Real-time Obstacle Avoidance for Silvermate Robot

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Key Words : Obstacle avoidance, Elastic force, Silvermate Robot

Abstract

This paper proposes the Elastic Force application on the obstacle avoidance of the Silvermate Robot. The method deals with the problem associated with the Silvermate robot driving to a goal configuration as avoiding obstacles. The initial trajectory of a robot is determined by a motion planner, and the trajectory modification is accomplished by adjusting the control points. The control points are obtained based on the elastic force approach. Consequently the trajectory of a robot is incrementally modified to maintain a smooth and adaptive trajectory in an environment with obstacles. The suggested algorithm drivers the robot to obstacle avoid in real-time. Finally, the simulation studies are carried out to illustrate the effectiveness of the proposed approach

1. INTRODUCTION

Recently, a robot is taking the place of human beings in the dangerous working environment. And the main part of the industry aimed for the aged that take the place of old person and disabled person in the present is expected. Like this, robots help human in an environment that human and robot are coordinated. The mobile-manipulator robot should be developed, which can cope freely uncertain environment in addition to transfer function and manipulation. Basic function that mobile-manipulator robot must have are as following. There is function that can judge naturally through realization for given environment, function that can create path and trajectories by real time to move. Collision avoidance algorithm development to recognize and avoid surroundings environment by real time for this should be attained.

A lot of studies were achieved about real time obstacle avoidance recently. Morayec.H.P. Certainty Grid(1) method for obstacle expression was proposed. This method displayed Certainty Value(CV) and displayed existence possibility of obstacle. However, a lot of problems were occurred in distance measurement of obstacle by impreciseness of CV value. Khatib.O. suggested Artificial Potential Field(APF)(2) method that force of virtual between object acts and exercises by the force if robot approaches in obstacle. And for the real time action plan of a mobile robot the virtual force field(VFF) was suggested by applying the certainty grid concept to the artificial potential field concept. Through extending the concept this concept the vector field histogram(VFH)(3*) method was suggested. This method is efficient to search path that a robot does not collide with obstacle. However, most of these researches never considered dynamic limitation. So, when a robot moves bottleneck actually, problem that do not escape is happened.(1)

Elastic strip(4-5) method proposed by Khatib supposes trajectory of robot as an elastic material and avoid obstacles in real time. When approaching to obstacles, the virtual force between objects is similar with the artificial potential field concept. However, this method reveals the stabilized navigation technology compared to the artificial potential field method due to the elastic force beside repulsive force while reaching to objects. Also, its application is easy to robots having multi-degree of freedoms. Is effective though integrate motion plan and execution of robot same time. And command algorithm that is optimized about real time obstacle avoidance in dynamic and uncertain environment.

In this paper, the collision avoidance algorithm was suggested, which a robot can create the safe path to target position using elastic strips. The simulation studies carried out to illustrate the effectiveness of the proposed approach.

2. HYBRID CONTROL CONFIGURATION

The control architecture of the robot is divided into deliberative layer and reactive layer according to change

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of the surrounding environment. The deliberative layer takes advantage of constructing knowledge information and cerates a transfer trajectory. The created trajectory is to be attained sequentially. And when decide task of higher level in the view of achieving optimize action of complex task, the deliberative layer decide effective high level tasks. As shown in Fig 1 control architecture is proposed, which is consisted of 3 hierarchical structures. Deliberative layer takes charge of role that a robot changes given command to executable machine instruction. At performs a plan by dividing role of a robot into navigation part and manipulation. The sequencing layer processes information obtained from sensor to execute planning and creates information sequentially.

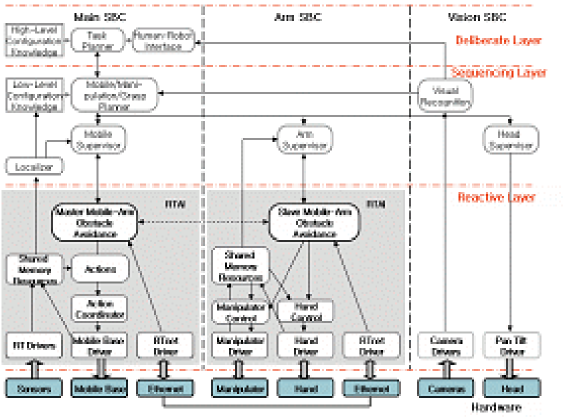

Fig.1 Proposed hybrid control architecture.

