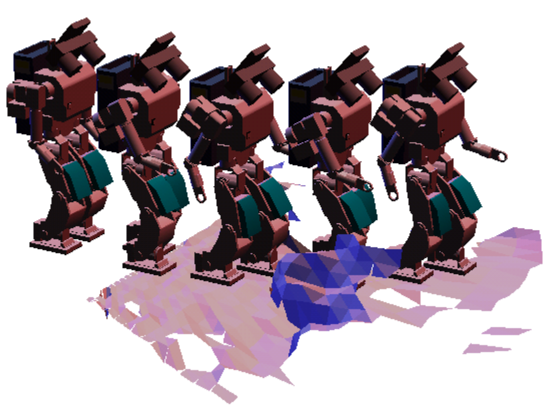
(A) Humaonid robot model and re-constructed environment model from stereo vision



(B) Cylinder representation model of the robot and obstacles used for a path plannning.

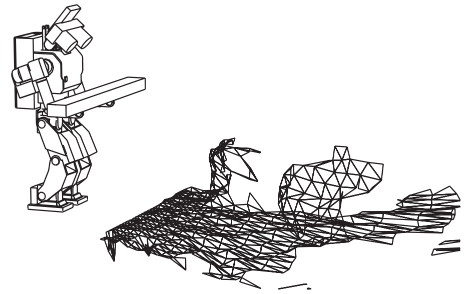


(C) Result of the path planning (topview). White cylinders are obstacles, and blue cylinder is the robot. Top left image shows an start and goal position of the robot.

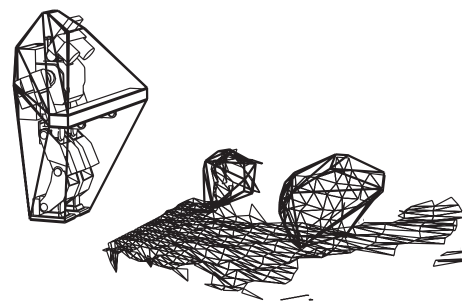


(D) Result of the path planning with an obstacle avoidance.

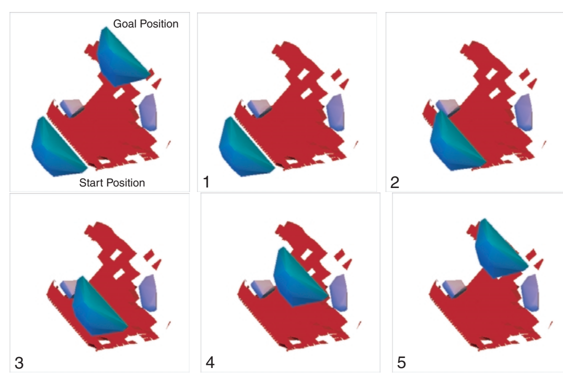
Fig. 5. Path planning result. Path planner used cylinder representation.



(A) Humaonid robot model and re-constructed environment model from stereo vision



(B) Convex hull representation model of the robot and obstacles which is used for a path plannning.



(C) Result of the path planning (topview). White convex hulls are obstacles, and blue convex hull is the robot. Top left image shows an start and goal position of the robot.

(D) Result of the path planning with an obstacle avoidance.

Fig. 6. Path planning result with the robot carrying an object. Path planner used convex hull representation.

VIII. ACKNOWLEDGMENTS

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