Massive Rock Handling by a Breaker -Graspless Manipulation and Object Recognition-

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Abstract

The purpose of this study is automated handling of massive rocks for moving them to a proper place and for breaking them down at a rock quarry. This paper reports our first approach in laboratory environment using a robotic manipulator with a small sized laser range finder(LRF) to handle a relatively small object. For tumbling operation, we apply image processing techniques onto range images created from a three-dimensional object using a LRF, we calculate the center of mass, the rotation axis and action point where the rock can be moved under mechanics consideration. We achieved tumbling operation of a stone of relatively simple shape which was taken from a quarry.

keywords:graspless manipulation, tumbling operation, shape recognition

1 Introduction

1.1 Background

We aim at achieving automated handling of massive rocks at a rock quarry for moving them to a proper place and for breaking them down. By 'handling' we mean the action of rolling over or sliding a rock with a chisel which is equipped at the top of a hydraulic breaker, as shown in fig.1. The hydraulic breaker is a secondary construction machine adapted from a hydraulic shovel with a 4 degree of freedom arm which can break a rock down into pieces. We call such a hydraulic shovel a breaker.

At a rock quarry, there are series of operations as shown below:

1. Blast bedrock, then a pile of massive rocks are generated.
2. Move the rocks to a proper place for breaking them down.
3. Break the rocks into pieces
4. Scoop up the rock pile by a wheel loader, and load them with a dump truck.

The breaker only performs operations of item 2. and 3. In 2., it is necessary to break the massive rocks into much smaller pieces because the rocks are too big to transport to the factory soon after the blasting. When rocks are too distant from the base of the arm, it is impossible to propagate enough force from its arm to the chisel to break a rock effectively. In order to overcome this problem, an operator must 'move' the rock to a location near the base where the arm can break the rock efficiently.

In this paper we will concentrate on the automated operation of 2. The reason we limit the discussion to 2.is that 3.will be easily achieved after realization of 2. As is mentioned above, what we consider is manipulation of an object without grasping, so it is relevant to graspless manipulation. This is a part of collaborative project with National Institute of Advanced Industrial Science and Technology(AIST).

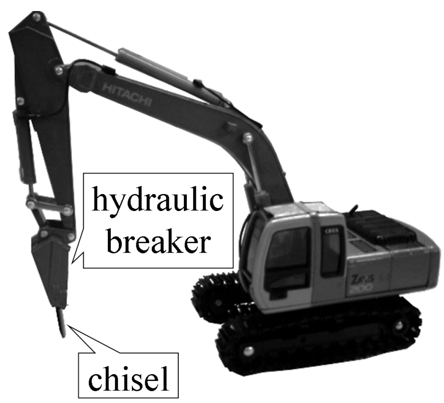

Figure 1: Model of a breaker used at a quarry

1.2 Purpose

The purpose of this research is automation of handling of an object with a diversity of shape by a single fingered end effector using Laser Range Finder(LRF) for shape recognition. It is preferable that tumbling operation is efficiently performed by the same number of operations of a human expert, which is very difficult to be accomplished when the target object has several shapes like rocks in a quarry. This paper reports our first approach in laboratory environment using robotic manipulator with a small LRF to handle a relatively small object before the experiment in a realistic site.

In this paper, we split the task into two stages:

1. Scrape out the target rock from a pile of rocks, while receiving complex interference from surroundings.

2. Handling a single rock which can be operated without interference from surroundings near the base of a pile of rocks, where the stones are comparatively few.

Here we focus our attention on 2. in the above-mentioned two points. As an element technology of 2., we will extract "object recognition and tumbling operation of a single target stone", which is the purpose of this paper.

The composition of this paper is as follows. In chapter 2, related studies are explained. In chapter 3, mechanics analysis for tumbling operation is described. Experimental methods of tumbling operation and result are described in chapter 4. Finally the summary and future prospects are given in chapter 5.

2 Related works

Aiyama[1] points out that graspless manipulation is greatly affected by friction between the target object and environment, and it is impossible to know exact frictional force distributed between them. Hence he suggests manipulating the target object based on observing how it had moved by robot fingers since frictional force cannot be estimated exactly in numerical value. The same may be said of this research, tumbling operation is strongly affected by uncertainty of friction from contact with environment, so it is necessary to deal with it.

