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Architecture and implementation of a shop-floor programming system for STEP-compliant CNC

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Abstract

STEP-NC (formalized as ISO 14649 and ISO 10303 AP238) is a new interface (or language) standard for the CAD–CAM–CNC chain, currently under establishment by ISO TC184 SC1 and SC4. Upon completion, it will replace ISO 6983, so called M & G codes used for CNC since 1950s. As the new language is being established, a new CNC controller called STEP-CNC (STEP-compliant CNC), capable of carrying out various intelligent tasks using the new language as an input, receives worldwide attention. Shop-floor programming (SFP) system is a computer-assisted part programming system interfaced with STEP-CNC. Its primary function is to generate part program in ISO 14649 (or STEP AP238) to machine the part geometry given by STEP AP203 or AP224 file. In this paper, we first present an architecture for the SFP system, followed by implementation technology including: (1) STEP physical file interpretation, (2) feature recognition, (3) process planning, (4) part program generation, and (5) verification. The developed methodology was implemented in a prototype called PosSFP, and tested with Korea STEP-NC system.

Keywords: STEP; Numerical control; CNC; ISO 14649; ISO 10303 AP238; Shop-floor programming

1. Introduction

Since numerical control technology was developed in early 1950s, it has undergone significant advancement to an extent that high speed machining with ultra-high precision is realized. However, contemporary CNC still needs further improvement especially to cope with the information-based modern manufacturing system, such as E-manufacturing. In particular, the current CNC language, so called M & G-codes (formalized by ISO 6983) which has been used since 1950s, is a low level language mainly specifying the cutter motion in terms of position and feed rate. Since it delivers only limited information to CNC (excluding the valuable information, such as part geometry and process plan implicated in the NC code), it makes CNC nothing but an executing mechanism completely unaware of the motions being executed [1]. Furthermore, since the G-code is exclusively used for CNC, it makes CNC isolated in the shop floor without understanding high level information such as STEP used in other manufacturing functions, such as CAD, CAM, CAE, PDM, etc.

Recently, a new and comprehensive language for CNC, called STEP-NC is under development by ISO TC184 SC1 and SC4. The new language to be formalized as ISO 14649 [2] and ISO 10303 AP238 (Note that ISO 14649 is ARM version, and ISO10303 AP238 [3] is AIM version of ISO 14649), is based on the product model STEP (ISO 10303) incorporates process plan information. As described in Section 2, ISO 14649 specifies information contents and semantics for various CNC manufacturing processes. It is currently available as a Final Draft for International Standard (FDIS) version, with its IS version to be completed soon. Upon completion, it will become a new CNC language replacing ISO 6983.

As the new language is established, increasing attention is being paid to the development of a new CNC, STEP-CNC (or STEP-compliant CNC), operated based on ISO 14649. Since the new language accommodates various information of 'what-to-make' (i.e. product information including 3D geometry) and 'how-to-make' (process plan), the STEP-CNC can undertake various intelligent functions which cannot be performed by the conventional CNC operated

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based on ISO 6983. Suh et al. [4] derived intelligent functions that can be realized by the STEP-CNC taking ISO 14649 as an input, and presented an architecture together with an operational scenario. Among the various technologies that need to be developed to materialize such a STEP-CNC, the shop-floor programming (SFP) system is a key component.

In essence, SFP is a computer-assisted part programming system for ISO 14649. Unlike for ISO 6983 part program, SFP system is required for ISO 14649 due to: (1) different interface scheme between CAM and CNC, (2) rich information, and (3) complicated syntax which cannot be edited by manual programming. Previously, there have been many kinds of computer-assisted part programming systems, run either off-line (i.e. CAM system) or on-line (conversational programming system implemented on CNC controller; [5]). However, SFP system based on the STEP-NC data model (ISO 14649) is an emerging technology requiring both theoretical and implementation technology in multiple domains, such as STEP, CAD, CAPP, CAM, and CNC.

