Motion Planning for a Mobile Manipulator with Several Grasping Postures

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***Abstract*— In this paper a motion planning method for a mobile manipulator is proposed. In general, humans can grasp an object by various way which depends on object posture, position and so on. The objective of this paper is to present how to detect a pose of a mobile manipulator under the condition that several grasp ways are given to the robot. Motion errors and object position errors are considered to detect robot pose in our method because these affect grasp motion of the robot hand. Especially, coping with these error, we will propose effective pose searching method for a mobile manipulator from numerous pose candidates. The performance of the proposed method is illustrated by simulation.**

***Index Terms*— Mobile Manipulator, Motion Planning, Position Error, Grasping**

I. Introduction

This paper describes a motion planning for a mobile manipulator for grasping a small object. A robot pose for grasping is detected from various pose candidates. Throughout this paper, "mobile manipulator" means a robot which consists of one robotic arm mounted on mobile platform. We call such mobile manipulator "robot" and discuss under the condition that "manipulator" and "mobile platform" are distinguished explicitly.

Mobile Manipulator researched are a widespread studied field. They are used in a large variety of tasks such as carrying objects from one place to another. Several researches have addressed the problem of manipulating objects in real environments.

We are interested in mobile manipulators which can carry objects in real environment. In this research we aim to develop a picking object task performed by a mobile manipulator. Conventionally, there are several researches to attack such challenging tasks with predefined object models [4], ID tags [1] or QR codes [3]. Because the importance of these researched are usefulness evaluation for how and what to give information to the object or a robot, grasp poses for the robot are often determined ad-hoc based on manually teaching. However, in case of human grasp, they know a variety of grasp ways toward an object. In such a case, grasp approaches depend on various factors, for instance, relative poses between human and the object. The fact tells us that secure and efficient grasp can be achieved as same as in case of robot by selecting a good grasp pose from several candidates.

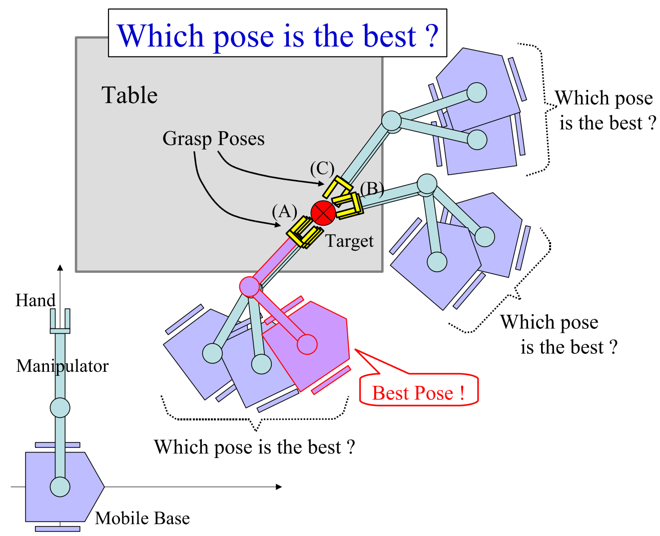

Fig. 1. Problem Definition

The objective of this research is to plan a robot pose for grasping under the condition that several grasp candidates are specified as end-effector poses. In our assumption, innumerable robot poses can be selected in the workspace where the robot can move freely as far as it is in object range (Fig.1). As a related work, we proposed a pose evaluation method for a mobile manipulator [11]. By utilizing the method, robot pose for stable grasp can be estimated when an object is grasped from anywhere. In this paper, we will expand the method into the case of given discretely end-effector poses.

In case of an object grasping by a mobile robot, the pose error of end-effector should be considered. This error is fairly influenced by pose error in the mobile platform. Therefore, redundant mobile manipulator system is utilized to improve its manipulability because of the pose error of end-effector can be canceled by joint motions of the manipulator mounted on the robot. Namely, the pose evaluation criteria comes from whether high manipulability will be kept or not toward given end-effector poses in our motion planning.

