Figure 1: A CNC milled styling block model of a perfume bottle, perfectly finished (courtesy of SDA)

RP with CNC

In the past few years, CNC milling has proved to be a valuable tool for prototypers. Reliable results and value for money mean that this class of technology shouldn't be overlooked

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In 1996 **DeskProto** made rapid prototyping available to a much wider audience by applying 'traditional' CNC technology to this area. The many enthusiastic DeskProto users have since then guaranteed a continuous stream of requests for improvements and additions to the software. This user wish-list has been carefully safeguarded, and was used for software updates.

As a number of these user requests did require major changes in the software, they could not be implemented in the short term. Still, their importance was recognised, and in 1998 the decision was made to develop Version 2.0 as a complete remake of the software. Now that the new V 2.0 has been released, the difference is clear: the current demo version can be downloaded and compared to the V 1.0 or 1.1 demo variant.

THEORY

Where most rapid prototyping systems are based on incremental build techniques (LMT = Layered Manufacturing Technology), the DeskProto approach is decremental. The system starts with a solid block of material (any material can be used) and removes as much as needed to create the prototype. This decremental build technique as used in DeskProto completely fulfils the three criteria for rapid prototyping:

- Based on a 3D CAD geometry description, DeskProto imports CAD geometry using STL files, which are the standard geometry file format for any rapid prototyping process;
- It builds using an automatic process – this differs from other CAM systems in that it is easy to use and functions almost fully automatically;
- It creates a prototype within a short timespan. The actual milling time with DeskProto can be very short indeed. Even more important (as the milling can be done without operator assistance) is the short preparation time (translation from CAD geometry to CNC toolpaths), and the short delivery time, as the complete system is ideal for in-house use.

Using CNC milling for prototype production is, of course, not new. However, DeskProto has made the technique available to CAD users without CAM knowledge and without a large investment budget. The software has been developed based on the idea of a black-box, Windows-based device driver, that just translates 3D CAD models to CNC data. While the ultimate black box has not yet been completely achieved, the resulting software already shows a remarkable level of automation. Note that a complete black-box is not even required: the user needs to influence a few parameters like the accuracy and the positioning of the geometry. Compare this to your Windows printer driver: choices are presented between draft and proof, and between portrait and landscape. Still, to keep it simple the number of parameters has to be as small as possible.

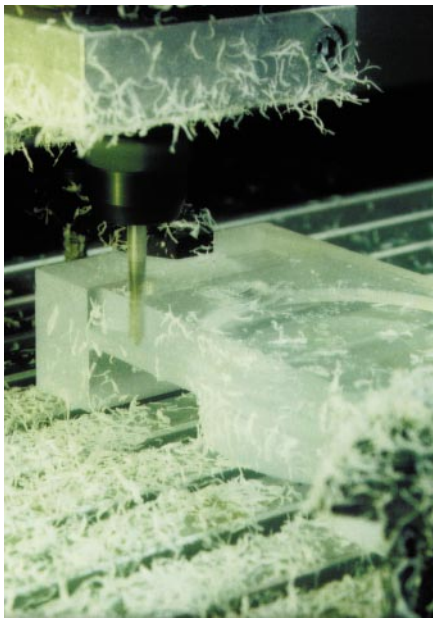

Figure 2: A prototype being milled in transparent perspex

A key factor in the success of DeskProto has been the recent availability of exciting new types of light CNC machines that are both low-cost and high-tech. As sales of these new desktop machines are rapidly growing, their production is done more and more on a large scale, resulting in lower prices. We have not yet seen the end of this development: real mass production will soon make these machines even more affordable. In any case, they are cheaper than LMT-based RP systems, as cutting off chips is an easier process than (fully controlled) material addition.

IMPROVEMENTS

DeskProto V 1 was a Windows 3.1-based software package. Obviously the new release had to be in Windows 95/98/NT style. Microsoft Windows™ is absolutely needed as a base, not because it is the best operating system available, but because it does offer an unrivaled unity in user interface. Virtually all current computer users are trained in using this interface, resulting in a very short learning curve for new Windows-based applications. To fully use this advantage the application has to completely conform to the Windows specifications as defined in the Microsoft Foundation Classes (MFCs).

The transition from 16-bit Windows 3.1 to a 32-bit operating system offers a major improvement in calculation speed. For heavy floating point arithmetic as used when calculating CNC toolpaths, the difference is large: improvements have been measured of more than a factor of 25! As with all time-intensive calculations the speed improvement was very high on the users' wish-list. Also in the field of computer technology is the improvement of using Open GL for the graphics, offering a gain in drawing speed, support of 3D graphics hardware, clear renderings of the geometry, and real-time viewpoint control using the mouse. Many 3D CAD users will already have a computer with a 3D graphics card, which will make this improvement even bigger.

