Rapid Graphical Registration for 3D Complex Objects for Construction Workspace Automation

Yong K. Cho
Assistant Professor, Dept. of Industrial Studies, University of Wisconsin, Platteville, WI 53818, USA
E-mail: choyo@uwplatt.edu

ABSTRACT: Although considerable achievement has been made to the development of methods of extracting 3D geometrical information of objects from a scene, there are still major difficulties to visualize complex objects into descriptive CAD models. This paper introduces a new framework for rapid 3D modeling for complex planar objects which would enable automated material handling and semi-automated equipment control, and could significantly improve safety by enhancing operator's spatial perception of the workspace

KEYWORD: *construction automation, 3D, CAD, complex model, laser range finder*

1. INTRODUCTION

Using automated or semi-automated equipment on a construction site requires rapid recognition and accurate measurement of objects in the workspace so that timely on-site decisions can be made. Graphic workspace modeling can help to optimize these automated and semi-automated equipment control, significantly improve safety, and enhance a remote operator's spatial perception of the workspace. Current methods for extracting geometrical data from construction sites are comprehensive local area modeling based on fusion of dense point clouds, which is impractical and unnecessary in practice in the near future [1][2]. By strategically incorporating human assistance, which can simplify and accelerate geometrical data acquisition of real-world objects considerably, the ability to extract models of real world objects in a construction workspace for equipment operations from only a limited number of scanned points is a significant advantage of this approach over full range scanning methods that require computationally intensive range data processing.

Recent research conducted from the University of Texas at Austin has successfully demonstrated rapid registration of 3D primitive objects to workspace based on measured scattered point data [4]. However, the research was confined to the registration for selected simple primitive models which require a certain number of parameters to determine the boundary of objects such as a cylinder and a cuboid. Since more complex objects can be easily found than primitive objects in construction workspace, there has been a strong need to develop algorithms and more efficient data measurement processes to rapidly register 3D complex objects to the graphic work environment. Due to the complexity involved to measure all required parameters to generate complex models, which is unacceptable in the midst of the on-going construction operation, there have been few efforts made to solve this problem.

This paper presented an on-going research at the University of Wisconsin at Platteville (UWP) and demonstrates a framework and a schematic process of algorithm development for graphical regeneration of real-time geometric information of complex planar objects with respect to their location and orientation.

2. MODEL-BASED RAPID REGISTRATION

The current approach to workspace modeling includes human-assisted sparse-points based local area sensing and fitting matching process with pre-stored models.

2.1. Human-assisted sparse- points based local area sensing

Since most target objects are known and man-made, they can be described as a generic set of parametrically defined graphical objects in a computer database [2]. For the rapid registration, the geometric information of complex objects needs to be graphically generated and stored in a computer database as pre-stored CAD models. Such a library of pre-stored models (related to facility design elements), with manual guidance, can provide graphic representations of forms that can be matched and fitted to sensed data from 3D position sensors deployed in the work environment.

Earlier version of the algorithm was programmed to directly measure vertices from the object. However, it was difficult and time consuming for the operator to measure exact vertices or edges from an object with a single-axis laser, which showed some inconsistent results. Figure 1 shows a reflection problem when a laser focuses on a vertex on the target object. The laser may read the behind reflected dot measurement.

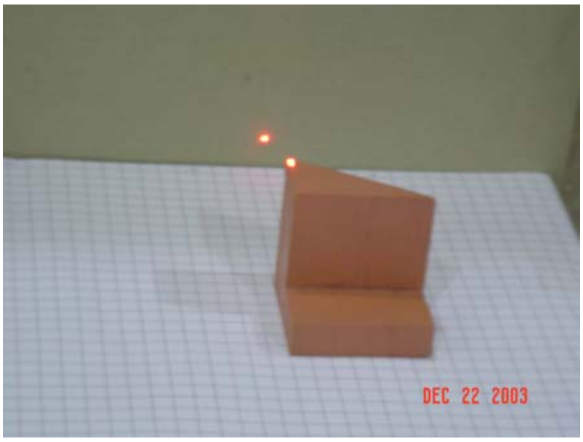

Figure 1. Reflection error showing a laser beam splits into two dots

For a more efficient and better user friendly measurement process, the algorithm needed to minimize the operator's possible position measuring errors. Therefore, the current algorithm which is currently being developed allows the operator to measure scattered random points from any visible surfaces of the object. This approach will provide a faster and more accurate position data measurement process rather than directly measuring vertices or edges from the objects.