On the other hand, Kurisu et al.[2] did path planning for tumbling operation of an object using GA, in the case of depending only on its shape which was assumed to be already-known polyhedron. However, it is very difficult to set shape models for rocks of several shapes in advance, thus in this research we will obtain the shape using a external sensor.

Although there is a possibility that the target object rolls in an unexpected direction according to the operation method, it will be possible to keep operating it continuously by repeating the scanning when rolling it once, so it is more flexible and realistic than setting shape models beforehand.

3 Mechanics Analysis

3.1 Problem Definition

We treat the tumbling operation of one object with a finger set on a manipulator, and assume the following conditions.

1. The object and the environment are rigid bodies.

2. Quasi-static operation is concerned.

3. Each of the coefficients of friction between a target object and a finger of manipulator, the object and ground, is assumed to be an already-known constant and uniformly distributed.

4. The finger of the manipulator comes in contact with the object at a point.

5. Operation is limited to be toward the direction to the base side of the manipulator, in other words, the rotation axis is set in a direction perpendicular to the direction of the operation.

In 5., the distance from the base(origin) of the manipulator to the rotation axis will be measured with the sensor, and not previously provided. However, for simplicity, the rotation axis is limited to exist on the plane orthogonal oriented to the straight line that connects the center of gravity of the object with the manipulator origin when we put the object.

A significant reason to the operation with such a limited condition is as follows. When generalizing more, it is possible to enhance it to the tumbling operation to the diagonal direction easily by adding the turn of the first joint of the manipulator which rotates around the vertical axis. In addition, for the first step the rock of relatively easy shape will be operated in this paper as preliminary step toward ideal operation of all the indeterminate form rocks.

3.2 Outline of tumbling operation

Tumbling operation is rotation of the object around the axis which is one of the edges of basal plane as shown in fig.2, and the object will move while changing its posture. This operation can be repeated quasi-statically by 2 fingers or more, but it is more difficult by one finger even though it is possible([3]). However, the chisel which is equipped at the top of hydraulic breaker is of rod-like shape, hence we aim at the achievement of handling by one finger in this research.

Now we assume the tumbling operation is performed only once in this paper, because it will be easy to enhance it to the repetition of the operation in the same way if it is possible to roll over once.

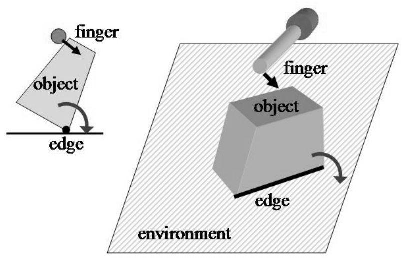

Figure 2: Tumbling operation

Figure 3: An example of a target object

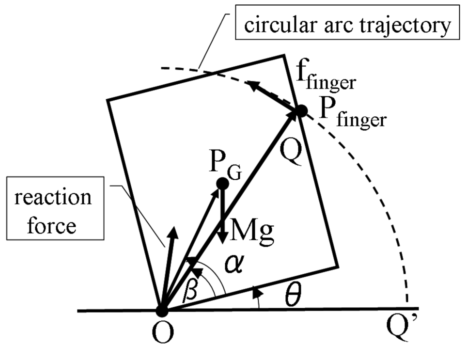

Figure 4: Conceptual diagram of tumbling operation

3.3 Approach

In this paper, the following procedures are tried under the above-mentioned problem definition using three-dimensional shape of the object which is measured by LRF.

1. Calculate the center of mass
2. Calculate the rotation axis for tumbling operation
3. Select the position where the finger of manipulator comes in contact

To be more precise, first of all, the shape of the target object is recognized with a laser range sensor. Secondly, we calculate the center of mass and rotation axis by applying image processing techniques to the range image created from the recognized 3D shape. Additionaly, the rotation axis should touch the ground, and longer one is preferable for the steadier tumbling operation. Finally, we determine the position of the action point where the object can be rolled most easily, in consideration of the above-mentioned center of gravity, the rotation axis, and the friction cone.

