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BRITE/EURAM 4527 PROBES
Surface modelling and quality control system for
manual and automatic co-ordinate measuring
machines

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Surface Modelling and Quality Control System for Manual and Automatic Coordinate Measuring Machines

Publishable Synthesis Report

Katholieke Universiteit Leuven, Belgium
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Abstract

This report presents the main objectives and major developments made through an European Brite-Euram research project on *Surface Modelling and Quality Control System for Manual and Automatic Co-ordinate Measuring Machines*. Some of the main achievements and key techniques are summarised. The project aims advancing the technology available for three-dimensional co-ordinate measuring machines.

Introduction

Recent development of CMM (Co-ordinate Measuring Machine), CAD/CAM (Computer Aided Design and Manufacturing) systems and CIM (Computer Integrated Manufacturing) have changed fundamentally the quality control procedures. Today, purchasing a CMM is much more than acquiring a piece of mechanical and electronic equipment. It also requires the capability to use local or remote software, networking, CAD/CAM/CIM interfacing, all conditioned by an underlying philosophy and organisation of quality control. There is, however, still a gap between this philosophy and practice. The application of CMM suffers a lot of limitations, especially in the field of model, mould and die making industry where CMM'S are extensively used for both quality control and creating CAD models from physical parts.

In the quality control domain, only the inspection of mechanical parts, characterised by classical analytical features (line, circle, ellipses, planes, cylinders, cones, etc.) is well solved and present on a variety of commercially available systems. Some of these software is already integrated into several CAD/CAM systems, e.g., Valisys in CATIA and UNIGRAPHICS, Quindos in Euclid, . . . Relatively less work has been done for free-form surfaces which are often encountered in model, mould and die making industry. Powerful, automatic and intelligent systems are required for free-form measuring path planning. Preferment filtering and fitting algorithms are needed for reducing errors during free-form shape identification.

For digitizing and modelling sculptured workplaces from physical parts using CMM's, several software, e.g., Zeiss HoloS, DEA Surfer, Renishaw MEATRACE and MEASURF, etc., offer partial solutions. These software, however, have only limited degree of automation and require a lot of interactive operator intervention. They are consequently manageable only by a CAD-specialist. Moreover, they don't solve many of the critical problems related to digitizing and surface modelling. Among others, the reduction of measuring errors, the selection of measuring point location and density, the detection of comers and edges, automatic selection of measuring probes, automatic subdivision of object in surface patches, local surface updating, treatment of randomly measured points and the integration into a CIM environment are of great interests in this context.

The application of CMM's in model, mould and die making industry suffer also hardware problems, especially for small and medium sized companies (SME's). Practical application requires the use of manual or automatic measurement, mechanical contact or optical non-contact measurement, point by point or continuous scanning measurement. These various techniques, nowadays, normally are undertaken by different CMM's or CNC controllers, More machines imply more cost. This is not

favorable for SMES due to the limitation of financial resources. Another critical issue is the environmental conditions. For a model, mould or die maker, a CMM is most probably located on site in the workshop. This may deteriorates the conditions demanded by such precision measuring machines.

Started in January 1992 and termed for three and a half years, the European Brite-Euram project *PROBES: Surface modelling and quality control system for manual and automatic co-ordinate measuring machines* was set up to provide more alternatives and to solve many of the above mentioned problems.

Objectives and Industrial Benefits

The main objective of the project is to advance the technology available for three-dimensional co-ordinate measuring machines. It develops a set of software and hardware tools for performing different types of measurements on free-form surfaces or objects. The software tools form a complete CMM based modular system, made of a cluster of CAD/CAQ application software and standard interfaces allowing for an integration into a CIM environment. The system is able to perform all surface digitizing, modelling and inspection tasks needed in a model, mould and die shop. The hardware development include a new concept of CMM for workshop environment and a flexible and low cost CNC controller. The developments include :

- A software module **INSPEC** has been developed for off-line measurement of known free-form features. **INSPEC** generates **DMIS** commands for controlling the movement of a **CMM**.
- An software product **SURFEYOR** for on-line measurement of unknown free-form features has been developed. This software uses triangulation principle and adaptively measures the unknown workpiece according to prespecified criteria.
- A software product **SHAPID** (**SHAPE** Identification) for surface modelling based upon digitised data of a CMM machine and upon advanced smoothing and fitting algorithms. Original algorithms have been developed for **NURBS** curve and surface fitting and interpolation. The software is also able to process randomly distributed points and to eliminates random errors generated during the measuring cycle.
- Standard interfaces for data exchange between the developed software modules and other CAD systems are developed. Interface modules interfacing the developed software with existing CAD/CAM systems and co-ordinate measuring machines are also developed. In particular, **BM**-interface was used to communicate between the developed software and **UNIGRAPHICS**, a product of **EDS**. A neutral CMM interface driver was developed for interfacing the developed software modules with CMM machines.
- Hardware developments for co-ordinate measuring machines: This part include mainly the CMM design feasibility study and the development of a PC-based CNC controller for quality control and surface digitizing.