In the meantime, because kinematical redundancy generates a growth of capable poses for the robot, efficiently pose searching algorithm are needed. We cope with this problem by searching the best position of the mobile platform globally while evaluating and optimizing the robot pose locally in each particular area.

This paper describes as follows: In the next section, related works are described. Section III presents a scheme of this study and problem definition. Section IV and V present the outline of motion planning. Section VI provides experimental results to demonstrate the effectiveness of our proposed method. Section IV concludes this paper.

II. Related Works

Traditionally for motion plannings of a mobile manipulator, end-effector's trajectory is given in advance [5][7]. Nagatani et al. [6] and Shin et al. [8] proposed planning methods for deciding platform pose which can keep manipulability [12]. This kind of motion planning is applicable if only one target trajectory is given. However in our research, as there are several grasping poses, motion planning also has to select an end effector's target pose. As other problem, although the motion of mobile platform is assumed in these researches, motion uncertainty such as position errors in mobile base is not considered very much.

Other approaches consider an uncertainly element of environment or robot was proposed. Yamashita et al.[9] proposed a motion planning method for an object manipulation by multiple mobile robots. The planning was performed estimating motion errors of the mobile robots before they move. However a way to manipulate and a shape of the object were relatively simple, it can be expected to implement a stable carrying task by multiple mobile robots, Our research has similar concept with these motion plannings at the point of considering errors in advance, however the purpose of our motion planning is to reduce the influence of end effector's pose error when it grasps a small object on a desk.

III. Problem Definition and Scheme

A. Assumed Task and Research Objective

We consider the task of grabbing a small object on a desk. A map of desk environment is given in advance. Before motion planning, end-effector poses for grasping are calculated by utilizing such a method as described in [10]. A mobile platform is nonholonomic two-wheel drive system which is considered to move on a flat surface. In this paper, we call pose to both, position and orientation.

The assumed task is performed according to the following procedure. The objective of this study is to detect the pose of manipulator and mobile platform through motion planning written in 2).

1) Robot moves and finds its target object using the object model which was acquired in advance. End-effector pose candidates are detected.
2) Robot pose candidates (i.e. Fig.1 A,B and C) are searched through pose evaluation, one robot pose is detected.
3) The robot moves to planned pose and measure the object again. If there are some errors in the robot pose, a new pose for grasping is re-calculated.
4) Grasping motion is performed.

While pose evaluation in 2), good evaluation can be found if the amount of manipulator motion has low change between planned pose to re-calculated pose for the manipulator.

B. Issues

The pose error of end-effector is a critical issue when the robot picks up an object. This error is sensitive to a pose error of the mobile platform. Odometry is often used to estimate the pose in general, but this can include error which is derived from initial position and wheel motion. Although the error can be corrected by utilizing external sensor data with the environment map, because of sensor inaccurate, the correction cannot be achieved totally. Moreover, because it is assumed that a pose of a grasped object is measured by sensors mounted on the robot, this positioning error is considered. The challenge is to search a robot pose which satisfies both, a few pose error and to be able to correct the error easily.

Other problem is kinematical redundancy of the robot. We assume that the degrees of freedom of the robot motion are more than needed to manipulate an object. An advantage is that it can increase a variety of the robot poses and improve its manipulability. However, robot poses exist infinitely. Fig.1 is an example. The robot can select all poses from A to C. In addition, as B1 and B2 in Fig.1 shows, there are not only one determined pose in each end-effector pose. The challenge is to detect the best robot pose from these candidates.

C. Approach

Coping with above issues, we propose an approach to find a best robot pose. Our planning method consists of two steps which are global search and local evaluation.