3.4 Mathematical scheme

3.4.1 Method for estimation of center of mass

The position of center of mass is calculated by integration of shape of the object as follows:

$$\mathbf{P_G} = \frac{\int_V \rho \mathbf{r_c} dV}{M}, \qquad \left(M = \int_V \rho dV\right),$$

where density ρ is a constant because the rock is assumed to be a sandstone, and the origin of coodinates is set on the bottom(base) of the manipulator. M is total mass of the target object, dV is a volume element, $\mathbf{r_c}$ is the position of the volume element. The position of center of gravity $\mathbf{P_G}$ is estimated by integration over the volume.

3.4.2 Basic policy for computation of rotation axis

The target rock used in this paper is of relatively simple shape, because the rocks just after blasting can be assumed to have almost rectangular shape. Therefore, almost all edges in contact with the ground can be assumed to a rotation axis when tumbled.

3.4.3 Position of action point

When Handling a target object, the motions of the object such as the rolling or slipping are controlled by the position of the finger of the manipulator and its effort force. Let the coefficient of friction between the object and the environment, and between the object and a finger of the manipulator be denoted as μ_{env} and μ_{finger} respectively. The finger does not slip on the object, if the direction of the effort force is inside of the friction cone. In general, for no slip the relationship between the norm of effort force $\mathbf{f}$ and normal component of reaction $\mathbf{f_n}$ from environment is defined by:

$$|\mathbf{f}| < \sqrt{\mu^2+1}|\mathbf{f_n}|.$$

Using this formula, we will start mechanics considerations referring to the analysis[1]: as the first step in our analysis, we will discuss a rectangular solid which is easy to analyze before the object of indeterminate shape. This model is considered to be approximately applicable to the target rock which has six comparatively clear faces and is of an almost hexahedron shape. In addition, the analysis of the rectangular solid is also important in a quarry for the following reason: very radical shaped rocks(e.g. extremely slender, have huge dent, etc.) are difficult to exist in comparison with normal shaped one like polyhedrons including a rectangular solid, because it is easily broken by quarry blasting.

Conceptual diagram of tumbling operation is shown in fig.4. When tumbling operation, if there is no slip between the target object and a finger of the manipulator, the one fingered manipulator cannot change the finger in contact with the object, hence the finger will keep pushing the same position $\mathbf{P_{finger}}$ of the object surface. Therefore, the finger $\mathbf{P_{finger}}$ will follow a circular arc trajectory QQ', whose radius is OQ or $|\mathbf{P_{finger}}|$. Then, for equilibrium of moment around the origin O, the size of force required to move in the tangent to the arc, that is, in the vertical direction to the $\mathbf{P_{finger}}$ is as follows:

$$|\mathbf{f_{finger}}| = \frac{cos(\theta+\alpha)cos\beta}{2cos\alpha}Mg.$$

If $\theta = 0$ in fig.4, $|\mathbf{f_{finger}}|$ becomes maximum. In this case one of the necessary conditions for no slip is as follows:

$$\mu_{env} < \frac{sin\beta cos\beta}{2-cos^2\beta},$$

where μ_{env} is the coefficient of friction between the target object and environment. On the other hand, the second condition is as follows:

$$\mu_{finger} < \frac{1}{tan\beta},$$

where μ_{finger} is the coefficient of friction between the target object and the finger of manipulator[1].

There is an important point: by the above two conditions we can deal with the operation in two-dimensional surface if the center of mass $\mathbf{P_G}$, the position of the finger $\mathbf{P_{finger}}$, and the rotation axis in contact with the environment $\mathbf{O}$ are in the same plane.

In this model, we limit and determine that object's plane which the finger of manipulator can push is perpendicular to the two-dimensional plane where the center of mass, the rotation axis and the action point co-exist. The target object used in this paper meets this condition, but rocks in realistic site may have inclined plane. In this case, the more inclined the plane is, the more the friction cone inclines three-dimensionally. Thus, the area of friction one in the two-dimensional plane becomes small and can disappear, then it becomes impossible to tumble the object stably any more. It is an issue in the future.