The complete architecture of the development is illustrated in *Figure 1*. In this figure, the **SURFEYOR** module performs the on-line adaptive digitizing of unknown workpiece. **SHAPID** is the **NURBS**-based surface modeler using digitised data coming

from a CMM. Inspection) is the module for manual and CNC inspection. Other elements of the system include the CMM hardware and the above mentioned interface modules. These developments will lead to dramatic shortening of the overall time when dealing with sculptured workplaces.

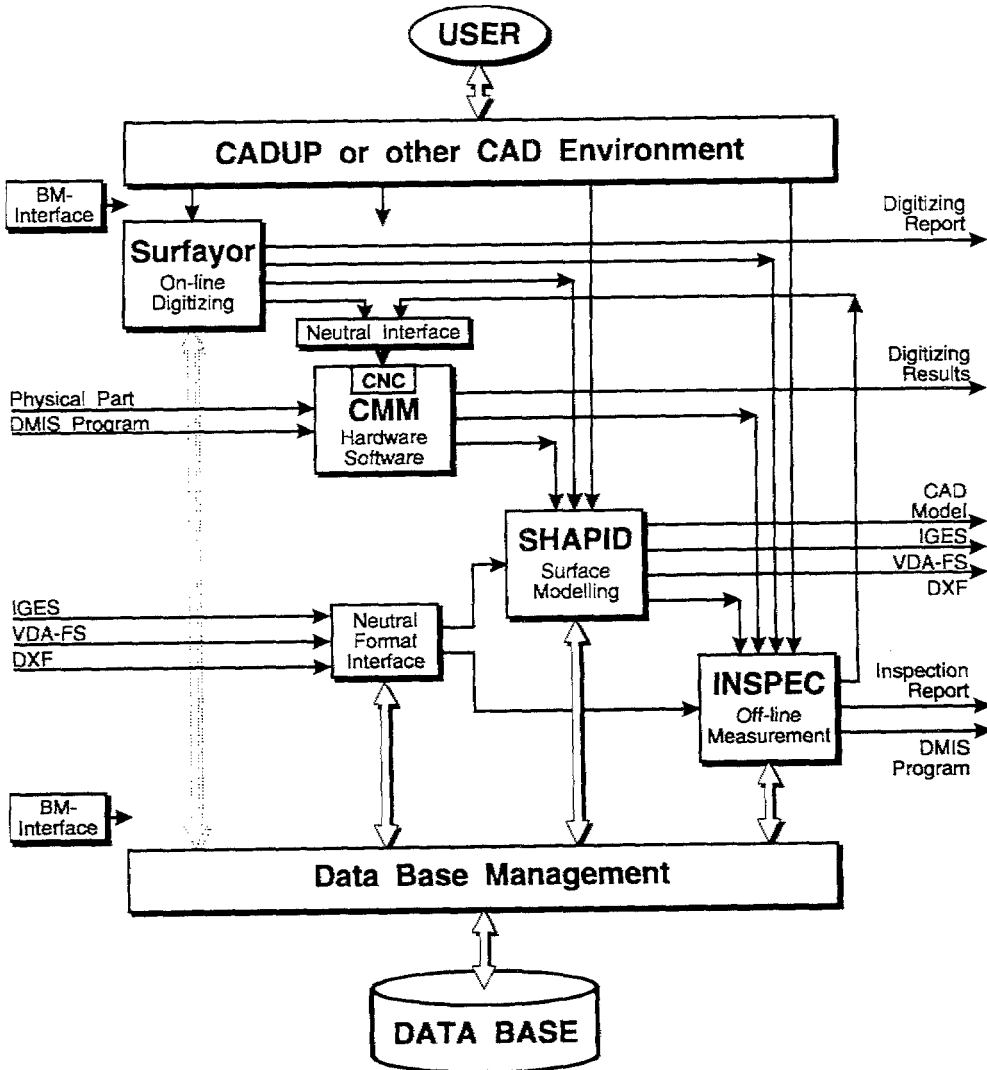


Figure 1: Overall architecture of the project

Potential users encompass model, mould and die makers, stylists, designers, prototype makers, manufacturers of fixtures and assembly equipment's. The addressed industrial sectors include the automotive and aeronautic industry, the design and manufacturing of TV-sets, computer boxes and telephones, household appliances, shoes, tires, turbine blades, fans, toys, machine tools and furniture.

Basic Strategies for Achieving the objectives

In this section we further report on some strategies applied to achieve the afore- summarised objectives.

Inspection

For inspection, we try to integrate the developments made through the project with existing solutions. Manual inspection and reports are integrated with Coord3 measuring software Winmeil. Results for off-line programming are integrated with both CAD-UP on PC environment and UNIGRAPHICS on VAX/VMS platform.

