Rapid Human-Assisted, Obstacle Avoidance System using Sparse Range Point Clouds

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Abstract

Safety is one of the foremost issues in the operation of heavy equipment because of its impact on the construction industry. According to the Occupational Safety and Health Administration (OSHA), a significant percentage of all fatalities in the construction industry stemmed from incidents involving the operation of heavy equipment (OSHA, 1990). One of the major causes of these fatalities is the lack of safety features installed on the heavy equipment that is currently in use. The objective of the research described herein is to develop a human-assisted obstacle-avoidance system with a 3D workspace model. Human-assisted obstacle avoidance system is proposed and algorithms for obstacle avoidance system such as artificial potential function and minimum distance algorithms are presented as well as algorithms for 3D workspace modeling such as convex hull algorithm and workspace partitioning algorithm. Preliminary results of simulation of obstacle avoidance system are presented.

Keywords: obstacle avoidance, 3D workspace modeling, heavy equipment operation

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Introduction

The high incidence of fatalities resulting from operation of heavy equipment is of major concern in the construction industry. According to an Occupational Safety and Health Administration (OSHA) study of on-the-job fatalities in the construction industry in the U.S. in 1985 through 1989, a significant percentage of all fatalities in the construction industry stemmed largely from operation of heavy equipment (OSHA, 1990).

On construction sites, environmental factors such as surrounding activities, noise, precipitation, and dust interfere with the ability of equipment operators to gain a clear sense of their surroundings. Guiding a sophisticated vehicle is a formidable task, one that is often complicated by the limited view afforded by the eyes of the operator or a TV camera. Under such conditions, an operator should exercise extreme care, especially in obstacle-cluttered environments such as construction sites.

One key component and safety feature missing from the tele-operated equipment currently available is an obstacle-avoidance system. The absence of such a safety tool is unfortunate, since most tele-operated systems require operators to have a good sense of how to perform the task *remotely* (i.e., from a distance) and/or to have an awareness of their surroundings in all directions at once. Implementation of an obstacle-avoidance system would reduce or eliminate the dependence of the equipment operator on certain factors that tend to cause accidents. However, given that the cause of most accidents is conventional equipments, the greatest potential would seem to exist in making conventional, manually operated equipment safer. Obstacle avoidance is a very effective and efficient tool for minimizing the incidence of certain types of human error, especially those that are due to operator inability or the nature of construction environments. Use of an obstacle-avoidance system would allow an operator to steer equipment at higher speeds and in cluttered environments, even in situations where visibility is poor. The aim of the research described herein is to develop a method of real-time obstacle avoidance system using a rapidly constructed local workspace model, which is expected to increase the level of safety and productivity in the operation of heavy equipment.

Human-assisted Obstacle Avoidance Process

A process is to be established for achieving obstacle avoidance in an efficient manner. The first step of the obstacle-avoidance process is modeling of the workspace around the place of operation. In this research, human-assisted workspace modeling will be applied, since human operators are adept at recognizing objects, especially in cluttered scenes. As mentioned earlier, fully autonomous object-recognition systems are not very efficient in cluttered or confusing scenes, because most of them were developed for use in uncluttered or indoor environments. In addition, in tele-operated systems the equipment operator can be the one directing the manipulator among the obstacles. Thus, it is more practical and economical to use a human operator for object recognition and obstacle avoidance than to implement a fully autonomous object-recognition system.

Once the workspace modeling is complete, the human operator will give commands to the machine control system, which will manipulate the equipment and perform the tasks at hand. If a collision is forthcoming, the obstacle-avoidance system will stop the equipment to secure the safety of the operation; otherwise, the task will be performed. A more detailed outline of the overall obstacle-avoidance process is presented in the flow chart in Figure 1.