4 Experimental methods

4.1 Experimental setup

We used a five-degree-of-freedom manipulator MOVEMASTER(fig.6) from Mitsubishi Electric Corporation as a breaker for tumbling operation. We had a wooden stick of 12mm in diameter in metallic bearing attached to its hand as a finger for tumbling operation instead of the gripper(fig.7). The top end of the stick is rounded like a chisel of the breaker. Moreover, we prohibited one of the degrees of freedom of the manipulator in order to make the manipulator have the same degrees of freedom as the breaker. Additionally, we installed small scanning laser range finder URG(fig.8) from Hokuyo Automatic Corporation on the hand of the manipulator, and obtain the shape of the object by turning the manipulator controlled by a computer using Linux operating system. The system configuration is shown in fig.5.

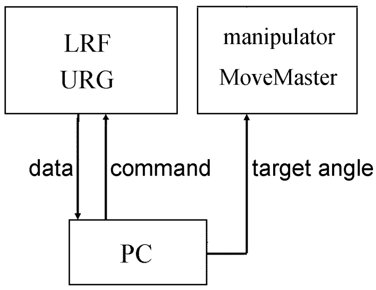

Figure 5: Experimental system configuration

Figure 6: MOVEMASTER

The target object in this paper is a rock(fig.3) whose size is 8[cm]x6[cm]x8[cm], and weight is 584[g]. Its shape is close to rectangular solid, the direction of the each plane of the object is clear, and it has edges in contact with the ground.

4.2 Experimental procedure

We obtained the shape of the object by coordinate transformation using homogeneous transformation matrix made from joint angles and link parameters of the manipulator, data from the laser range finder(LRF) and its step angles, joint angles of the manipulator. Then we calculated the center of mass and rotation axis from the obtained shape, and select the optimum action point.

4.2.1 Calculation of the center of mass

We calculated the center of mass in the orthogonal coordinate system. Using the scanned data from LRF we obtained the three-dimensional position coordinate of the target object in this paper(fig.3), while increasing the first joint angle of the manipulator.

We created a PGM range image(9-1) using 4 by 4 millimeter grid data that average point data in a grid was adapted as height data z(x,y) correspond to brightness of the image, when xy-plane was parallel to the ground. Then we calculated the 3-D position coordinate of the center of mass(see 3.4.1) as shown in fig.10 displayed as the

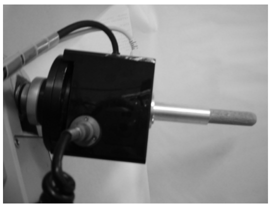

Figure 7: Attached finger on the hand

Figure 8: Laser range finder URG on the hand

height of the ground is zero. We corrected the observational error caused by URG(LRF) because when measuring the object near URG the distance data becomes shorter than it is, dependent on the distance to the object. In this case, the size of the error of distance is about 3cm.

4.2.2 Calculation of the rotation axis

The procedure for calculating the rotation axis is as follows. First we obtained the edges of 1 pixel width (fig.9-2) by applying Canny operator to the range image created in 4.2.1.(fig.9-1). Then, we extracted straight lines to be candidates for the rotation axis by applying the Hough transformation operator to the edge image(fig.9-3). Here the parameters of both operators were set optimally in advance. We selected a optimum line for a rotation axis in the multiple candidates(fig.9-4). The line is perpendicular to the desired direction for tumbling, and the closest to the origin of the manipulator, as shown three-dimensionally in fig. 11.

4.2.3 Determination of the action point

We determined the action point or position the finger of manipulator to come in contact with as follows. First of all, it is necessary to be in the plane which contains the center of mass and the vector of desired direction to move to. If not, the target object will rotate around the z(height) axis. The coordinate values of the points at the intersection of the plane and the surface of the object can become candidates to be the action point. Second, it is needed to meet the conditions for no slip as mentioned in 3.4.3. To be more precise, the position where is most difficult to cause slippage between the finger and the target object is the most upper part of the right side of the object in fig.4, at the same time the most difficult position to slip between the environment and target object is around $\beta = 35[deg]$ on the same side. Thus, we determined the action point using weighted average of these two conditions. The determined action point of the target object is shown in fig.12.