Overall Strategy for CAD modelling

The basic strategy to create a CAD model of a sculptured workpiece from its physical model is illustrated in *Figure 2*. The procedure begins with the digitizing of the physical workpiece by using a Co-ordinate Measuring Machine (CMM). An own developed software SHAPID is then applied to identify all kinds of geometrical features from digitised data of CMM's. A standard CAINCAM software is used to complete the CAD model using ordinary CAD techniques, like trimming and surface matching. The kernel of this approach is the identification of different kinds of features directly from digitised data of CMM.

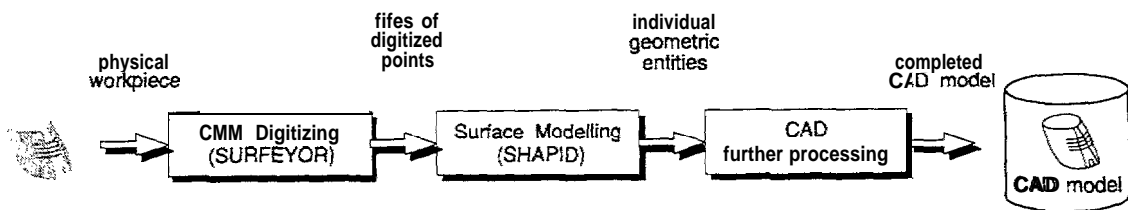


Figure 2: Basic strategies for CAD modelling

Digitising Strategies

As shown in *Figure 3*, three different digitizing strategies are currently used:

1. *Manual Digitising*: The first solution can be realised by digitizing the workpiece manually or using the build-in TEACH-IN possibilities of a CMM. This method is simple and the set-up time is short. It is, however, a time consuming work if a large number of points are to be digitised.
2. *Automatic Digitising with Off-line Programming Environment*: With this alternative a rough CAD model is first created from limited number of digitised points of the workpiece. These points are usually selected to represent roughly the boundaries of the workpiece. Based on this model, a measuring path can be generated and saved in DMIS (Dimensional Measuring Interface Specification) format. The CMM then digitises automatically the workpiece using the measuring path.
3. *Adaptive Automatic Digitizing*: This strategy can be used for digitizing unknown workplaces. The measurements are done adaptively following a triangulation strategy.

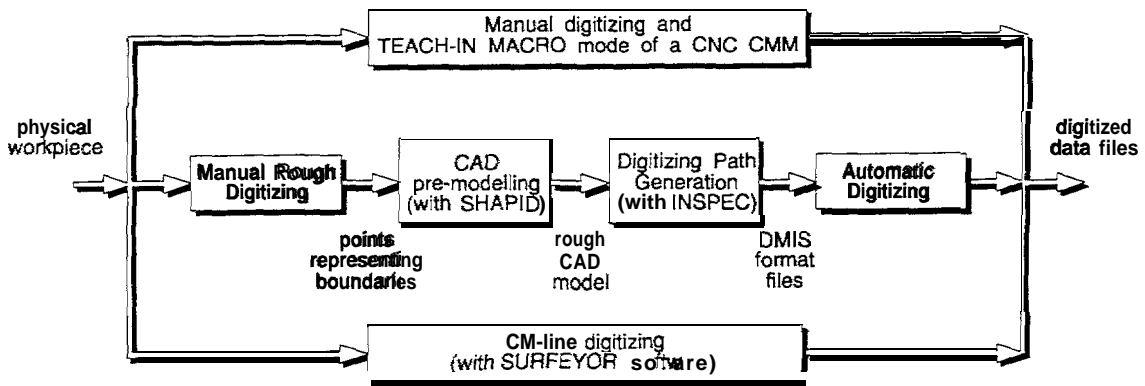


Figure 3: Digitizing strategies

The selection of the digitizing method depends on what kind of CMM machine is available, what kind of workpiece is to be digitised and how many times the digitizing process has to be repeated. During the project, different machines have been used. These machines include Coord3 machine, MITUTOYO machine and DEA machine.

Mathematical Modelling

For the representation of free-form curves and surfaces, many alternatives exist. Among others, Non-Uniform Rational B-Spline (NURBS) curves and surfaces have now been widely accepted due to their nice properties. The most important properties are the local support property and its potential to represent conical and other complicated shapes, or even shapes with discontinuity problems. A NURBS curve is defined as

$$P(u) = \frac{\sum_{i=1}^n [P_i \cdot w_i \cdot B_i(u)]}{\sum_{i=1}^n [w_i \cdot B_i(u)]}$$

in which $b := \{B_i(u) | i=1, 2, \dots, n\}$ are the normalised B-splines. They are completely defined by the order k (degree $k-1$) and a knot sequence $t := \{t_i | i=1, 2, \dots, n+k\}$.