In regard to STEP-CNC having SFP function, two systems have so far been reported; (1) NC prototype of Europe presented in 2000 SC4 Meeting in Charleston [6], and (2) Super Model of USA presented in 2001 SC4 Meeting in San Francisco [7]. The former was implemented by wrapping an existing 840D CNC kernel with a newly designed MMI that conforms to STEP-NC data model. The latter was implemented by externally interfacing existing commercial CAM systems with STEP-NC specific modules made by commercial toolkits. The SFP in these systems is implemented as a preprocessor rather than an integral part to the STEP-CNC system.

SFP system is a complex one requiring various capabilities including STEP interface, feature recognition, process planning, ISO 14649 part program generation, and CNC interface. Furthermore, to build seamless integration and to fully exploit practical gains from STEP-NC paradigm, systematic analysis and architecture design are required. In this paper, we first review the information contents of ISO 14649 in Section 2, followed by design considerations and functional architecture for SFP system in Sections 3 and 4, respectively. Based on the presented architecture, implementation methodology together with a prototype development are presented in Section 5, and verification and integration with Korea STEP-NC in Section 6, followed by remarks in Section 7.

2. Overview of ISO 14649

2.1. Brief background

ISO 14649 (and ISO 10303 AP238) is often called STEP-NC, an acronym originated from the STEP-NC Project carried out in Europe (ESPRIT IV 29708). The initial effort on the new data model was made by WZL of Aachen University between 1994 and 1996 as the European Project called OPTIMAL (ESPRIT III 8643). In this project, the data model for 3D milling was investigated based on STEP paradigm, in which STEP data was first used as the basis of interface scheme between CAM and CNC. The STEP-based interface scheme was extended to 2.5D milling and other operations, such as turning and EDM, in the subsequent European Project ESPRIT IV 29708 between 1999 and 2001 [8]. The new interface scheme, having gained worldwide consensus, will be completed by the international consortium composed of Europe, US, Swiss, and Korea early 2002 as an international project IMS STEP-NC [9]. The research results have been formally documented as ISO 14649 and ISO 10303 AP238, respectively by ISO TC184 SC1 and SC4. Currently the overall framework and the milling process are available in FDIS version, and other processes will be finalized in the near future (Phase 2 and 3 in Table 1).

2.2. Information contents and structure of ISO 14649

The data model incorporated in the present SFP system is based on the FDIS version of August 2001 [2]. Although some details need to be changed in the future version, its structure and information contents will be kept. ISO 14649 is basically a structured feature-based representation of process plans for such manufacturing processes as milling operation, turning operation, EDM, etc. Currently, ISO 14649 is under development for milling operation based upon the geometric information of ISO 10303, such as AP 203, AP213, and AP 224. As illustrated in Fig. 1, information contents of ISO 14649 are composed of: (1) *task description*, (2) *technology description*, (3) *tool description*, and (4) *geometry description*. *Task description* describes the logical sequence of executable tasks (e.g. *machining_workingstep*, *NC_function*) and data types. Details of each *workingstep* are covered in the *technology*

Table 1
Current status of ISO 14649 documentation

Part No.	Title	Phase	Publication
1	Overview and fundamental principles	1	FDIS
2	Language bindings, fundamentals	3	
3	Language binding in Java	3	
9	Glossary	3	
10	General process data	1	FDIS
11	Process data for milling	1	FDIS
12	Process data for turning	2	CD
13	Process data for wire-EDM	2	CD
14	Process data for sink-EDM	2	CD
111	Tools for milling	1	FDIS
121	Tools for turning	2	CD