Finally, Reactive layer executes commands delivered form higher level as lowest layer of control architecture. And when obstacle appeared in an environment, it copes with by real time.

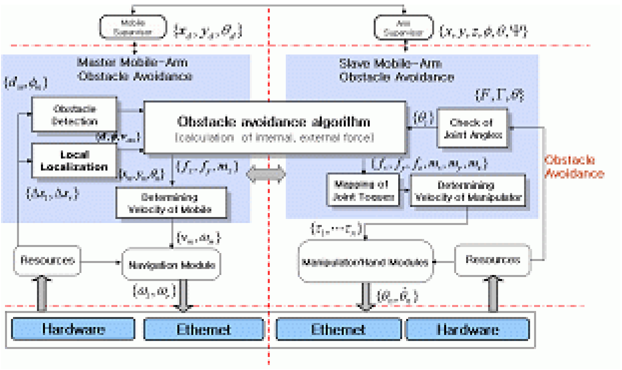

Fig.2 Mobile-Arm Obstacle Avoidance Modules.

As shown in Fig 2, the reactive layer contains resources and actuator and obstacle avoidance module. Resources contain information of sensor value. Obstacle Avoidance module consists of Master Mobile-Arm Obstacle Avoidance and Slave Mobile-Arm Obstacle Avoidance module which take charge of avoidance of mobile department and manipulator .

Master Mobile-Arm Obstacle Avoidance consists of Obstacle Detection, Obstacle avoidance algorithm and Determining Velocity of module, and cooperates with local localization. Obstacle Detection has distance of obstacle and direction information when sense detects obstacles. Local Localization has information on current position of a robot. And Obstacle avoidance algorithm module decides obstacle avoidance and direction for control for obstacles of Mobile and Manipulator. Also, Determining Velocity of Mobile module decides the obstacle avoidance speed and angular velocity of a robot.

Slaver mobile-Arm Obstacle Avoidance consists of Check of Joint Angles, Mapping of joint torques, Determining velocity of manipulator. Check of Joint Angles has information on current angles of robot joints. Mapping of joint torques changes rectangular coordinates to value of each joint coordinates. And determining velocity of manipulator is concerned in avoidance speed of joint for reaction of obstacle.

3. ROBOT SYSTEM ANALYSIS

As shown in Fig 3, the silvermate robot has manipulates having and a mobile connected by manipulators 7 degree of freedoms. Mobile robot travels by two wheels drive method. And LRF, IR, Sonar Sensor attached detect information for surrounding environment.

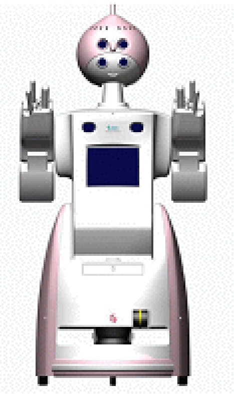

Fig.3 The Silvermate Robot having mobile base and seven joints manipulator

Mobile and manipulator appear in world coordinates of a robot through speed kinematics. Mobile state of robot is expressed by vector ${}^{j}P_m = [x_m \ y_m \ \phi_m]^T$ having position and orientation. The position of manipulator joint is expressed with ${}^{j}P_i = [x_m \ y_m \ z_m]^T$ from rectangular coordinates space. And vector of joint variables ${}^{j}q_i$ is i represented by $q = [\theta_1 \ \theta_2 \ \theta_3 \ \theta_4 \ \theta_5 \ \theta_6 \ \theta_7]$ (9-10), where ${}^{j}q_i$ is i times joint and corresponds to j robot posture(10).