$$a = t_1 = t_2 = \dots = t_k < t_{k+1} \leq t_{k+2} \leq \dots \leq t_n \leq t_{n+1} = \dots = t_{n+k} = b$$

Similarly, a NURBS surface is defined by

$$P(u, v) = \frac{\sum_{i=1}^{n_u} \sum_{j=1}^{n_v} B_{ui}(u) \cdot B_{vj}(v) \cdot w_{ij} \cdot v_{ij}}{\sum_{i=1}^{n_u} \sum_{j=1}^{n_v} B_{ui}(u) \cdot B_{vj}(v) \cdot w_{ij}}$$

in which

- $P(u, v) = [x(u, v), y(u, v), z(u, v)]^T$ is a point on the NURBS surface.
- u and v are *location* parameters defining the location of point $P(u, v)$ within the length and width of the surface.
- n_u and n_v are the number of control points along u and v direction respectively.

- $v_{ij} = [x_{ij}, y_{ij}, z_{ij}]^T$ with $i = 1, 2, \dots, n_u; j = 1, 2, \dots, n_v$ are the n_u times n_v control points controlling the shape of the NURBS surface.
- $w = [w_{11}, w_{12}, \dots, w_{1n_v}, w_{21}, \dots, w_{n_u n_v}]^T$ is a set of weights allocated to the control points.
- $b_u = [B_{u1}(u), B_{u2}(u), \dots, B_{un_u}(u)]^T$ is a set of normalised B-spline functions for the u direction which is uniquely defined by the order k_u and a knot sequence t_u of the NURBS surface. The value of $B_{ui}(u)$, and later $B_{vi}(v)$, for fixed u or v respectively, can be evaluated with the recursive Cox-de Boor algorithm
- $b_v = [B_{v1}(v), B_{v2}(v), \dots, B_{vn_v}(v)]^T$ is a set of normalised B-spline functions for the v direction which is uniquely defined by the order k_v and a knot sequence t_v .
- $t_u := \{t_{ui} | i = 1, 2, \dots, n_u + k_u\}$ is the u knot sequence.
- $t_v := \{t_{vi} | i = 1, 2, \dots, n_v + k_v\}$ is the v knot sequence.

Strategies for LSQ fitting from Digitised data of CMM's

For the identification of sculptured surfaces from digitised data of CMM's, most of the currently available CAD/CAM systems use interpolation techniques and generate the features through all the digitised points. The main drawback of this is that the interpolated surface may not be stable due to the random errors contained in the digitised data generated during the digitising process. A better choice should be least-squares fitting techniques.

Two different LSQ fitting strategies are currently used. The first strategy applies to analytic features. In this case there are relatively few number of parameters to be identified compared with free-form features, usually less than ten. The identification is realised by minimizing the sum of fitting errors measured as the normal distance from digitised points to a fitted feature. There are different least square definitions. For free-form surfaces, following definition is used.

$$\underset{X}{\text{minimize}} F(X) = \sum_{i=1}^m \|f_i(X)\|_2^2$$

Where

$$f_i(X) = 0$$

is the mathematical model of the underlying surface. X is a vector containing the *definition* parameters with which the underlying surface is uniquely defined. $f_i(X)$ is called the i -th observation of the mathematical model. In this way, the least square solution of NURBS curves and surfaces is directly defined from digitised data of coordinate measuring machines. For a NURBS surface, which is a parametric surface, there are a large number of unknown definition parameters to be identified. Moreover, there is no unique LSQ NURBS surface: the number of definition parameters used to describe the surface is not defined uniquely and there may be an infinite number of parameter sets and solutions.

Further CAD processing

All the identified features can be further processed with ordinary CAD techniques. These techniques include offsetting of the fitted surfaces for probe radius compensation, extension and intersection of surfaces for further trimming, trimming and smoothly matching of adjacent surfaces to complete the CAD model. This step can be done by most of the existing CAD/CAM systems.

CMM Feasibility Analysis

The objectives imposed by the project have induced a total redesign of the structures of the new machines in order to be executed in light materials like the aluminium alloys, Alternative materials have been used for some machine parts, like the carbon fibres, according to the filament wiring technology. On a production plan, the use of light alloys needs strong initial investments and great fixed assets in production equipment like foundry models and wiredrawing dies. On a business strategy point of view, the consequence is to induce to the increase of produced units on one hand, and to keep common parts in different models of machine on the other. On an economic point of view, a resort to these solutions involves a 3593 saving as of traditional technologies.

The reduction of the number of parts which form the family of new machines has been 15%. This reduction had advantages on costs and supply times, and it is in agreement with the need to make more reliable machines while reducing the number of critical parts. The planning has been especially executed on those parts which have been subject to most frequent maintenance interventions, after an analysis of Pareto curve which has been made on after-sale services.

