3D Reconstruction for Pipe-Shaped Object Using an Omnidirectional Camera and a Spherical Mirror

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***Abstract*—Micro tunnel excavation is limited to straight paths due to size constraints that prevent human entry through the jacking pipes. A compact, wide-angle system enables the measurement of enclosed spaces with complex paths. This paper proposes a 3D estimation method using a catadioptric imaging system, which consists of an omnidirectional camera and a single spherical mirror, to capture monocular images without relying on training data. The applicability of our method is confirmed by measuring the geometry of a pipe designed to imitate a propulsion pipe used in tunnel excavation.**

I. Introduction

Tunnel excavation is necessary for installing infrastructure essential for our daily life, such as transportation, electric and water supply, and communication networks. In jacking evacuation, a tunnel excavation method suited for micro-tunneling to medium-diameter pipes, a boring machine is installed in the launch pit and uses jacking pipes to propel the drilling head forward. During this process, regular measurements are required to confirm whether the boring machine is advancing along the intended path. While traditional methods like laser surveying are used for these measurements, micro-tunneling is limited to straight paths due to the size constraints of entering the jacking pipes. A compact, wide-angle system enables measurement of enclosed spaces with complex paths. Furthermore, as the position of jacking pipes in tunnel excavation is dynamic, estimation from a monocular image becomes an efficient method.

The catadioptric imaging systems utilizing curved mirrors can observe a wide angle of view all at once, surpassing the field of view achievable by typical cameras [1][2]. Moreover, employing an omnidirectional camera in conjunction with a regular camera enables the realization of a virtual two-viewpoint system, allowing for 3D estimation from a monocular image without the need for prior knowledge, thus making it feasible with a compact device [2]. This paper demonstrates the effectiveness of 3D estimation using a catadioptric imaging system composed of an omnidirectional camera and a spherical mirror applied to an enclosed space created in a real-world setting.

II. Proposed Method

Our proposed method for estimating 3D information follows the outlined steps illustrated in Figure 1. In this research, a catadioptric imaging system consisting of a spherical mirror and an omnidirectional camera is placed inside the pipe-shaped object to reconstruct its 3D shape.

The process calculates the estimation of 3D information from multiple viewpoints by identifying the mirror reflection at each reflection point and its corresponding area in the omnidirectional image. Stereo matching along the computed ray directions, derived from a backward projection method, utilizes the calculation of visibility similarity. The 3D information offering the highest visibility similarity is then selected. The computation of visibility similarity leverages a color histogram and accounts for the distortion introduced by the spherical mirror's shape. The mask for obtaining the color histogram is set to correspond to the shape change according to the position at which the reflection point is imaged and the positional relationship between the reflection point and the object.

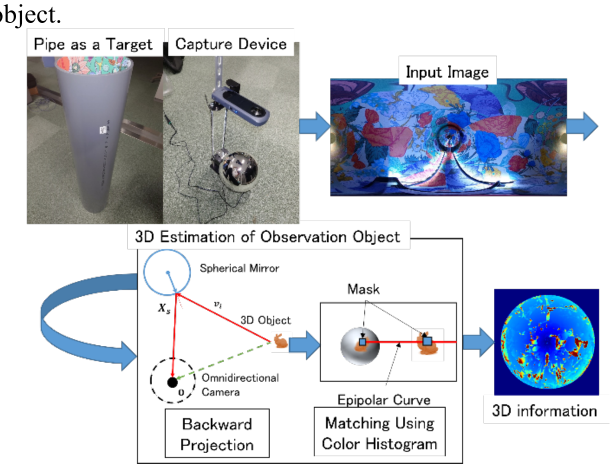

Figure 1. Overview of A 3D Estimation of an Enclosed Space Using an Omnidirectional Camera and a Spherical Mirro

To validate the accuracy of the estimation technique, we designed a tube-shaped real-world setting because the proposed methodology is anticipated to be particularly effective in the side area of the imaging system. In this constructed environment, images were captured, and the 3D shape of the tube was estimated. This experiment served to validate the effectiveness of the proposed method.

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