For a fitting and matching process, a minimum of certain number of scanned points measured from surfaces of objects are required. In this approach, a minimum of three vertices are required for fitting and matching process for objects which have planar surfaces. To generate three vertices, well-selected five planes should be generated. To generate a plane, a minimum of noncollinear three points on the surface are required. Therefore, a minimum of total fifteen points (=5 surfaces x 3 points) should be measured using a single-axis laser range finder with manual guidance.

Figure 2. Sparse points sensing by a single-axis laser range finder.

The current three degree-of-freedom (DOF) laser system (including a laser beam), however, measures points from limited visible surfaces due to its lack of DOFs (Figure 2). For example, it is untenable to have five surfaces of box viewed from one location. To obtain required point range data from five different surfaces, therefore, the laser range finder should move around the object. This problem can be solved when the laser system is mounted on a robot arm like an eye-on-hand configuration (see Figure 3). Papanikolopoulus [5] describe that the robot-mounted camera (eye-on-hand configuration) can eliminate the need for accurate calibration and assumptions about the workspace.

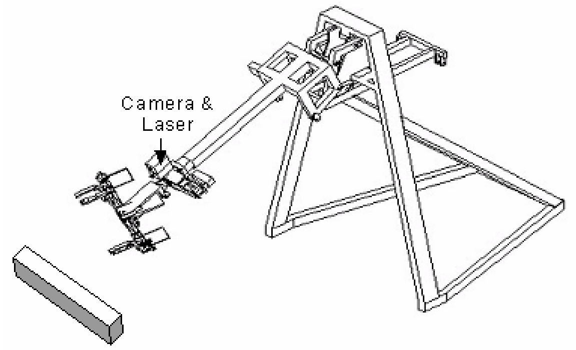

Figure 3. The Laser and Camera System on the UT Large Scale Manipulator.

2.2. Fitting and Matching Process

For a fitting and matching process for a planar complex object, there are mainly two algorithm development steps as follows:

2.1.1. Determining vertices

Once the sets of three points data are received, planes are determined by the equation of plane, ax+by+cz+d=0. Two planes always intersect in a line as long as they are not parallel. The intersection of three planes can be determined by solving the set of linear equations with Cramer's rule [3].

$$a_1x+b_1y+c_1z+d_1=0 \text{ ------- } P_1$$
$$a_2x+b_2y+c_2z+d_2=0 \text{ ------- } P2$$
$$a_3x+b_3y+c_3z+d_3=0 \text{ ------- } P3$$

By solving each set of three plane equations, four vertices of the object are determined (Figure 4):

1st Vertex from $P_1P_2P_3$
2nd Vertex from $P_2P_3P_4$
3rd Vertex from $P_3P_4P_5$
4th Vertex from $P_1P_3P_5$

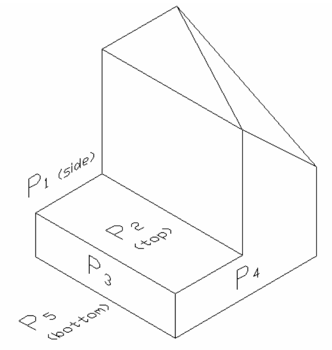

Figure 4. Example of five planes selection

2.1.2. Fitting and matching a pre-stored model to the vertices

As a second major step, the algorithm moves and rotates the pre-stored model to the corresponding vertices obtained from the previous step. First, a selected vertex on a model is moved to one of measured positions. Second, a distance between first and second measured points is calculated. Third, the program searches a second point from the model which has the same distance calculated from the measured first two vertices. These three steps continue until the program matches the corresponding two points. Fourth, once the program found the two points on the model, an arbitrary axis is generated to rotate the second point on the model to the measured second vertex with certain angle. The angle can be obtained by solving concatenated inverse transformation matrices. Finally, the program uses the first two fitted and matched points as an axis to rotate a third point on the model to the measured third vertex. Another angle needs to be solved from the same inverse transformation matrices. However, sometimes three points may induce a directional confusion in the boundary. An additional point can prevent this problem (Figure 5).

