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CAD-Based Robotics

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Abstract

Computer Aided Design (CAD) has played a major role on the design side of manufacturing for many years. CAD tools permit the rapid exploration of design space as well as a quantitative specification of geometry. CAD is now starting to play just as important a role on the manufacturing side as well. We describe how 3D Computer Aided Geometric Design can be used not only to produce numeric control codes for NC milling machines and turning centers, but also to control multisensor inspection and manipulation of manufactured objects.

Keywords: CAD, Automatic Inspection

1 Introduction

CAD modeling systems have been a great boon to manufacturing for many years now. However, most such systems are restricted to 2D designs. Modern CAD systems permit 3D object design based on several different modeling paradigms. These include Constructive Solid Geometry (CSG), boundary representations, and sweep-based methods. These are much more powerful representations than 2D views, and directly support several major new applications:

- process planning for machining parts
- 3D quality control and inspection, and
- grasp and manipulation planning for manufactured parts.

We describe these ingreater detail below.

2 CAD-Based Process Planning

a 3D CAD model gives the geometry of a part, but does not necessarily define an explicit process for producing the part. Several approaches have been proposed to facilitate the generation of process plans. A CSG design may be used in such a way as to make explicit any subtractive processes. These then can be directly related to machining operations. Another approach is to design using manufacturing features (e.g., slots, pockets, counterbored holes, etc.) and then to develop algorithms to translate the feature definition into a manufacturing sequence. When features are parameterized, this is even more powerful, since it permits modifications of the feature in a straightforward way and makes the design of similar parts easy.

Another possibility is to produce a physical prototype directly using additive processes; for example, at the University of Utah we have a stereo lithography machine which produces a plastic part by laying down cross-sections. This does not involve subtractive operations, and although there may be some eventual warping of the part, this technique does allow integral physical parts to be produced. (It actually allows the manufacture of objects which cannot be milled; e.g., interlocking parts.)

At the University of Utah, the Computer Aided Geometric Design group has developed a sophisticated 3D spline-based solid modeler called Alpha_1 [15, 16] which allows the use of manufacturing features, as well as Boolean operations, for the design of freeform surfaces. Although this is an area under extensive research, several full scale examples have been designed and manufactured, including a special diesel engine and a turbine blade.

In order to support these studies, an Advanced Manufacturing Laboratory has been established. This facility is comprised of 2 5-axis NC Milling machines, a sophisticated Turning Center, a Coordinate Measuring Machine, a 3D Systems Stereolithography machine, as well as a PUMA 560 arm, a Technical Arts White 3D scanner, and two workstations. The facility is worth approximately $1M dollars and is housed as a separate facility within the College.

The issue of process planning is an active research topic and requires several levels of knowledge. Not only must the geometrical aspects of the metal removal be addressed, but also the sequence of operations, the rates and translational speeds of drills, etc. Path planning is crucial to avoid collisions between the part and the NC machine and tools [2].

Another area of study is remote manufacturing. This involves the off-site design of a part and the local manufacture of the part from specifications derived from the CAD model.

3 CAD-Based Inspection

Given the CAD model for a part, it is possible to specify features of interest to be measured. This can involve both dimensional measurement or structural validity. We have been working for several years on CAD-Based Computer Vision techniques [9, 11, 10, 13, 14, 19]. The overall approach is to define knowledge of:

- geometry,
- algorithms, processors and implementations,
- user requirements, and
- application synthesis rules.

The goal is to automate the synthesis of inspection and validation codes from strong knowledge. This has led to our current CBCV system [12] which is our research tool for CAD-Based inspection.

More recently, we have been studying high-precision part measurement using a very sophisticated Coordinate Measurement Machine touch probe. This machine can perform measurements to one micron given adequate conditions. The Alpha_1 research group has been developing semi-autonomous touch probe sequences based on the process plan used for the manufacture of the part. Our group has been investigating the use of Discrete Event Dynamical Systems (DEDS) to define a strong observability model for monitoring the inspection process for safety and reliability [17, 18]. We are currently looking into strong methods for using the data from multiple modalities (e.g., the touch probe, 2D and 3D vision) for coarse to fine inspection strategies.

Reverse engineering is the (semi-) automatic development of a CAD model based on measurements of an actual part. We are currently exploring new techniques for the identification of manufacturing features. Once such features are hypothesized, it is possible to run a simulation forward to simulate the manufacture of the part, and then to compare that result with the actual part. This permits closed-loop corroboration of the hypothesis. This approach is also called Vision-Based CAD.

4 CAD-Based Manipulation

The third application we have investigated is the use of CAD models for the design of grasping and manipulation strategies [3, 6, 8, 4, 5, 7]. In general, not only must the geometry of the part be known, but also the geometry of the robot gripper. This ranges from simple parallel grippers to complex, multiple DOF dextrous hands like the Utah/MIT Dextrous Hand.

For certain tasks in the manufacturing environment, enough is known to make this approach feasible. However, dextrous manipulation is itself an area of intense research, and much of the current effort is aimed at understanding the mechanics and control aspects of manipulation.

In a related effort, we have recently performed work in CAD-Based Biomedical Modeling and Visualization [1]. The goal is to bring CAD modeling techniques to bear on the study of the biomechanics of the human finger. One very interesting result is that humans do not seem to have a static joint sensor. Our CAD model has shown that one possible explanation for this is the many to one relationship between joint angle configurations (three angles: $(\theta_1, \theta_2, \theta_3)$) versus tendon settings (three tendon lengths: (d_1, d_2, d_3)). We believe that such studies may give some insight into the design and control of robotic manipulators.

5 Conclusions

In this paper we have presented an overview of our recent work in CAD-Based Robotics. Three major applications are:

- CAD-Based Process Planning,
- CAD-Based Inspection, and
- CAD-Based Manipulation.

In the talk, examples in each of these areas are given, as well as a discussion of the major research issues.

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