Local pose evaluation: Local area means fixed positions which are selected for the mobile platform through global searching. In each of the local area, manipulator pose is evaluated whether it has high manipulability or not. "High manipulability" means that less joint motions of the manipulator are needed for changing the end-effector pose. The evaluation is performed to find such manipulative robot pose against error of the end-effector. As a result of local evaluation, optimized joint angles of the manipulator is acquired in each position of the mobile platform.

Global pose searching: As mentioned above, innumerable robot poses can be found in the workspace of the mobile platform, Coping with the abundant pose searching, we prefer to take an approach to divide the workspace into small grids. The pose evaluation is performed in each grid and a best pose is selected based on a grid which has best evaluation. Moreover, utilizing the property of proposed pose evaluation, effectively searching algorithm are performed.

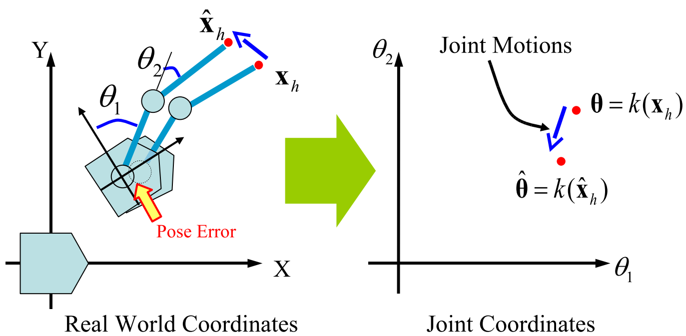

Fig. 2. Pose Error

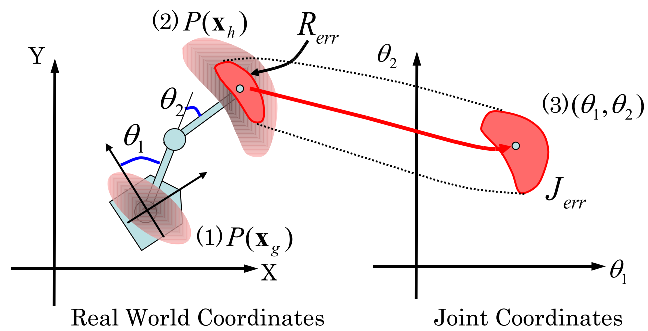

Fig. 3. Probabilistic representation

IV. Local Pose Evaluation

This section explains a pose evaluation method discribed in [11]. By utilizing this method, we can calculate and judge robot poses for realizing stable grasp when a platform position is given. Variables are defined in this section as follows:

- $\mathbf{x}_h$: End-effector pose in robot coordinates
- $\mathbf{x}_b$: Object pose in robot coordinates
- $\mathbf{x}_H$: End-effector pose in world coordinates
- $\mathbf{x}_B$: Object pose in world coordinates
- $\mathbf{x}_G$: The platform pose in world coordinates

At first, platform pose $\hat{\mathbf{x}}_G$ and object pose $\hat{\mathbf{x}}_B$ are given. End-effector pose $\hat{\mathbf{x}}_H$ is calculated from them and pose evaluation is performed.

A. Summary

Pose evaluation is calculated from joint motions. For this reason, joint coordinates are considered. This consists of a set of the joint variables of a manipulator.

Evaluation function is represented by using the following equation:

$$C = \int |k(\mathbf{x}_h) - k(\hat{\mathbf{x}}_h)| P(\mathbf{x}_h) d\mathbf{x}_h, \quad (1)$$

where $\mathbf{x}_h$ is end-effector pose and $\hat{\mathbf{x}}_h$ is a expected pose which is selected by global searching. These are defined in mobile platform coodinates. $k(\mathbf{x})$ is a function for solving inverse kinematics with respect to a given hand pose $\mathbf{x}$. The value of $k(\mathbf{x})$ are joint vector which is represented as $\theta = (\theta_1, \theta_2, \cdots, \theta_n)$. $P(\mathbf{x}_h)$ is a probabilistic distribution of end-effector pose. If C becomes smaller, the pose is better.