CNC Development

Coord3 has identified all the specific features related to the general use of a CNC and the one especially addressed to the measuring machine. The analysis threw light on the trend of the system for axes control and gave a good outline of the market offer. A lot of the performances of the numerical control available nowadays on the market are also required for CMM's, while others are not available among the basic functions of these numerical control and must be implemented by the CMM manufacturer directly. The technology selected for the hardware was based on the DSP 24 bit microprocessor due to the signal processing speed achievable on this class of devices.

Based on this kind of hardware, the company developed a dedicated set of drivers for the basic and the special functions of the numerical control. The axes control was worth of a lot of care, in order to achieve the best metrological behaviour from the mechanics. The axes motion quality must be very smooth to avoid dynamic stress to the machine structure. Therefore a full proportional-derivative-integrative control system (PID) was developed, able to calculate the acceleration deviate (jerk) value and to use it in order to achieve a reasonably smooth motion. Different motion profile have been set and tested in different mechanical condition by using CMM'S having different strokes, different driving system (more or less rigid), different resolution (from less than a micrometer to 10 micrometers), different probe sensitivity. The kinematics

profiles obtained during some measuring task of the machine have been gathered and analysed by means of a dedicated software utility, running with the motion control software.

The need to easily adapt the new numerical control to any CMM in order to achieve the best performances, presses the company to develop a special software module for the set up of the system with a fine adjust of the main motion parameters. This sub-product of the numerical control allows a sort of auto-tuning of the system after the installation, and can be used by any technician even not specialised.

Probes Interfacing

An hardware configuration is chosen, able to be interfaces with different probes, trough trigger and analogic signals. Tests on commercial optical probes are only performed on a beam laser sensor, like Opimess and Wolf&Beck. Some hypotheses babe been made about the type of calibration devices that should be used for such sensors in order to be easily oriented in different positions, maintaining good accuracy.

Technical Achievements

INSPEC: Implementation for Part Inspection

This module can be used to generate a measuring path automatically using an existing CAD model. The generated path is then saved in a DMIS (Dimensional Measuring Interface Specification) format file. Co-ordinate measuring machines can then execute this path to digitise the workpiece. The results of digitizing are feedback to the software and may be used for either surface modelling (with SHAPID) or for inspection. In the latter case the deviations from the digitised points to the nominal shape are evaluated and statistical information is provided. Some basic features of this module are:

- *Probe definition:* Probes can be defined prior to the generation of measuring path. The maximum number of probes is unlimited to the software.
- *Select area to be measured:* The user is prompted to select a surface with the mouse from the screen. The measuring area can be further delimited by u and v parameters. The number of points to be measured can be selected by the user.
- *Path planning and automatic probe selection:* The program will automatically generate the measuring path and select probes well suited for a particular region to be measured. The selection is based on the inclination of the surface to be measured.
- *Measuring path optimisation:* The final measuring path will be optimised in such a way that the total measuring time is the shortest, the length of the probe movement is the shortest and the number of probe changes is the smallest.
- *Strategies for collision avoidance:* Strategies are currently implemented to avoid collisions between the measuring probe and the part to be measured. This is

mainly realised by the introduction of several global parameters, like approach and retract distance, and two kinds of retract planes.

- **DMIS Output** : The final measuring path is saved in a file with DMIS format. Any CMM having a DMIS interface can then execute this path.

See figure *Figure 4* for an illustration on CNC measuring path planning. Some of the results on this part of work were presented at the CAPE9 conference in July 1993 [1]. See Annex D for more information.