The linear velocity and angular velocity of fingertip for world coordinates of mobile-manipulator can be calculated through (1). Jacobian matrix J_i can be obtained equation.

$$^{j}\dot{P}_i = \begin{pmatrix} J_1 \\ \cdots \\ J_i \end{pmatrix} \dot{q}_i = J_i \dot{q}_i \quad i = 1, .., 7 \qquad (1)$$

4. OBSTACLE AVOIDANCE ALGORITHM

Among autonomics navigation technology of the mobile-manipulator, on obstacle avoidance is a most basic and important skill in safety estimation. In this paper, the real time obstacle avoidance algorithm of mobile-manipulator robot is designed based on (1).

4.1 Robot posture and control point acquisition

If an obstacle is detected while a robot travels along the trajectory created by the motion planner in beginning with elastic force, the trajectory causes transformation according to every sampling time.

The robot posture is required to be set for the trajectory transformation. Here, the robot posture is configuration being established in given time from target point to target posture in early posture. A lot of robot posture establishments load to smooth navigation when reacting to obstacles but a lot of calculations are required. And a robot can collide with actuality obstacles even if conflict of trajectory and obstacle take that is not if robot posture is not established enough. Therefore, The robot posture is required (11).

Control point(3-4), part that receive force in position transformation by collision avoidance of obstacle in robot posture, is established. $^{j}P_i\,(i = m, 1, \cdots, 7)$ corresponds to control point of i th joint value of j th robot posture. In this paper, the control point of the silvermate robot is established as shown Fig.4.

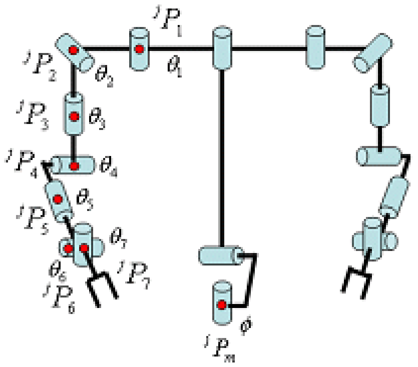

Fig.4 Control points on the body

4.2 Elastic Force action

Elastic Force is algorithm that uses a virtual force field of repulsive force and elastic force. Repulsive force occurs between a robot and an obstacle and the elastic force occurs between a robot and a target point. A robot movement according to the force occurred in this force field causes the collision avoidance(4,5,11). Elastic Strips happens the repulsive force from an obstacle. Transformation of trajectory is caused to direction receding from an obstacle. So, smooth trajectory is regenerated. The artificial potential field method is applied to obtain the repulsive force acting to the silvermate robot.

$$V_r(^{j}P_i) = \begin{cases} \frac{1}{2} k_r (d_r - d(^{j}P_i))^2 & if \quad d(^{j}P_i) < d_r \\ 0 & \end{cases} \qquad (2)$$

$^{j}q_i$ is position vector in (2). $d\,(^{j}P_i)$ is distance with the nearest obstacle from $^{j}q_i$. And d_r corresponds to the virtual distance influencing around obstacles. Where, k_r is the gain value which refers to the avoidance reaction degree by repulsive force action that is exerted on a robot when approaching to obstacles.

Force which happens to $^{j}q_i$ by the artificial potential field is obtained from gradient in $V_{rep}(^{j}P_i)$ an shown in (3). Where, $\vec{d}$ depicts the vector value between the nearest obstacle and point with $^{j}q_i$.

$$^{r}f_i = -\Delta V_{rep}(^{j}P_i) = k_r (d_r - d(^{j}P_i)) \frac{\vec{d}}{d} \qquad (3)$$

This equation expresses the external force which pushes out outside to avoid obstacles. The elastic force corresponds to the internal force that resists in repulsive force to check trajectory secession when a robot recedes with obstacles.

Configuration about the robot posture should be considered for the elastic force calculation. When sampling time is $t-1$, t, $t+1$ each robot posture appears by $^{j-1}q_i$, $^{j}q_i$, $^{j+1}q_i$. $^{j-1}q_i$ corresponds to current configuration $^{j}q_i$ next to before $j-1$th robot posture. And $^{j+1}q_i$ is robot posture of $j+1$th to be changed future.