The meaning of eq.(1) is illustrated with a planar mobile manipulator in Fig.2 as example as follows. The robot can grasp a target object at $\hat{\mathbf{x}}_h$ if it has no error in the pose. However, there may be some errors in real works so that the end-effector pose will be shifted to such a pose as $\mathbf{x}_h$ in Fig.2. In our index, it is important that less joint motions from $\mathbf{x}_h$ to $\hat{\mathbf{x}}_h$ for adjustments are desirable. In other words, good evaluation is acquired if a distance between $\hat{\theta}$ and θ in Fig.2(2) becomes small in joints space. Eq.(1) calculates the expectation of joint motions for its adjustments utilizing a probabilistic distribution.

B. Calculate Pose Evaluation

A probabilistic distribution $P(\mathbf{x}_h)$ is calculated from $\mathbf{x}_G$ and $\mathbf{x}_B$ according to following equation:

$$P(\mathbf{x}_h) = \iint P(\mathbf{x}_h | \mathbf{x}_B, \mathbf{x}_G) P(\mathbf{x}_B) P(\mathbf{x}_G) d\mathbf{x}_B d\mathbf{x}_G. \quad (2)$$

We utilize Monte Carlo method to calculate this $P(\mathbf{x}_h)$. Practically, approximating $P(\mathbf{x}_B)$ and $P(\mathbf{x}_G)$ as normal distributions, ellipsoidal areas where maharanobis distance is less than predefined thresholds D_1 and D_2 are considered.

$$\begin{array}{c} (\mathbf{x}_G - \hat{\mathbf{x}}_G)^T {\Sigma_G}^{-1} (\mathbf{x}_G - \hat{\mathbf{x}}_G) = {D_1}^2 \\ (\mathbf{x}_B - \hat{\mathbf{x}}_B)^T {\Sigma_B}^{-1} (\mathbf{x}_B - \hat{\mathbf{x}}_B) = {D_2}^2, \end{array} \quad (3)$$

where Σ_G and Σ_B are covariance matrices related to robot pose $\mathbf{x}_G$ and object pose $\mathbf{x}_B$.

The evaluation is performed according to following procedure:

1) A reference pose of mobile platform $\hat{\mathbf{x}}_G$ is specified. A motion path for the platform is planned and the pose error is estimated along the path from initial pose to $\hat{\mathbf{x}}_G$.
2) End-effector pose $\hat{\mathbf{x}}_h$ in robot coordinates are calculated from $\hat{\mathbf{x}}_G$ and $\hat{\mathbf{x}}_H$.
3) $\hat{\theta} = (\theta_1, \theta_2, \cdots, \theta_n)$ is calculated by solving inverse kinematics of $\hat{\mathbf{x}}_h$,
4) C is calculated iteratively by following procedure.
   a) $\mathbf{x}_G$ and $\mathbf{x}_B$ in world coordinates is detected from inside of ellipsoids in eq.(2). These are randomly sampled according to normal distributions $P(\mathbf{x}_G)$ and $P(\mathbf{x}_B)$.
   b) End-effector pose $\mathbf{x}_h$ is calculated using sampled $\mathbf{x}_G$ and $\mathbf{x}_B$.
   c) θ is calculated from this $\mathbf{x}_h$.
   d) An absolute difference between $\hat{\theta}$ and θ is added to C.

Good pose evaluation is acquired when the C becomes small. Fig.3 illustrates the probabilistic regions which appear above calculations. If $\mathbf{x}_h$ exists inside of R_{err} according to calculation by the way to 3) b), the distribution θ forms a region J_{err} in joint coordinates (Fig.3,(3)). If J_{err} become smaller, a good evaluation is acquired in eq.(1).

V. Global pose detection

In this section the global pose detection method is described. We propose a novel algorithm for motion planning.