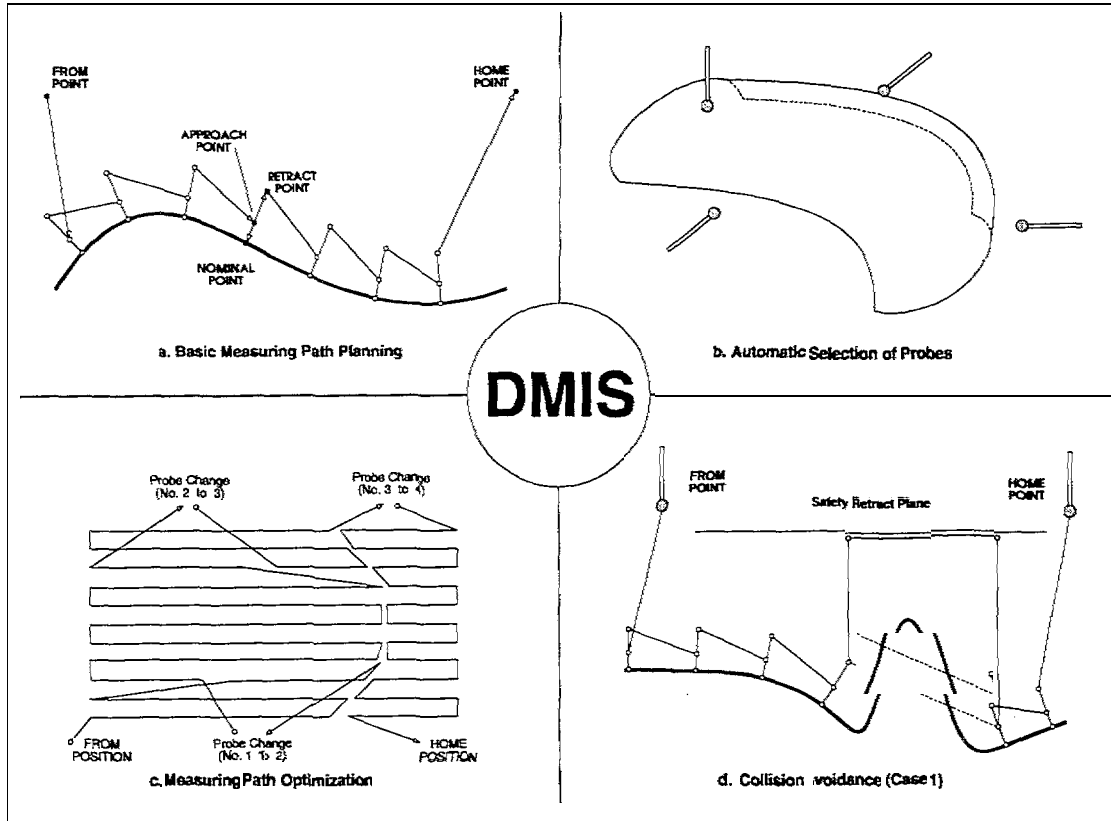


Figure 4: path planning

For better integration in the PC environment, a new version of INSPEC is now available on the PC platform under MS-Windows. It uses the graphical interface of CAD-UP,

WINMEIL: Manual Inspection and Reporting Modules

Measuring machines cannot be used without a proper measuring software. The common inspection software's have not to be particularly open because they should communicate just with the machine or with some special software module achievable from any CMM manufacturer when the basic packages are not enough. This fact makes those software products very closed and difficult to interface with any external package. It must be considered that the typical features of the CMM's have to be available even if the main task of the machine is measuring or fitting of surfaces: they are commonly used for the starting operation like creating a reference system and

measuring fundamental geometrical parts (holes, planes, straight lines and others). From this point of view the inspection software can be considered as the main module, carrying out of the basic operation and managing the element data base, that has to be shared with any other application. Another important integration takes place between the inspection software and the numerical control: any step of the machine motion is set by the part-program that belong to the inspection module list of functions.

The development of the inspection module started from an existing measuring software by a new data base structure. Before adding new capabilities to the main measuring modules, the developers have tested carefully the algorithms quality, by the use of special data set available from the most important WECC laboratories. The syntax of the language was completely revised, adding every useful command foreseen in the future project job. Every new keyword is as much closer to the standard DMIS as possible, in order to facilitate the portability of the part-programs. As it was pointed out in the work program, the capability to generate different output from the measured data is fundamental for many reasons. The output results are managed in a special software module, called CAD-UP who takes care of the input-output of the measuring results, setting up the inspection report upon different graphical options.

The use of the Microsoft Windows was very helpful in order to make the objectives of this sub-task easier to reach. A few word processors have been interfaced in order to give to the user the possibility to stay in a familiar environment to set up the output data: customised pictures can be imported as well in the final report, giving the widest module creation possibility.

SURFEYOR: On-line digitizing software

To measure a free-form surface of which there does not exist a mathematical or CAD model, only very general scanning techniques or inefficient point-to-point probing is available in today's measuring software. For measuring these unknown complex surfaces, it was necessary to develop a more intelligent software to control the machine. The objective of this task was to make the measurement process for unknown free-form surfaces highly automatic. Therefore an on-line measuring strategy was developed for efficiency purposes, that takes into account the different probes and controllers available. This software is called SURFEYOR.

The basic idea that is behind SURFEYOR, is quite simple. Initially, the surface is divided into triangles. After that, each triangle is measured (See *Figure 5*). The middle point of each triangle is calculated and measured. Then there are four new triangles, that can be refined in the same way, This recursion has of course to stop somewhere. There are two stop criteria for this. The first defines the global density of the point distribution over the surface, This is achieved by putting a limit on the size of each triangle. The other stop criteria is that there should be enough information in the points that are measured to model the details on the surface. Therefore a curvature dependant distribution of the points over the surface is necessary. This is achieved to put a constraint on the deviation between the calculated mid point of each side and the actual measured point. Basically one could summarise these two criteria as follows:

- There should be everywhere at least some amount of points

- At the bumpy parts of the surface, there should be more points than on flat areas.