The three import filters of DeskProto (ASCII STL, binary STL and subset DXF) have been extended with VRML, to enable easy integration with the Internet. As rapid communication is a very important factor for rapid prototyping, the Internet can be quite useful here.

The main stream of users' wishes was of course focused on DeskProto's functionality. A number of requests were made for new, extended functionality: extra milling parameters offering more possibilities. Here the important factor in deciding whether or not to implement the request has been the idea behind DeskProto:
simple and cheap. There are many excellent high-end CAM packages available on the market, meant for trained users like mouldmakers, with which DeskProto must not compete. As said before, to make the software understandable for users without CAM experience the number of milling parameters has to be as small as possible. It has therefore been a conscious decision to not include certain functionality, like IGES import and some advanced milling strategies. As extra functionality still can be useful, obviously for every request a trade-off decision had to be taken between ease of use and extra functionality.

These trade-off decisions could be eased by using an intelligent way to present the available process parameters. In DeskProto V 2.0, tab dialogues have been used, offering the available choices in order of complexity. A beginner-level user will only look at the front tab-screen, the more advanced a user becomes the more tab-screens can be used, up to the final 'advanced' tabs. These dialogue screens offer sufficient room to explain each parameter using clear drawings (larger than an unreadable button-sized icon (Figure 3)). Two sets of tab dialogue screens are present: one is called part parameters and defines what geometry will be produced, the other is called operation parameters and defines how it will be machined.

Some of the user wishes could be implemented maintaining the ease of use: adding only one parameter choice (and a lot of calculation algorithms). For instance, the option 'inverse milling' was asked for by many mould-making customers. It is just one 'check-box' added to the dialogue screen, making the software convert a positive geometry in the STL file into its negative (the mould) to be milled. Or some extra milling strategies: in addition to the options of toolpaths parallel to the X-axis and the Y-axis (both in fact presenting a slicing approach) now 'rectangular spirals' are possible too, both inside-out and outside-in (Figure 3). To improve the quality of the resulting model an optional extra contouring toolpath around the geometry has been added.

More complex in user interface, so hidden for casual users, is the new option that allows 'subsegments' to be used to easily add extra finishing operations for a small area only. For instance, to create sharp inner radii using a small tool, exactly where needed. Some new functionality is invisible for the user: for instance, the recognition of vertical walls in the model, where DeskProto V 1 did not always create exactly vertical tool movements.

Invisible too is the division of the software into two separate parts: an EXE file containing the DeskProto client (the user interface) and a DLL containing the kernel (calculation routines, etc). Advantages of this construction are easier software maintenance, and also that it is now easily possible for software developers to include an OEM version of DeskProto in their own application, preserving their own user interface. Several joint projects have started already. Finally, this separate user interface makes it easier to create language versions. Where DeskProto V 1 was only available in English, DeskProto V 2 will soon be available in other major languages as well.

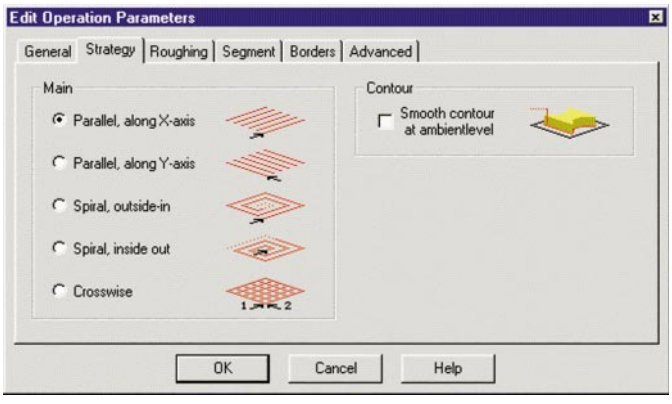

Figure 3: The application of tabs and illustrations has made the DeskProto dialogue screens easier to use

Figure 4: CAD rendering of a futurist motorbike, created doing a modelling course (courtesy of Delft University of Technology and Sonny Lim)

Figure 5: A CNC milled concept model in foam of the geometry shown in Figure 4 (courtesy of Delft University of Technology and Sonny Lim)

APPLICATION AREAS

The two most important application areas for the DeskProto way of rapid prototyping are styling block models and concept modelling.

Styling block models for presentation purposes are the primary DeskProto application. Here we refer to solid prototypes (without the inside geometry) that have been perfectly finished for a 100 per cent outside resemblance to the final product (no visible differences) – for this application the big advantage of CNC milling is that any material can be used. For example, tooling board for models that have to be finished in high gloss paint, or various engineering plastics for prototypes requiring certain material properties. In Figure 1 a good example is presented: a perfume bottle, CNC milled in transparent perspex. After milling it has been polished and finished with a cap and lettering. It is impossible to create models like this using a layer oriented RP system. The actual milling in perspex can been seen in Figure 2.