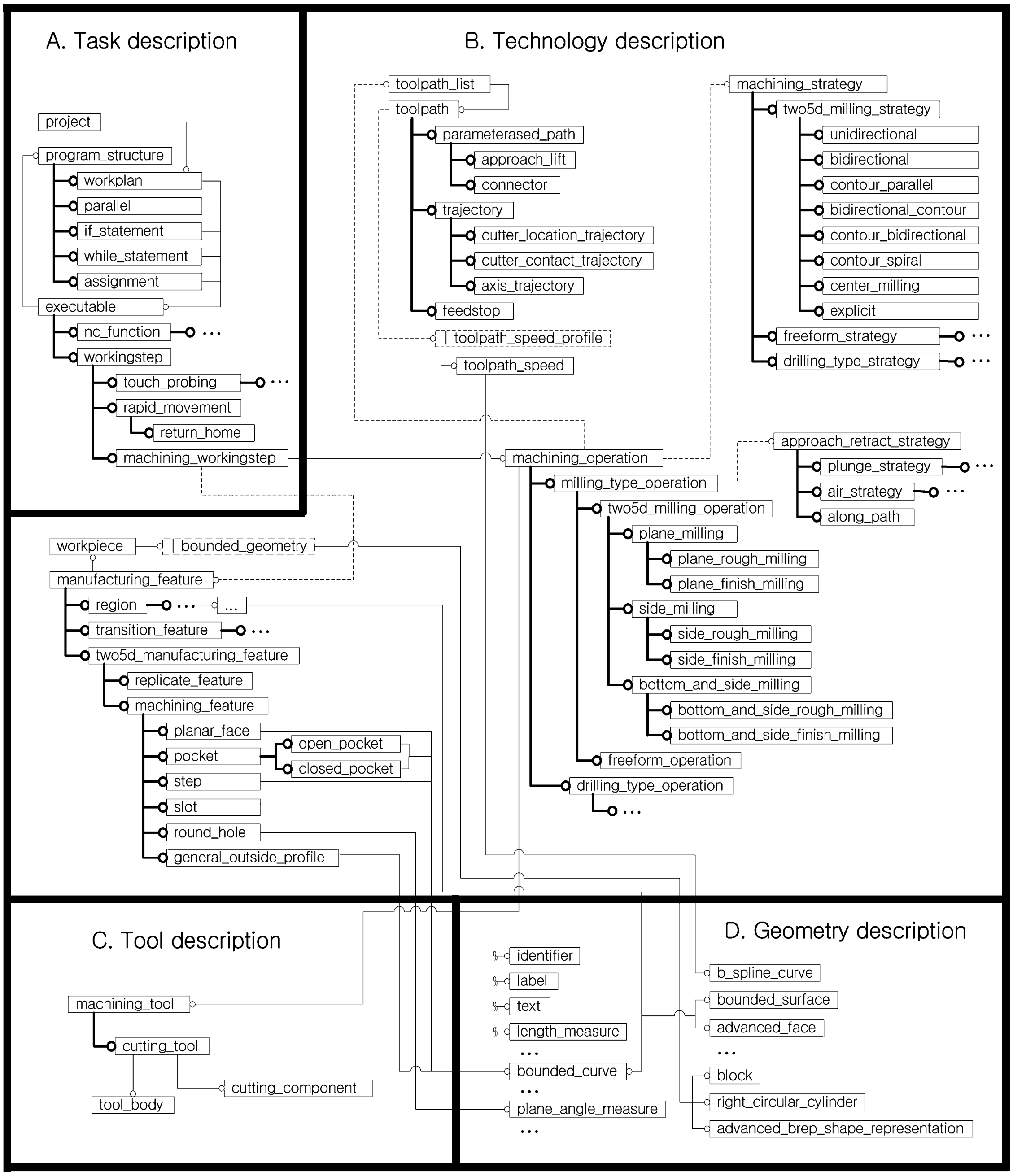


Fig. 1. EXPRESS-G representation of overall schema of ISO 14649.

description in reference with the *tool description* and the *geometry description*.

Specifically, the *workingsteps* include manufacturing features for 2.5D (*two5D_manufacturing_feature*) and 3D milling operations (*region*), and each *workingstep* has its subordinate sub-features (such as *planar_face*, *pocket*, *step*, *slot*, *round_hole*, and *general_outside_profile*) together with cutting condition information. It is important to note that the tool path specification in ISO 14649 is 'optional', unlike in the current NC programming where the tool path in terms of machine axes is the main information content. Thus, the capability of tool path generation is essential for STEP-CNC.