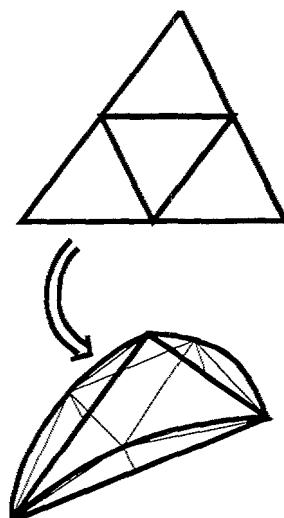


Figure.5: *refinement of a triangle*

The newer achievements concerning SURFEYOR lay in the different initial subdivision of the surface into start-triangles. Experience has learned that the best result -that is the best distribution of measured points over the surface- is obtained if the initial triangles are as equilateral as possible. So the initial subdivision into triangles must give a good idea of the topology of the surface but also the triangles must be as good as possible. Some improvements are made in this field. We certainly believe that even further optimisation of the measuring strategy must be sought in this way.

SHAPID: Implementation for CAD Modelling

A special software package, SHAPID (SHAPE Identification), has been developed for CAD modelling of sculptured workplaces from digitised data of CMM. At the present stage, following entities have been implemented: a line entity with 4 parameters; a circle entity with 6 parameters; a plane entity with 3 parameters; a cylinder entity with 5 parameters; a cone entity with 6 parameters; a sphere entity with 4 parameters; a NURBS curve entity with up to 170 control points and 20th order; a NURBS surface entity with up to 400 control points and 20th order. These NURBS entities include the following kinds of free form shapes: general open curve, general closed curve, general open surface, general open-closed surface (i.e., cylinder-like surface, which is closed in one of the u or v parameter directions) and general closed surface (i.e., torus-like surface, which is closed in both of the u or v parameter directions).

SHAPID can be divided into three parts. The first part, SHAPID native main frame, is a mini-CAD software package with user and graphical interface, database management and other supporting modules. The second part, SHAPID least square fitting modules and supports, include all subroutines for the least square fitting of the above mentioned regular features and free-form features. This part is the essence of SHAPID. It can be accessed from a single entry. Part three is intended for interfacing the essence of

SHAPID with the user and graphical interface and the database management modules. The following figure shows the modular structure of SHAPID.

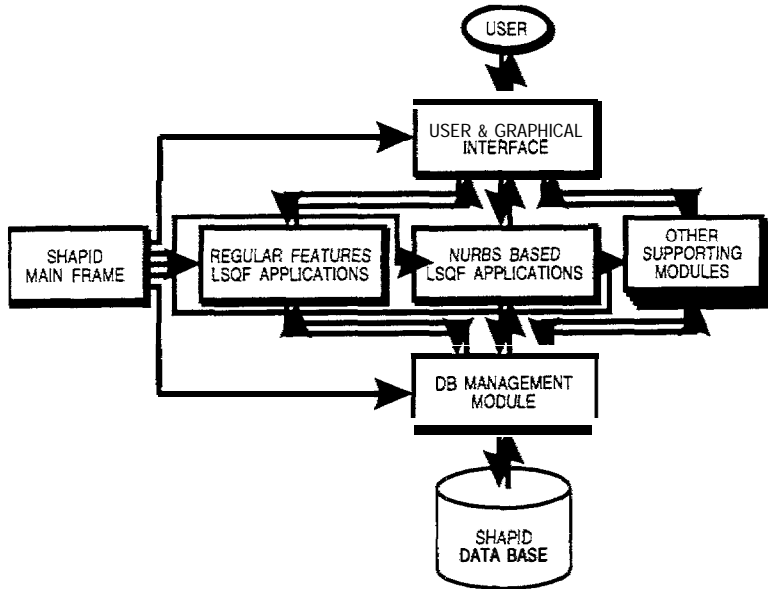


Figure 6: Modular Structure of SHAPID

Due to its modular structure, SHAPID can also be easily integrated into any foreign CAD/CAM software. Integrating SHAPID with a foreign CAD/CAM software implies the integration of the main part of SHAPID into that software, not all the supporting modules as most of which can also be found in standard CAD/CAM software. There are only three entries to access all least square fitting subroutines for regular features, the NURBS curve and the NURBS surface respectively. As shown in the following figure :