The i th point was linked to each robot posture between these robot posture $^{j-1}q_i$, $^{j}q_i$, $^{j+1}q_i$. The elasticity force is acted like spring force. Force that acts in $^{j}q_i$ is consisted of union of new force by calculation of and $^{j+1}q_i$ as follows.

$$^{e}f_i = k_c \left(\frac{d_i^{j-1}}{d_i^{j-1} + d_i^{j}} (^{j+1}P_i - {}^{j-1}P_i) - (^{j}P_i - {}^{j-1}P_i) \right) \qquad (4)$$

$$i = m, 1, \cdots, 7$$

Where, d_i^j is scholar value which is distance between ${}^jq_i$, ${}^{j+1}q_i$. And k_c is the contraction gain value for elasticity force which is on obstacle avoidance degree. Elasticity force created by these control points is influenced in degree of elasticity as well as shape of trajectory in existence section of obstacle.

Finally, force which affects to Elastic Force by obstacle is obtained from (5). (5) obtains the last force that combines elastic force with repulsive force of (3),(4).

F_i is Elastic Force which receives in control point i and is expressed by vector $F_i = \left[f_{i,x} \quad f_{i,y} \quad f_{i,z} \right]^T$ as following.

$$F_i = {}^r f_i + {}^e f_i \;\; (i = m, 1, 2, \cdots, 7) \qquad (5)$$

4.3 Transformation of trajectory

Force given for each point causes the transformation of trajectory at the same time robot posture transformation by Elastic Force.

Transformation of a robot posture means the robot direction and change of joint variables. The transfer and rotation of robot are proportional for joint torque or joint force. And the force is responsible for torque which is created by repulsive force and elastic force at control point.

Joint transfer needs Jacobian matrix of manipulator. Obtained F_i calculates torque value about rotation and transfer of each control point with Jacobian matrix in (1). Therefore, $\tau_i = [\tau_1 \quad \tau_2 \quad \cdots \quad \tau_i]^T$ is obtained form the remainder joint torque value by control point i . Calculated torque value is calculated to sum of 7 joint torque with (7). Finally, the torque value for a robot posture transformation is same $\Gamma = [\tau_1 \quad \tau_2 \quad \cdots \quad \tau_i]^T$.

$$\tau_i = J_i^T F_i \qquad (6)$$

$$\Gamma = \sum_{i=7} (J_i^T F_i) = \sum_{i=7} \begin{pmatrix} \tau_1 \\ \cdots \\ \tau_i \end{pmatrix} \qquad (7)$$

Robot posture is updated in finally whole sampling times. This time, torque value of joint also in every time decides transfer of robot posture. These transfer value of mobile and joint are proportional with each torque value. Rotation and translation transfer of mobile and joint are decided in sampling time with (8),(9),(11).

$$\delta\theta_i = \alpha_i \tau_i, \; (i = m, 1, 2, \cdots, 7) \qquad (8)$$

$$\delta x_m = f_{m,x}, \; \delta y_m = f_{m,y}, \; \delta\phi_m = \alpha_m \tau_m \qquad (9)$$

When, $\delta\theta_i$ is turning amount of joint for a robot posture transformation by torque τ_i of i th joint. And δx_m and δy_m correspond to travel for next robot posture transfer. $\delta\phi_m$ with (8) depicts the amount of rotation correspond to center z axis of mobile. α_i and α_m are rotation comparison coefficient of each joint mobile If these value is increased, fast rotation is possible in every sampling time of much because the amount of rotation is increased.

5. SIMULATION

In this paper is verified for applicability of the proposed obstacle avoidance method through simulation. And the performance and characteristic are observed.