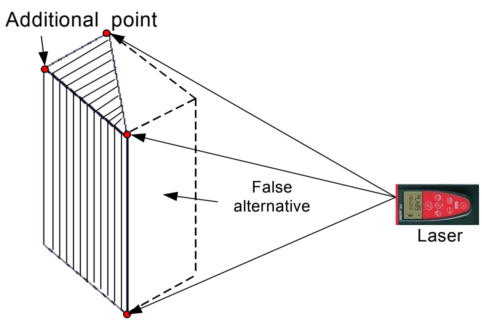

Figure 5.

3. ERROR ADJUSTMENT

In the field of automation and robotics, sensors have long been used in the laboratory under controlled conditions. However, sensing often fails due to unanticipated problems relating to the sensor, the robot, the integration of their respective systems, and the environment [5]. For a single axis laser range sensor, the sensing errors depend on distance to measured points, laser power, target reflectivity, angle of incidence, and laser beam focus.

In the fitting and matching process, there are two places requiring error adjustment due to the aforementioned error sources. First, the measured scattered points on each surface should be modified to generate ideal surfaces. After grouping points for each surface, a statistical approach will be used to reposition erroneous points to each ideal surface. Second, certain tolerance should be allowed when the points on the model are fitted to the measured corresponding vertices of the object.

Compared to the method which creates or draws models from measured and calculated boundary data, however, this model-based fitting and matching method yields higher accuracy. Although position and orientation error problems still remain due to the nature of sensing error sources as mentioned before, this method does not distort nor deform models in the fitting and matching process because the models are designed and stored to the library in exact dimensions.

4. Simple demonstration of fitting and matching process

A simple test for rapid registration was conducted for the object which had eight planar surfaces (see Figure 4). Since the object is sitting on the horizontal surface as a known base surface (height, z = constant), data were collected from only four surfaces instead of five. Figure 5 shows the fitting and matching process for this object. Actual processing time takes less than a second.

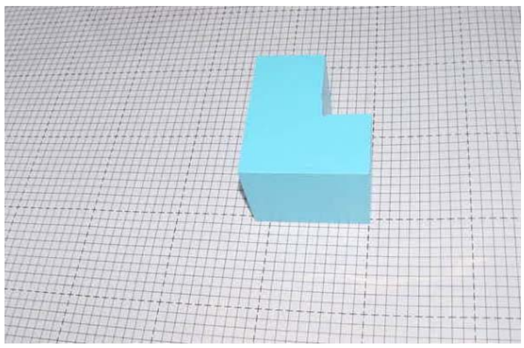

Figure 4. An object with 8 planar surfaces on a grid sheet

Figure 6 illustrates a framework for the overall rapid graphical registration process which is being developed.