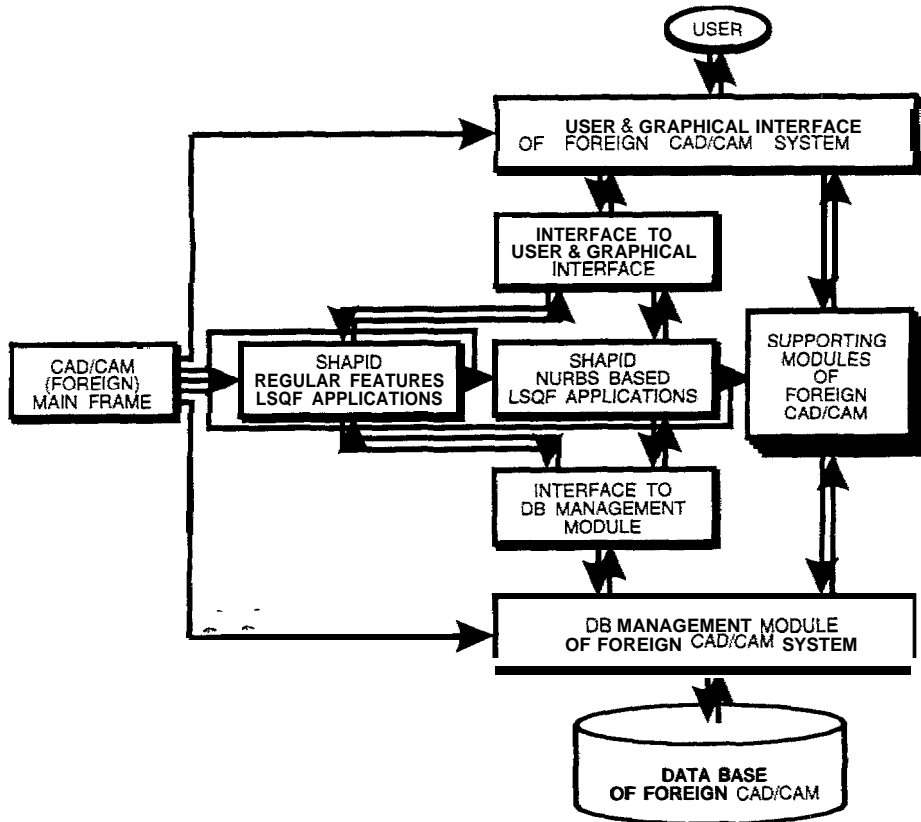


Figure 7: Interfacing SHAPID with a Foreign Software

On the VAX/VMS platform, SHAPID has been successfully integrated with UNIGRAPHICS, a product of EDS. SHAPID was also partially transported to the PC platform under the environment of an own developed CAD environment, CAD-UP.

Interface Modules

Interface modules integrate the developed software modules into an complete environment with graphical and user interfaces. There are two interfacing problems :

- Interfacing of the developed software with existing CAD/CAM systems.
- Interfacing for geometry conversion among different CAD/CAM systems.

Supporting modules for geometry transformation through neutral format interface, e.g. IGES, VDA-FS, and DXF have been developed. As mentioned in previous tasks, there are three different working environment. VAX/VMS and UNIX environment provide the complete package for surface modelling and inspection application. The PC platform provide an integrated environment for both digitizing, surface modelling and inspection applications.

CMM feasibility Study

The design and the manufacturing of a small machine applying the above listed technologies allows to practically test the different solutions. Some tests have been carry out to compare the behaviour of a small size granite machine and the new one,

providing information regarding the accuracy in a non-conditioned environment and the medium term stability of the new structure. Also from the point of the manufacturing process, the machine had a much shorter assembly time than the conventional machines, even though it was a prototype.

CNC development

The development of an electronic (mainly digital electronic) system is strongly conditioned by the technological progress achieved on the market during the research time. Considering the state of the art of the market we can claim that the technological contents of the project are still innovative also regarding the electronically devices developed in the last three years. Furthermore the achieved results seems to be easily adaptable to any industrial production, with a considerable economical advantage in relation to the actual technology, The motion control technology reached by the project satisfies completely the requests of the modern measuring machine market. The software structure was conceived in such a way to make easier the extension to the functions that are still not enabled at this moment.

The developed prototype consist of few functions not previously foreseen. In particular, a macro-language with a meta-command syntax has been developed, to be able to face directly with the production line. Thank to those last developments, a series of functions are now available, able to manage: workpiece automatic feed (loading and unloading) to the measuring machine; workpiece identify by using bar code or other read-only devices; line status analysis; reading of the different condition coming out from peripheries like safety barriers or others.

Probes Interfacing

Deep market researches have been made in order to value some products of recent sale on the European market. The work of inlet-facing of different types of touch probes has been made easy by the statement of the CNC project (task 8) in which we had already considered the need of using non-conventional sensors for measuring machines.

In this task, a series of electronic cards have been developed in order to permit the use of different touch probes on the same machine. At this moment, the research is addressed to the use of telecamera systems for measuring on sheet metal parts principally.

Conclusions

A project has been described that aims the development of hardware and software tools to further enhance the application of co-ordinate measuring machines and especially to satisfy the needs of the SMES as model, mould and die makers. Prototypes of software and hardware have been developed. The implemented software modules are mainly used for automatic digitizing with CMM's, CAD modelling from digitised data points and product inspection. These developments will be further investigated and enhanced within the project. Future development will focus not only on basic functions but also on system integration and a higher level of automation and flexibility.

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- COORD3 SAS di Berri C, Turin, Italy,
- Dicomol SA, Barcelona, Spain,
- Ateliers Gilbert Garcia, Paris, France, and
- STOLA Spa, Turin, Italy.

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