DeskProto is very well suited for concept modelling for a number of reasons. Firstly, no perfect solids are needed to create a prototype. In most cases the first design concepts for a product shape are created using surface modellers like Alias™ and Pro/Designer™. DeskProto will accept the still incomplete geometry from these 3D CAD systems to calculate CNC toolpaths. Secondly, both material and accuracy can be chosen to produce 'quick and dirty' models. For instance, when using light foam and a large distance between the toolpaths, the model will be ready within a coffee break (at very low material cost, which is important for concept modelling as well). Or a complex detail can be accurately milled in tooling board, to evaluate the surface quality. The third and final reason is the low investment needed. A concept modeller needs to be readily available at the designer's own desk without a queue. To make this possible the system has to be idle most of the time, which is only feasible in case of a cheap system (compare this to your 'personal deskjet printer').

A special type of concept modelling is the use of RP for educational purposes. When training students in using CAD/CAM technology, the three criteria just mentioned are valid as well, in a slightly different form. Students are known to produce incomplete CAD models, due to their inexperience and to the limited time available to do the course. The possibility of producing 'quick and dirty' prototypes is valuable for educational purposes, as then during the course two or three subsequent models can be produced for each student, prototypes that really support him/her in achieving a good end result. The DeskProto system even enables the students themselves to operate the system and produce the prototypes, offering valuable experience in both RP and CNC milling. Obviously the low investment needed is important for schools as they are known to have limited budgets. Several universities worldwide have included DeskProto in their programmes.

While as stated before DeskProto has not been designed to suit the advanced needs of mouldmakers, it can nevertheless very well be used for (rapid) tooling applications. A number of current users have proved this in commercial projects. Current tooling applications include:

- Small series produced by (vacuum) casting in a silicone rubber mould, created from a CNC milled master prototype;
- CNC milled moulds in tooling board for vacuum forming and hand-layup in polyester. Two typical current DeskProto users in this field are a chocolate mould manufacturer and a packaging company that rapidly creates blister packagings;
- CNC milled tools in special tooling board for sheet metal forming. This material can be easily polished after milling, and is then ready for use in the sheet metal press;
- Models in foam or wax for lost foam/wax metal casting processes. DeskProto is known to be used to cast aluminium using the lost foam process, and to cast jewellery in gold or silver using lost wax;
- CNC milled aluminium tools for small series injection moulded parts. DeskProto can be used here to create

CASE STUDIES

Case 1

One of the specialities of design bureau Sinot Design Associates in Hoofddorp, the Netherlands, is the design of new perfume bottles. The bottles are designed using Alias™ CAD software, capable of calculating superb presentation renderings. However, in order to present a new design to the customer for evaluation, a physical prototype is needed as well. SDA's model shop uses DeskProto and two desktop CNC milling machines to produce these models.

Case 2

Delft University of Technology in the Netherlands offers education for an academic degree in Industrial Design Engineering. One of the courses given is CAD modelling of complex surfaces, including the creation of a few foam models of the resulting geometry. Currently both Amapi and Rhino3D are used as CAD systems, and DeskProto for the prototyping part. The examples in Figures 4 and 5 show the results achieved by student Sonny Lim. He modelled a futurist motorbike, using the Honda Zodia design study as a lead. Obviously (as it is a short course only) this is one of the more detailed resulting models. In addition to Amapi he used 3D Studio, to model the engine and to calculate renderings. The resulting geometry from 3D Studio could be easily processed by DeskProto.

CASE STUDIES

Case 3

The examples in Figures 6 and 7 show a production mould created using DeskProto by Molds Direct (in West Jordan, USA). The product is a small (40 x 25 x 15mm) mouthpiece of a flexible plastic, part of a water dispensing system for endurance athletes (courtesy of Ultimate Direction, in Rexburg, USA). Interesting detail in this project is that DeskProto was applied due to geometry exchange problems using IGES, SAT and STEP files. The mouldmaker said: "Fortunately DeskProto rescued us."

Figure 6: This electrode, to create the cavity in a production mould, was milled using DeskProto. It has been used for the mouthpiece presented in Case 3 (courtesy of Molds Direct and Ultimate Direction).
The core of the mould was directly milled in tool steel using DeskProto.