2.3. Three types of STEP-CNC

Depending on how ISO 14649 or ISO 10303 AP238 (simply ISO 14649 henceforth), is implemented on CNC, there are three types: (1) conventional control, (2) new control, and (3) new intelligent control as shown in Fig. 2. Type 1 simply incorporates ISO 14649 to conventional controller via postprocessing. In this case, conventional

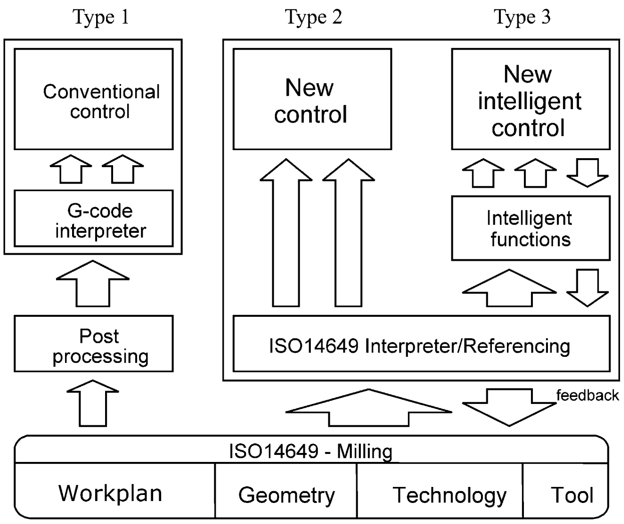


Fig. 2. Three types of STEP-CNC.

CNC can be used without modification. Strictly speaking, this cannot be considered as a STEP-compliant CNC as it should at least be able to read ISO 14649 code. Type 2, the 'New Control,' has a STEP-NC interpreter in it, by which the programmed workingstep is executed by CNC kernel with built-in tool path generation capability. Type 2 is the basic type where the motion is executed 'faithfully' based on the machining strategy and sequence as specified by ISO 14649 part program. In other words, it does not have intelligent functions other than the tool path generation capability. Most of the STEP-NC prototypes developed up to the present time fall into this category.

The third type, much more promising than the predessors, is the 'New Intelligent Control' (Fig. 2), in which CNC is able to perform the machining task 'intelligently' and 'autonomously' based on the comprehensive information of ISO 14649 [1]. Some examples for intelligent functions are automatic feature recognition, automatic collision-free tool path generation including approach and retract motion, automatic tool selection, automatic cutting condition selection, status monitoring and automatic recovery, and machining status and result feedback.

3. Design consideration for shop-floor programming system

ISO 14649 part program is composed of various machining information such as machining feature, machining sequence, machining strategy, cutting tool, machining technology, and geometric information, and the corresponding parameters should be specified exactly according to the given schema. Unlike the G-code program, it would be very difficult to program ISO 14649 manually even for a simple shape. Hence, it is required to develop a computer-assisted part programming system called shop-floor programming system system (SFPS) for STEP-CNC. It can be developed either as an off-line system like typical CAM system or an on-line system of built-in STEP-CNC. (Note that originally the latter type is meant by SFPS from the standpoint of CNC maker, but later the former is also referred to as SFPS from the standpoint of CAD/CAM supplier). In either case, a programming system should be developed so that appropriate information can be retrieved from the CAD/CAPP/CAM kernels.

As far as the architecture and functionality are concerned, SFPS for STEP-CNC has not been reported in open literature except for a rough definition of SFPS function; i.e. generating ISO 14649 part program for the part whose geometry is given by AP203. Considering that SFPS can be used for diverse purposes, its architecture should be designed so that they can be accommodated by SFPS. Specifically, the followings should to be taken into consideration in designing the architecture of SFPS.

1. Full compliance with ISO 14649 and STEP APs. This is the fundamental requirement for SFPS for STEP-CNC. At least SFPS should be able to read both AP203 (3D geometric file), and AP224. At the present time, AP203 file can be generated by most CAD systems, but not for AP224. In the future, however, feature-based CAD system will be able to provide AP224 as well.
2. Feature recognition/mapping capability. ISO 14649 part program is depicted with respect to the machining features. If the part geometry is given by AP203 (or AP224), feature recognition (mapping) is required for SFPS before proceeding to the process planning procedure.
3. DB structure for STEP interface. The database of SFPS should be structured such that it can interface with other STEP databases such as STEP-repository storing all information, using a complete suite of STEP schema.
4. Internet interface. It is probable that CAD database and SFPS are located in different places and SFPS loads a remote CAD file using the Internet. It is true of SFPS and STEP-CNC. A part program generated by SFPS can be delivered to STEP-CNC through the Internet. In this context, Internet interface is essential required for SFPS.
5. XML support. To enable querying and updating STEP data in the database over the Internet, it is required to deliver information as XML objects over the Internet. This capability is optional.
6. Distributed system. Underlying modules of STEP-CNC can be physically distributed over the network. Depending on design intention, SFPS and other components of STEP-CNC can be distributed and run communicating with each other by means of a distributed networking service such as CORBA.
7. Accommodation of two types of SFPS. There are two types of SFPS; off-line CAM type, and on-line or