A. Summary

In section IV, the pose evaluation method for the robot pose is presented under the condition that both pose of end-effector and mobile platform's position are given. The purpose of this section is to adopt the evaluation method to multiple candidates of end-effector pose.

In the case of redundant robot, infinite robot poses for grasping exist. To solve this extensively, workspace of the mobile platform is divided into grids. The poses of manipulator are optimized in each of grids. This approach has an advantage in our planning scheme which copes with platform's pose error. Although the pose error of end-effector is adjusted by manipulator motion, this error is caused by motion trajectory of the platform. That is to say, as manipulability of the end-effector and pose error of the end-effector are produced from different source, it is difficult to optimize both platform's pose and manipulator pose simultaneously. On the other hand, by means of holding platform position in each pose evaluation, our approach can achieve compact pose evaluation.

The global searching process obeys such rules below,

- The best robot pose is detected every candidates of end-effector pose.
- The workspace of mobile platform is divided into small grids. As a position of the mobile platform is the center of each grid, the robot pose is evaluated.
- The best robot pose is acquired from the result of searching among whole grids.

As mentioned above, because robot poses are evaluated in fixed position of a mobile platform, resolution on evaluation depends on the grid size. Manipulator poses are optimized in each evaluation against the fixed mobile base and end-effector poses.

In this grid based evaluation, some grids can be removed if it exists inner obstacles (i.e. desks) for the mobile platform. Using environment map and operational area for the manipulator, these useless grids are found relative easily.

B. Efficient pose searching

Fig.4 shows an example of pose evaluation described in Section IV. Planar mobile robots mounting 1000[mm] length manipulator(2-DOF or 3-DOF) is assumed and reference end-effector pose is set on $(x, y) = (1000, 1000)$. In this simulation, it is assumed that a target object can be grubbed from anywhere. The graph shown in Fig.4 indicates the evaluated map about the mobile platform's position. Good evaluation is acquired if the mobile base exists in the solid ellipse. However, local minimum can be found if the mobile base exists far from initial position as shown as dashed ellipse. This is why there are several spots where manipulability of the manipulator becomes high against error distribution of end-effector. In addition, it can be seen that the evaluated value is changed smoothly depending on the position of mobile platform.

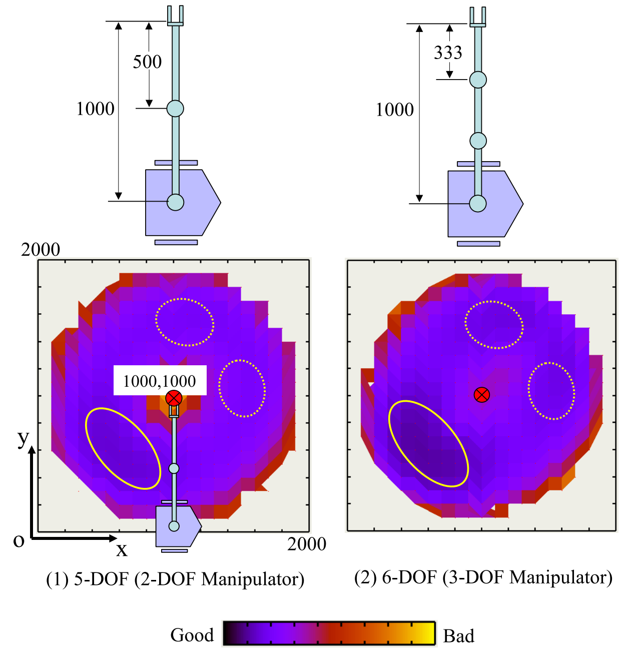

Fig. 4. Pose Evaluation

The best robot pose is searched considering with such behavior above. A basic policy is as follows:

- Instead of searching every grids, starting from randomly selected grid, neighbor grid which has better pose evaluation is traced incrementally. Because of evaluation map changes smoothly, good evaluation can be found with the result of this tracing.
- Above The tracing process are repeated from 10 to 20 times with changing initial grid. Because there are few local minimum on the evaluation map, the best evaluated grid found in these trials is capable of optimum grid.