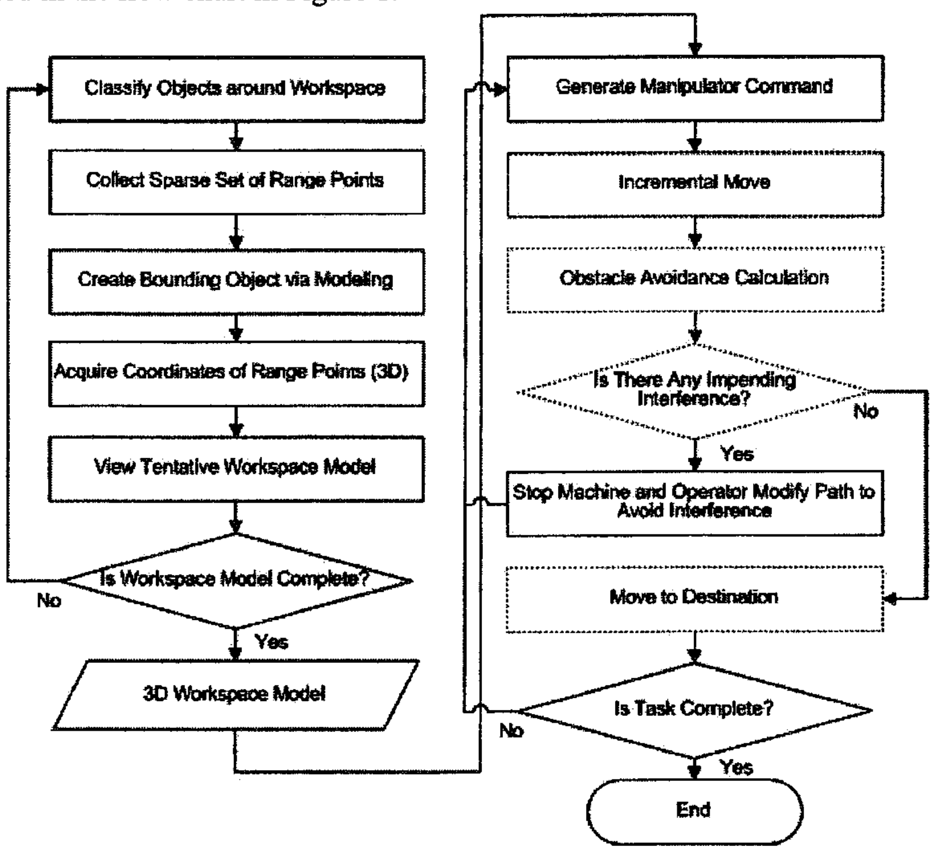

Figure 1. Flow chart of obstacle-avoidance process. (* The dashed portions of the flow chart are independent of the degree of autonomy of the machine.)

Rapid 3D Workspace Modeling for Obstacle Avoidance

The world model employed in any obstacle-avoidance system is the feature that allows the manipulator to plan and execute its tasks, so the ability to construct a proper world model is of utmost importance in devising an obstacle-avoidance system (Barry et al., 1995). There are several institutions at which research on the modeling of industrial scenes is under way. One of these, Sandia National Laboratory, has developed a method for making use of primitives to model industrial scenes (Luck et al., 1998). Their method is a good example of using primitives to make 3D world models. Geometric primitives are not limited to the representation of industrial scenes, however; they can be ideal for modeling construction environments as well, since they require very little memory, even for large world maps, and they are easy to store and manipulate.

Prominent candidates for primitives that can be used to model construction-site scenes are convex hulls and workspace partitioning. Convex hulls can be employed in the representation of a wide range of construction-site scenes, such as pipe racks, building structures, and other types of equipment and workspace partitioning algorithm can be used to delimit workspaces. Detail descriptions of algorithms are described in McLaughlin, 2003 (McLaughlin et al., 2003).

Photograph of an actual construction site used as testbed for 3D workspace modeling is presented in figure 2. Figure 3 shows the results of 3D workspace modeling.

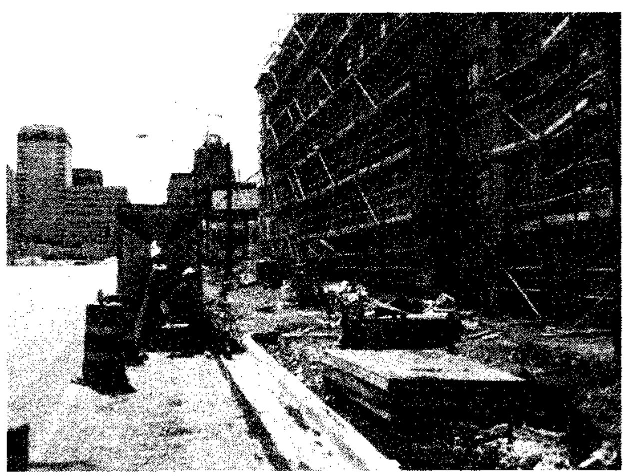

Figure 2. Picture of construction site scene.

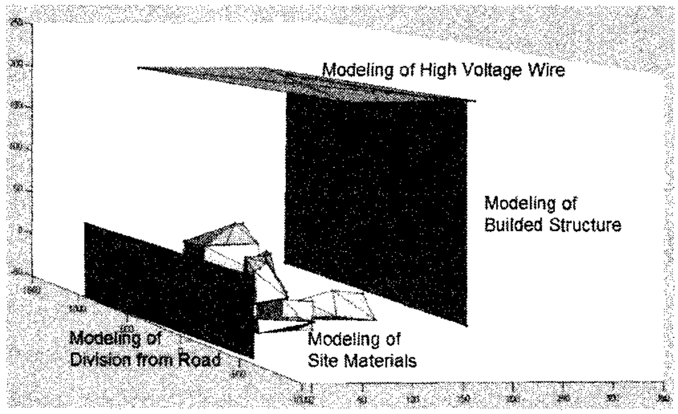

Figure 3. 3D workspace model.