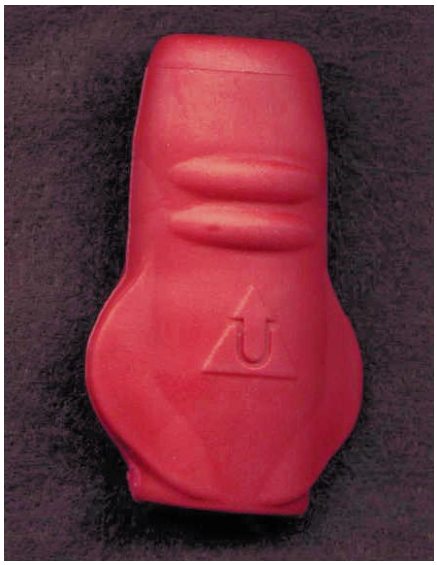

Figure 7: The resulting silicone mouthpiece, created using the mould in Figure 6.

both cavity and core. For all other operations, as needed for the coolant channels, the guiding pens, etc, an additional simple 2.5D CAM package must be used. Recently a special tooling board has become available for prototype tooling as well;

- Electrodes for spark erosion – to be used to create production tools in steel. In fact DeskProto can also be used to directly mill in steel on a large CNC machining centre: see the application example in Figures 6 and 7.

An application area that is often mentioned with rapid prototyping is reverse engineering. Where in 'normal' engineering a CAD model is created based on ideas only, in reverse engineering a CAD model is created by accurately measuring an existing physical product. The 3D scanners used to measure the existing product produce a cloud of point data. It is quite difficult to convert such data to a valid CAD model consisting of NURBS surfaces and/or perfect solids. In contrast it is very easy to convert the point cloud data to an STL file: the basic file type for DeskProto. The car model shown in Figure 8 is a perfect example: without DeskProto it would have been a very complex and tedious job to transform the scan data to surfaces – with DeskProto the job proved to be an easy one.

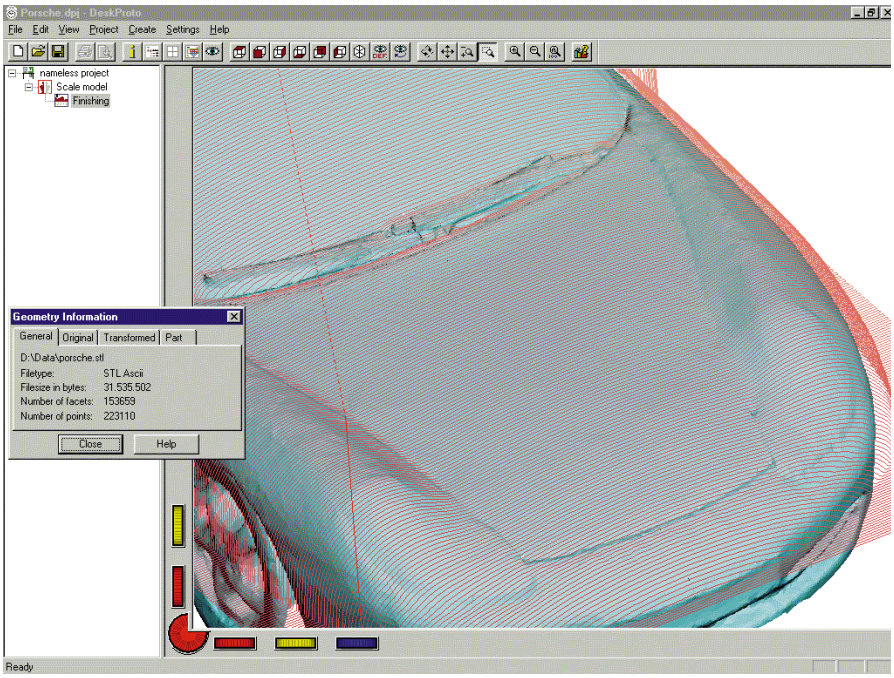

Figure 8: This DeskProto screen shows the scanned data, and part of the finishing toolpath (courtesy of Eurometric)

CASE STUDIES

Case 4

Figures 8 and 9 show reverse engineering in practice at Eurometrics NV in Belgium: a scale model car has been scanned to create a model on a different scale. The example may seem simple as the geometry of the complete car is seen as one part instead of an assembly – in fact it is quite complex. The freeform geometry has to be represented very accurately (high surface quality), resulting in a massive amount of data (STL file of 30MB). Fortunately this data does not need any further processing (except of course the scaling); DeskProto will calculate the toolpaths directly on the output of the scanner software.

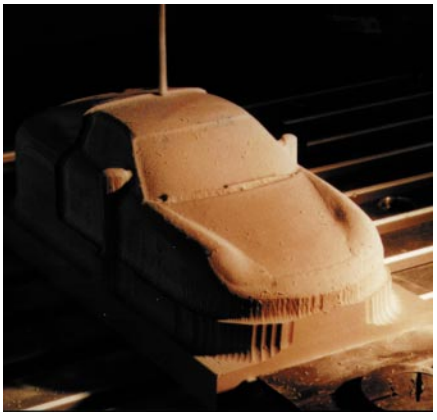

Figure 9: Milling the top of a scale model Porsche in tooling board. After first roughing, the actual surface is milled