In this study mobile collision avoidance simulation was carried out about greatly 4 cases. First, case 1, 2 observes change of collision avoidance trajectory of robot by speed of obstacle. Case 3, 4, 5 observes collision avoidance trajectory of robot by intervals between two obstacles. And trajectory about collision avoidance of robot was observed in case obstacle scatters atypically in case 6. Finally, case 7 observes collision avoidance trajectory though 3D simulation of whole robot system.

5.1 Simulation condition

When two obstacles are situated in case 1~5, the obstacle avoidance trajectory of a robot was observed. The obstacle avoidance trajectory of a robot was also observed when free obstacles are situated in case 6. Simulation conditions are equal about all cases with table 1, 2.

Table 1 Parameter values for the case

	Value
Initial position	-3000, -3000
Target position	6000, 6000
Direction of initial robot()	$\pi/6$
k_c	0.5
k_r	0.3

Table 2 Conditions for the cases

Case	Transfer tilt of Mobile$[rad]$	Safe distance $[mm]$	Distance between two obstacles$[mm]$
Case 1	$\pi/6$	1500	2100
Case 2	$\pi/3$	1500	2100
Case 3	$\pi/3$	1500	1000
Case 4	$\pi/3$	800	1000
Case 5	$\pi/3$	1500	100
Case 6	$\pi/3$	1000	-
Case 7	$\pi/3$	1500	2100

5.2. Simulation Result

Fig 5, 6 are simulation results about each case 1, 2. All two cases illustrate the transformation of trajectory and obstacle avoidance slowly by action of repulsive force from (-1500, -1500) point by obstacle 2 that is sensed in safe distance area in the midst of travel along trajectory.

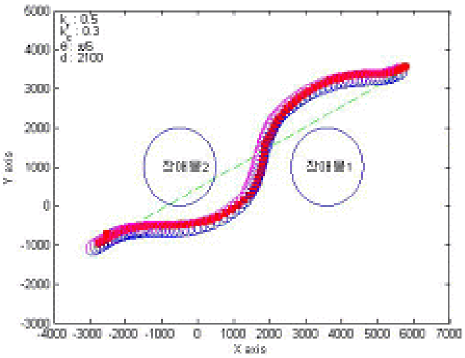

Fig.5 Collision-free robot motion for the case 1

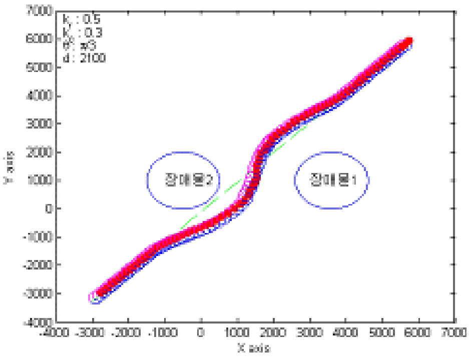

Fig.6 Collision-free robot motion for the case 2

Elastic Force that acts to a robot after avoiding obstacle1 and obstacle2 amounts to 0. Therefore, it shows reaching in target position without problem along previous trajectory. Case3, 4 shows an example of motion that avoids obstacle when streets of two obstacles are less than safety area.

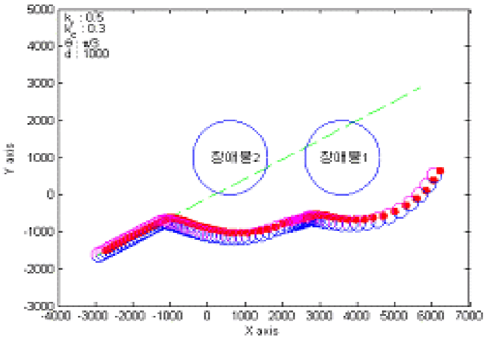

Fig.7 Collision-free robot motion for the case 3

As show in Fig 7, case 3 can not pass two obstacle intervals by distance, because interval between obstacles are less than the safe distance

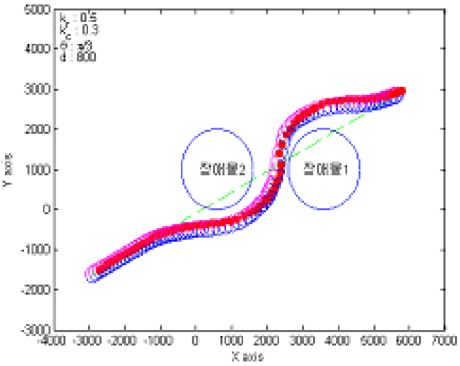

Fig.8 Collision-free robot motion for the case 4

Case 4 changed safe distance in case 3 by 800*mm*. The robot passes two obstacle intervals without problem as shown in Fig 8.