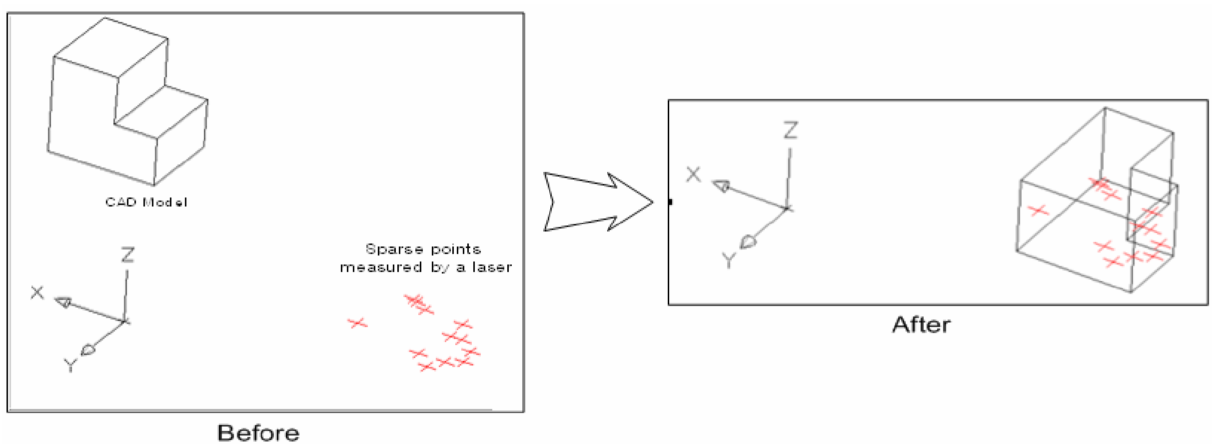

Figure 5. Fitting and matching demonstration

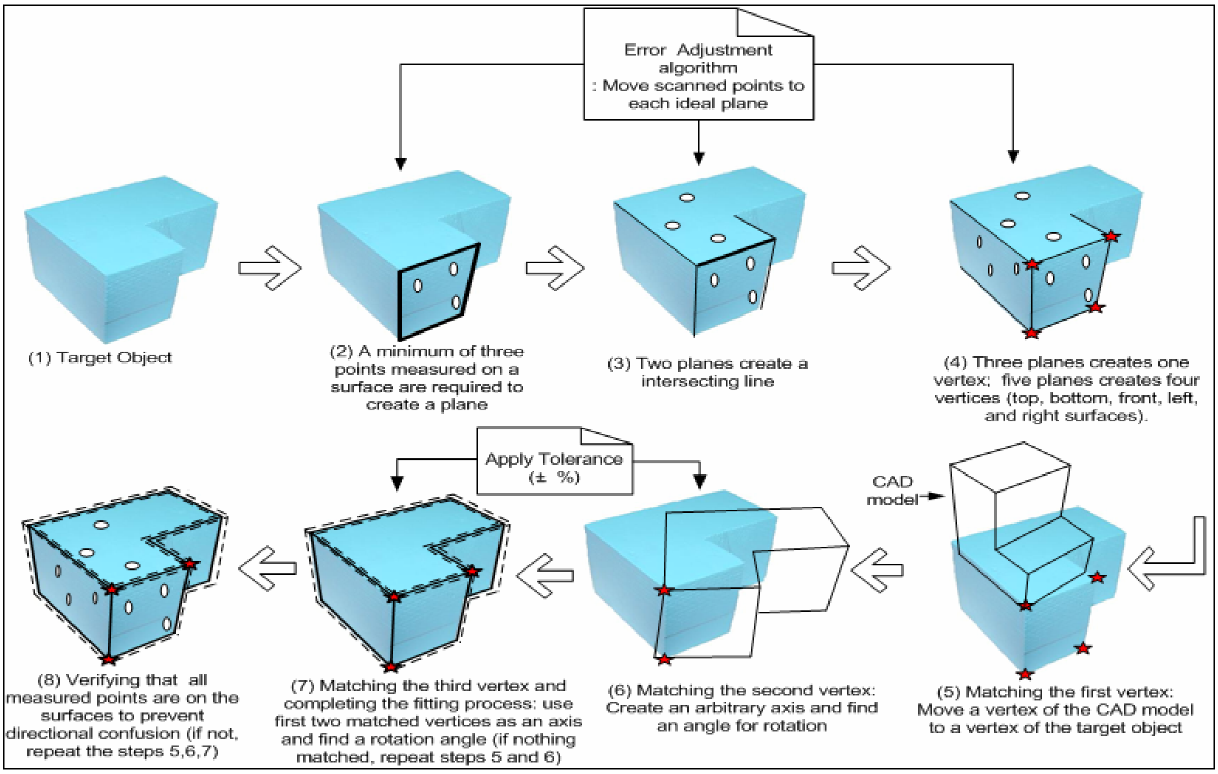

Figure 6. A framework for rapid graphical registration process

5. Current and up-coming research tasks

Current tasks this research are conducting include developing a measurement error adjusting algorithm and developing a fitting and matching algorithm for curved surfaces including a cone, a tiered cylinder, a pipe elbow, a sphere, and combination of curved and planar objects. As a final stage of this research, test beds with one of available robots at UW Platteville lab (see Figure 7) for material handling and welding will be designed for the final performance evaluation and improvement of this method for practical use in the construction automation industry.

Figure 7. Miller 6 DOF welding robot at UWP.

6. CONCLUSIONS

Recent research indicates that the ability to match and fit pre-stored models with real world objects in construction workplace is a significant advantage of workplace automation. This paper presented an on-going research at the UW Platteville which introduced efficient methods for rapid registration of 3D complex planar objects to the graphic work environment.

The rapid approach will be useful in construction in order to optimize automated equipment tasks and to significantly improve safety and a remote operator's spatial perception of the workspace.

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