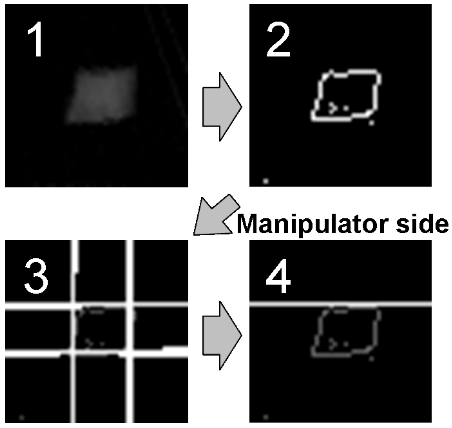

Figure 9: 1.Range image
2.Edge detection by Canny operator
3.Line detection by Hough transform from a edge image
4.selection of a rotation axis from multiple lines

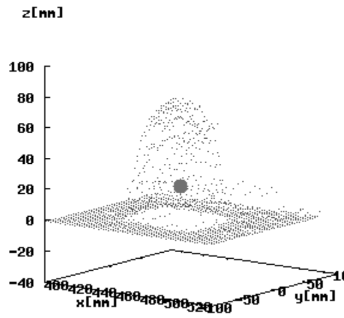

Figure 10: Center of mass

4.3 Result and discussion

We realized the tumbling operation of a relatively small rock in laboratory environment as shown fig.13, using the center of mass, rotation axis, the action point given above. In order to improve the operation, we should take sliding operation into account not only tumbling in the future because slipping often occurred when experiment caused by the uncertainty and smallness of the coefficient of friction. For this purpose, it will be useful to classify the operations its behavior like the description in reference[1].

5 Summary and future prospect

In this paper we reported the calculation of the center of mass and rotation axis, the determination of the action point under mechanics consideration, and realized the tumbling operation of the rock of relatively simple shape taken from a quarry in the laboratory environment. Now there are two future tasks: 1.handling of a more complex shaped rock, 2.Recognition and handling of multiple rocks.

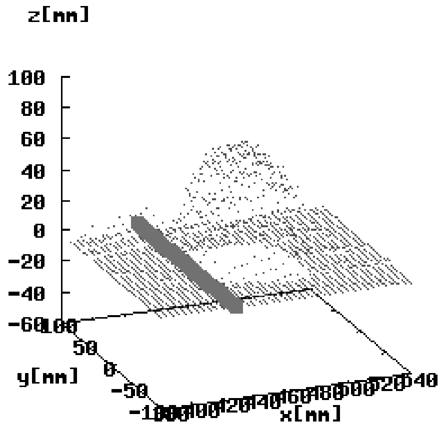

Figure 11: Decided rotation axis in three-dimensional space

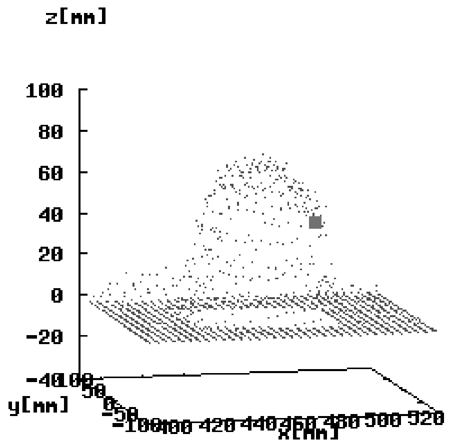

Figure 12: Obtained action point

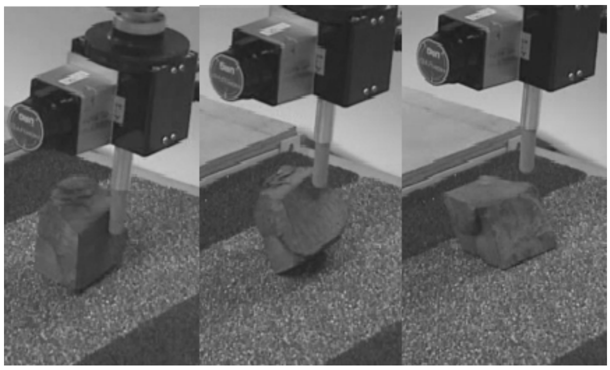

Figure 13: Realized tumbling operation

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