

NIST Integrates CAD into Robotic Chamfering

On the morning of December 17, 1903, Orville Wright made history's first powered airplane flight. This first flight, which lasted 12 seconds and covered 37 m (120 ft), was the first step towards the aviation technology that exists today.

A lot has changed in the almost 90 years since that first flight at Kill Devil Hills on the breezy North Carolina coastline. We now fly across the country in 5 hours and highly-maneuverable jet fighters control the air in combat.

The need for greater performance in jet aircraft components and parts has increased the demand on manufacturing tolerances and quality. A small imperfection in an engine component could propagate into a catastrophic failure that could destroy a multi-million dollar piece of machinery and, more importantly, jeopardize the lives of the passengers on board as well as innocent bystanders on the ground.

AUTOMATED CHAMFERING CELL

Engineers at the National Institute of Standards and Technology (NIST), working with United Technologies Research Center (UTRC) and Pratt and Whitney, are developing an Advanced Deburring and Chamfering System (ADACS) to automatically produce precision chamfers on aircraft engine components manufactured from titanium and inconel. These chamfers, which are 45 degree beveled edges, must be placed on several edges on the engine hubs and bearing housings after manufacturing to remove burrs (excess material remaining after the machining operations) and to reduce stress concentrations which could lead to the failure of the engine, and to allow easier mating of subassemblies.

The workstation consists of a robot, an actively compliant tool and a servo positioning table. A six-axis electric robot is used as a macro-positioning device to carry a two-degree-of-freedom force sensing tool with a carbide cutter at the tip. This Chamfering and Deburring End-of-arm Tool (CADET), which is mounted to the robot's flange, incorporates actuators and force sensors to provide control over cutting forces and to keep the cutter on the edge. The servo table is used as a part fixturing and manipulation device. Each device is controlled separately and is coordinated under the control of the system supervisor using the NIST-developed hierarchical Real-time Control System (RCS). RCS allows feedback from a variety of sensors to be easily integrated with the robot control, accommodating for robot inaccuracies which may result from off-line programming. A CAD graphical user interface allows the user to graphically select which features of the part are to be chamfered and specify system parameters (feed rate, chamfer depth and direction of cut) to obtain the required chamfer of each edge.

With the increasing use of Computer Aided Drawing (CAD) and Computer Aided Manufacturing (CAM), many parts are designed employing the aid of a computer, therefore a CAD description of the part usually exists for the machining process. NIST is taking this one step further, using the existing CAD data for the finishing process.

AUTOLISP INTERACTION

Using AutoLISP and the Advanced Modeling Extension (AME) with AutoCAD Release 12*, a LISP program was written to extract the necessary edge information from a part to calculate the robotic trajectories. For a line-edge, this information includes the starting and ending points of the edge, and the two normals of the surfaces that construct the edge. These normals are required to determine where the "solid" of the part is, which is required to

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obtain the proper tool orientation to produce a 45 degree chamfer. The extracted information for an edge that is an arc is similar. The data contains the starting and ending points of the arc, the center of the arc, the length of the arc, the normal to the plane that the arc lies in and the normal at the starting point and the normal at the ending point of the arc. This data allows the tool to keep a 45 degree orientation to the edge as it traverses along the arc.

GRAPHICAL USER INTERFACE

The graphical user interface, developed with use of AutoLISP programs, allows the user to select specified edges that need to be chamfered. This virtually eliminates the need to teach program the robot. Teach programming is a very tedious and time consuming effort that is often inaccurate. For complex geometries, such as arcs and splines, hundreds if not thousands of points need to be taught along the surface for the robot to perform the trajectory accurately. With the interactive user interface, the user highlights the edge, and the exact trajectory is automatically calculated from the CAD data base.

The user selects the edge to be finished, which is then highlighted. A directional cone is then superimposed on the edge to indicate the direction of the trajectory to follow. A prompt then asks if this is the required direction of travel. If the user answers yes, the directional cone remains on the edge and the user is prompted to select another edge. If the user answers no, the previous directional cone is erased and the correct cone that indicates direction is superimposed on the edge and the user is prompted to select another edge. When the user is finished, the result is a part drawing with the robotic trajectories superimposed on the edges that need to be finished. This allows the user to visualize the paths that the robot will follow.

In order for the robot to perform the trajectories correctly on the real part, the CAD system must be "calibrated". This means that the part drawing must have the exact position and orientation as the actual part in the robot workspace so the robot will know exactly where the part is and how it is oriented. This procedure can be accomplished in one of two ways. One method is to specify an origin, where the X, Y, and Z coordinates are all zero, someplace on the part drawing. All the calculations will then be with respect to this reference origin. After the data has been extracted, the user specifies where the reference point is in robot space (for example the origin that was specified on the part drawing may be at 1524.0 mm, 0.0 mm, 0.0 mm in robot space). This transformation is then added to all the calculated trajectories. The orientation of the part drawing must still be that of the part in the workspace. The other method is to actually move the part drawing so that it is in the same position and orientation as the part in space. For example, the part may have a specific corner which is known to be located at 1625.1 mm, -36.8 mm, 24.9 mm in robot space. The user would then move the part drawing, with the base point snapped to this reference corner, to 1625.1 mm, -36.8 mm, 24.9 mm and then run the program to extract the data.

In the graphical user interface, the user also specifies several machining parameters for the cutting operation. These include the spindle speed, the required chamfer depth for the edges, and the required feed rate. The force needed to obtain the chamfer depth is then calculated and downloaded to the active tool, which updates the force it is applying to the part's edge every one-thousandth of a second.

After the user has completed the edge selection process, a file is created containing the necessary information to calculate the robot trajectories. In the specific case of chamfering, the tool must keep a 45 degree orientation to the edge at all times. The necessary robot trajectories are then calculated using a trajectory generator. The ADACS currently uses the Level II Library trajectory generator which is maintained by the Indiana Business Modernization and Technology Office. After the trajectory generation is completed, the trajectories and tool commands are downloaded to the robot controller and are executed.

ADDITIONAL APPLICATIONS

The CAD-driven Graphical User Interface is a very powerful tool for robotic programming and is especially useful in small batch manufacturing where robotic teaching is not a feasible alternative. The interface can easily be adapted to fit any application. For example, several parts that need to be welded together can be imported into a drawing and assembled. The weld line could then be selected and the required trajectory calculated and downloaded to the robot automatically.

The AutoCAD Graphical User Interface is now being employed on the Advanced Deburring and Chamfering System (ADACS) workstation at NIST and is being employed on several other projects at NIST, one being the RoboCrane. This is a new type of crane that was developed by engineers at NIST for use in construction and in grinding and welding of construction materials. Popular Science named the RoboCrane one of the top 100 inventions in 1992.

BENEFITS TO INDUSTRY

Automation of finishing and chamfering will benefit industry in several ways:

- At the present time, manual chamfering of parts is very time consuming, inconsistent, and prone to errors that can damage expensive parts beyond the point of repair. Automation will reduce the scrap rate and rework costs.
- Automation will allow the repeatable placement of chamfers on the edges with a tighter tolerance than those now placed manually.
- Manual deburring and chamfering jobs have a high turnover rate with low employee self-esteem. There are also health-related incidents that can occur when working with the hands in a confined area for extended periods of time. The most notable of these is carpal-tunnel syndrome.

At the present time, manual finishing accounts for 20% of the total labor cost and 10 - 30% of the manufactured parts need rework after the manual finishing process. By automating the finishing and chamfering process, tolerances could be held to less than ± 0.07 mm (± 0.003 in), the finishing costs could be reduced as much as 50%, and the rework rates could be reduced to 0%.

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