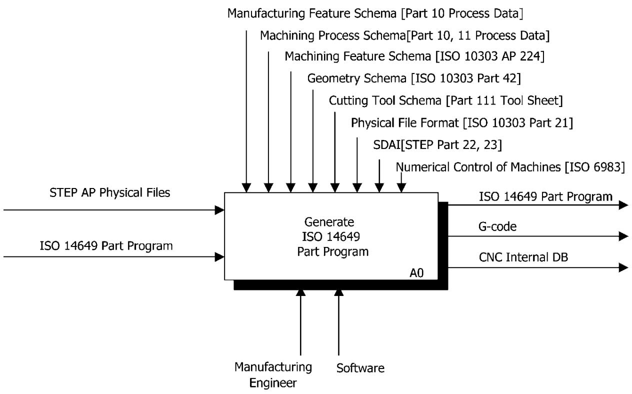


Fig. 3. Topmost IDEF0 diagram of SFP system for STEP-NC.

built-in type. For generality, SFPS needs to be designed for both usages. For on-line type, physical file form of part program is not necessary since the database can be directly accessed by STEP-CNC. In this case, interpreter in STEP-CNC is not necessary, either.

8. Accommodation of conventional CNC. As mentioned earlier, there are three types of STEP-CNC depending on how ISO 14649 is interfaced with CNC. The first type uses conventional CNC based on ISO 6983 via postprocessing. To accommodate conventional CNC, SFPS should be designed to output in the form of ISO 6983 as well as ISO 14649.
9. Editing capability. SFPS is also used for editing existing ISO 14649 part program. For such a purpose, SFPS should be able to read (interpret) the ISO 14649 part program, and check the logical and syntax errors in it.
10. Human interface. For accuracy and efficiency of part programming, SFPS should be designed user friendly, showing what he or she is doing. GUI and diagnostic message together with visual verification means are necessary. Ideal human interface is made of push-button operation.
11. Process sequence editor. Conventionally, process sequence is given in a linear (sequential) fashion. In practice, however, there often exist cases that process sequence is not necessarily linear (Section 5.3). In ISO 14649, the sequence of workingsteps (*program_structure*) can be given in a non-linear fashion. This is to give flexibility to CNC in executing the tasks. However, programming non-linear process plan is not easy for the programmer, and hence process sequence editor should be provided by SFPS.
12. Optimization/knowledge-based system. Completion of ISO 14649 part program requires technical information. Even if push-button interface is used, specifying all the entries may be cumbersome. Thus, minimization of input and provision of optimized values (cutting conditions, tool selections) are necessary by knowledge-based algorithm and technical database.

4. Architecture design for SFPS

Based on the design considerations, a functional architecture of SFPS is designed in this section. IDEF0 diagram is used for the detailed functions to be implemented in SFPS. Loosely speaking, SFP system (Fig. 3) is to generate ISO 14649 part program by referencing ISO 14649 Part 10, 11, 111, and ISO 10303