C. Algorithm

The best robot pose is searched according to the following procedure.

1) One end-effector pose is selected from the candidates.
2) Grid space is constructed in x-y coordinates. Some of grids which go into such objects as desk are removed. Next, some other grids are removed if it can not solve inverse kinematics of the manipulator toward given position of end-effector and mobile platform. As a result, a group of grids are acquired as the pose candidates of the mobile platform.
3) A grid is randomly selected until specified number, and
   a) the robot pose is evaluated by the method described in section IV,
   b) same evaluation is performed about 8 neighbors,
   c) go to 4) if a best evaluation is acquired in present grid, otherwise selecting neighbor grid which has

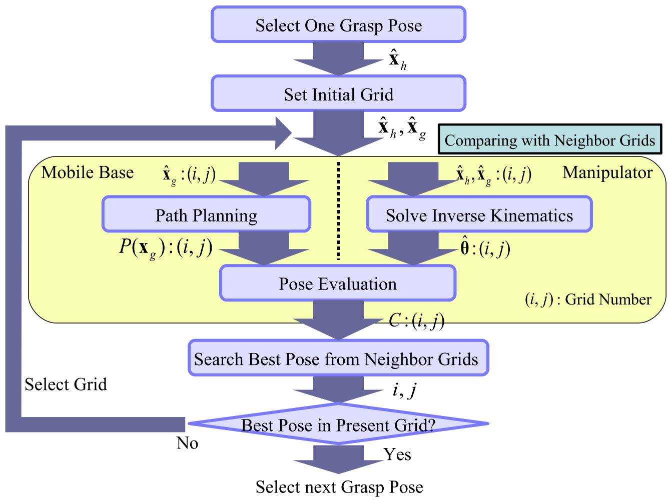

Fig. 5. Planning Algorithm

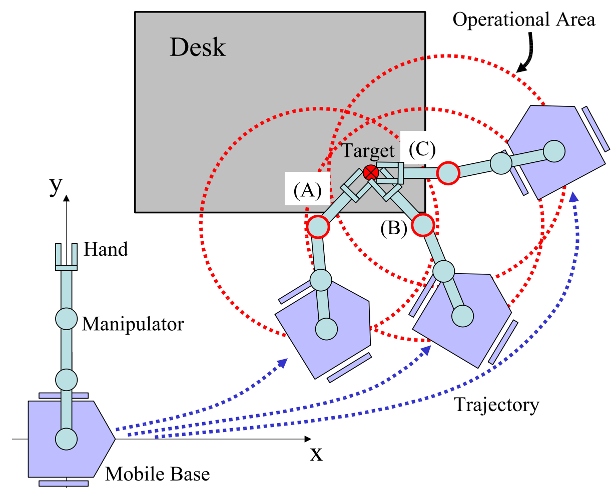

Fig. 6. Experiments

better evaluation than the present grid, and return a).

4) Finally, the best evaluated grid through processing in item 3) is selected as the best robot pose for the selected end-effector pose.

Fig.5 shows the algorithm. This process is performed all of end-effector poses and finally, the best pose through whole evaluation is selected with the pose of manipulator θ and mobile platform $\mathbf{x}_G$.

VI. Simulation

Our motion planning was simulated such environment as shown in Fig.6. A mobile robot mounted a 3-DOF horizontal manipulator was assumed under the condition that both of joint limits and collision between arms were not considered. The initial pose error of a mobile platform was given as 1σ=10mm and 1σ=10deg with respect to normal distribution. The position error of an object was 1σ=5mm and direction error was not considered. To plan a path of the mobile platform, a planning method using a Laplacian potential field[2] was utilized.