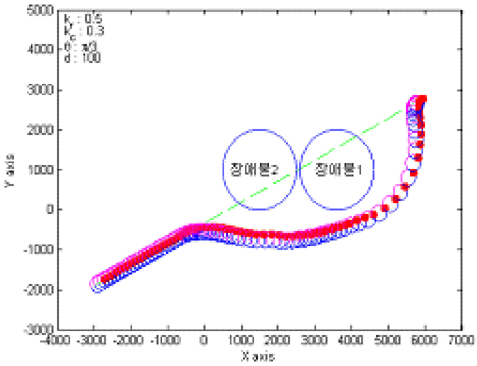

Fig.9 Collision-free robot motion for the case 5

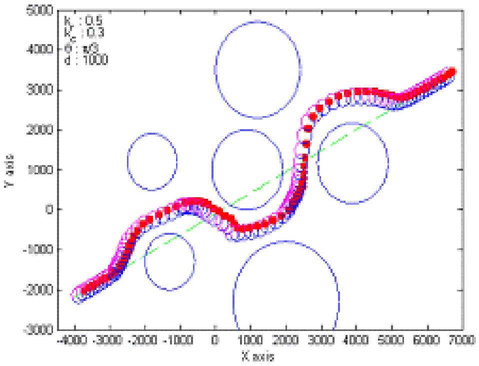

Fig.10 Collision-free robot motion for the case 6

Fig 9 shows detour without passing path between two obstacles with case 3 in case 5 equal. However, a robot is arriving well in target point finding target point since obstacle avoidance by function of elastic force after avoiding obstacle unlike case 3.

When obstacles were put in the free point in case 6, it is the reaction simulation of a robot. As shown in Fig 10, with free several obstacles a robot reaches objective position.

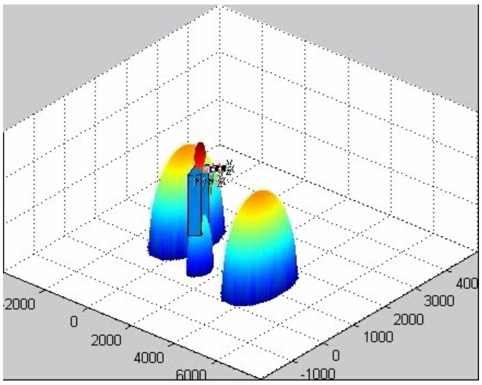

Fig.11 Collision-free robot motion for the case 7

Fig.11 shows the real time obstacle avoidance simulation about whole robot system. Robot suspects conflict of obstacle and manipulator at the same time mobile part avoidance as following and is showing state that position transformation of manipulator happens.

6. CONLUTION

In this paper, the hybrid control for the silvermate robot and real time collision avoidance algorithm in Reactive layer architecture were suggested. And it is confirmed that the proposed algorithm is applicable to the silvermate robot through collision avoidance simulation of mobile and whole system. Therefore following conclusions are obtained.

Hybrid control architecture can achieve the fast and stable real time avoidance motion by modularization of Reactive layer in the motion of a robot. Also, the methodology for the robot system integration was suggested.

The suitable algorithm in intelligence robot kinematics was presented by employing Elastic Force. And if a proper safe distance and k_r and k_c values are decided the real time obstacle avoidance of various position without problem be expected.

The suggested algorithm achieved simulation about the static obstacle. In future, algorithm study will be needed for real time avoidance of dynamic obstacle for the silvermate robot in addition to many-sidedness obstacle for better performance.

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