Obstacle Avoidance Algorithm

As a result of a review of the literature on obstacle-avoidance algorithms, it was concluded that the approaches that are the most suitable for application in the construction industry are an artificial-potential formulation and a minimum-distance algorithm (McLaughlin, 2002).

Obstacle-avoidance algorithms can be classified as either global or local. Though global methods may be appropriate for cluttered environments, they have a rather high cost of computation and require a highly intelligent system. When it comes to cluttered environments such as construction sites, local algorithms are the more appropriate choice because their cost of computation is considerably lower. Among local methods currently available, the one chosen for this research was an artificial-potential formulation that is at once very simple, fast, and versatile (Feddema and Novak, 1997). The following formulation was used to compute the artificial potential U_i experienced by manipulator link i:

$$U_i = \left[\frac{d_0 - d_{\min}}{d - d_{\min}} \right]^p$$

Here, d_o is the distance at which U_i is equal to unity, $d_{\min}$ is the user-specified shortest-allowable distance from the manipulator link to the obstacle, d is the actual minimum distance, and p is a user-specified spring coefficient. The actual minimum distance can be found either by use of sensors or by carrying out geometric calculations from digital models (as was done here). Using the former method can be quite fast, but outfitting large manipulators with a sufficient number of sensors is generally very expensive (Feddema and Novak, 1997).

The potential field method relies heavily upon the use of a distance function such as a minimum-distance algorithm (Hague et al., 1990). Therefore, a companion algorithm was selected for the purpose of performing fast computations of the minimum distance between convex polyhedra in three-dimensional space (Gilbert et al., 1988). The Gilbert, Johnson, and Keerthi (GJK) algorithm for computing the minimum distance between convex polyhedra in three-dimensional space was used as a fast method of proximity calculation. This algorithm has its origins in mathematical programming and uses a descent procedure to compute distances between elementary polytopes in convex sets (Gilbert et al., 1988). The algorithm is nearly linear in the total number of points, making it ideal for use in obstacle-detection systems.

Obstacle Avoidance Simulation

An obstacle avoidance simulation was performed in order to demonstrate the applicability of the modeling methods to obstacle detection for the purposes of equipment operator feedback and control (McLaughlin, 2002). The simulation consisted of a three-dimensional, three degree-of-freedom robot was designed to traverse over a box. Experiments on obstacle avoidance were performed for two scenarios: one with the box located far from the robot, in which case no collision is expected (Figure 4), and one with the box located close to the robot, in which case a collision would be imminent (Figure 5). As expected, robot operation is stopped whenever it is determined that a collision on the intended path is likely.

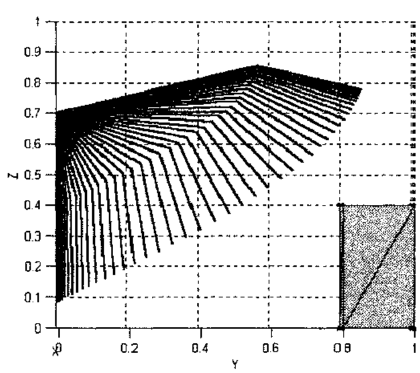

Figure 4. Case 1: No Collision.

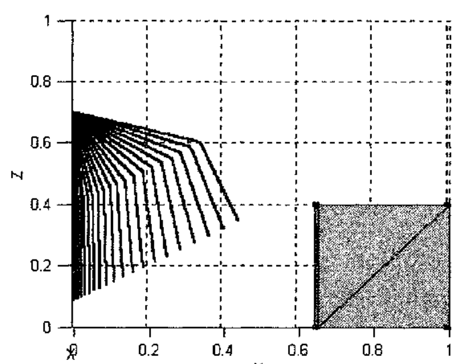

Figure 5. Case 2: Impending Collision.

Experiment of obstacle avoidance simulation is still on-going and it will be performed using characteristics of actual construction sites to develop models of construction-site workplaces.

Conclusion

The research described herein is for the development of an obstacle-avoidance system with a 3D workspace model that will prevent collisions with obstacles on construction sites Such a system can work in two modes:

1) real time obstacle detection and alarm that will alert a human operator or cease machine movement, or
2) obstacle avoidance feedback to an operator who is planning machine motions in a 3D simulation that will ultimately be executed automatically in a playback mode.

Preliminary tests of the simulation process indicate that such an obstacle-avoidance system can be successfully implemented, hence that it may significantly increase the safety of equipment operation, which is one of the ultimate goals of the construction industry. It is believed that the approach described herein will result in safety improvements while at the same time lessening the need for skilled workers to operate heavy equipment in a wide range of working conditions.

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