Fig.6 shows the abstract figure of environment setting. Global pose detection described in Section V were simulated against three target poses for end-effector. These orientations were (D)45[deg], (E)135[deg] or (F)180[deg] against x-axis. In addition, it was assumed that there is a desk in the environment. In this situation, third arm of the manipulator was restricted by end-effector pose. Dashed circles where center is third joint of the manipulator in Fig.6 are shown the workspace of mobile platform.

Fig.7 shows the result of whole grid evaluation. Each grid size was set as 50[mm] in this simulation. The best evaluation was acquired from a grid which is on $(x, y) = (1850, 650)$[mm]. Computation time was 14.5[sec](Pentium IV, 2.8GHz) while the evaluation was performed toward three end-effector poses.

On the other hand, using our algorithm proposed in Section V, same grid was selected in spite of taken only 980[msec]. In this simulation, randomly grid selection described in section 4.3 was performed 10 times and the number of particle for pose evaluation was 1000. Moreover, other idea were implemented for speed up our algorithm. In case of several grasp candidates were given as this simulation, considerable part of operational area overlapped. Because the workspace is divided into grids sized regularly, once the pose error of mobile platform is calculated on a certain grid, the estimated error can also be utilized for pose evaluation toward other end-effector poses at the same grid. This is an advantage of grid base planning. From these simulation, it is illustrated that the speed of searching process was 15 times faster by our algorithm.

VII. Conclusion

In this paper, we presented motion planning for object grasping under the condition that grasp pose is not restricted to just one way and robot can move freely as far as it is in its operational area of the object. In our method, a position of the mobile platform and the manipulator pose are detected by investigating the amount of joint motions for recovery of end-effector pose error. The result of shows the effectiveness of the proposed method.

As a future work, more faster processing is necessary yet, and to realize object carrying task by a mobile manipulator utilizing proposed method in this paper.

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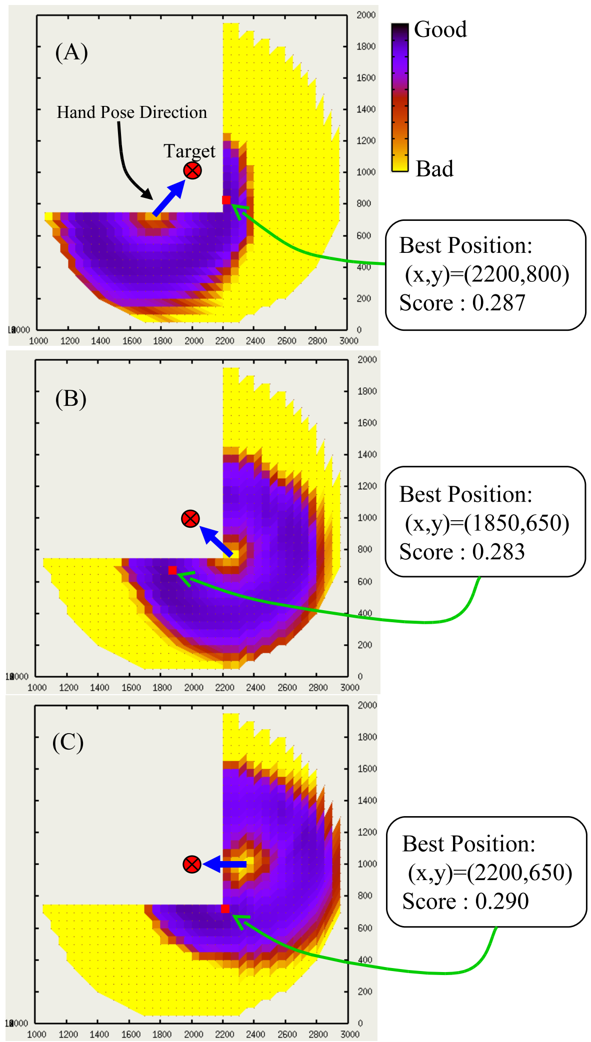

Fig. 7. Simulation Result

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