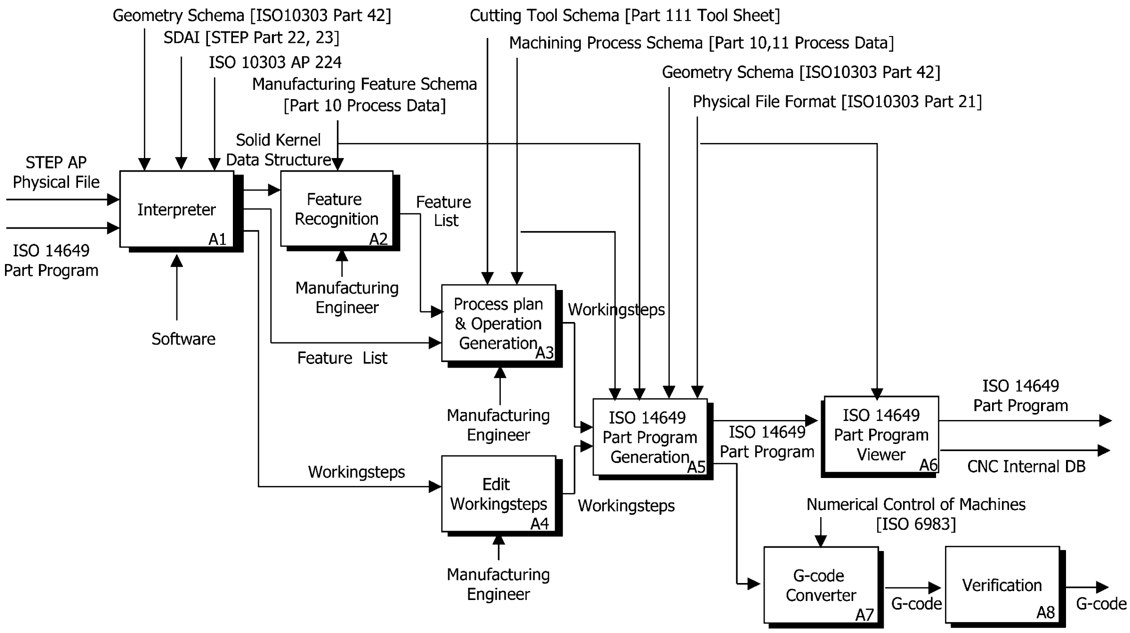


Fig. 4. Second level IDEF0 diagram of SFP system.

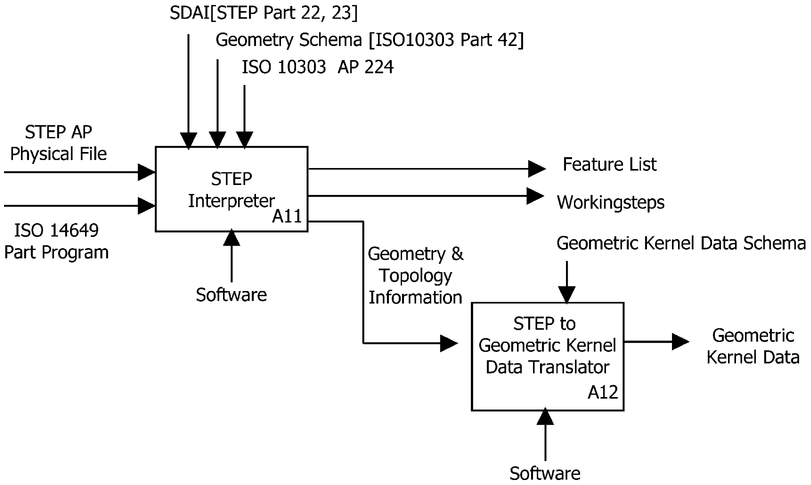


Fig. 5. Functional diagram of the interpreter module.

Part 21, 22, 23, 42, 203, 224 from the input of STEP AP physical file that defines the final shape of the part (*design consideration #1*), or previously written ISO 14649 program (*design consideration #9*).

A series of processes is controlled by a manufacturing engineer, and the process planning software. Basically, the output is ISO 14649 part program in either physical file format (for the external SFPS (Fig. 7) to be explained later), or CNC-internal data (for the built-in SFPS type). Furthermore, G-code could be another output to accommodate the conventional controllers (*design considerations #8*). Details on the output will be given later in this section.

The topmost function of SFPS (A0) can be achieved by five major modules (Fig. 4): (1) interpreter (of STEP AP file and ISO 14649 part program), (2) feature recognition module, (3) process planning module, (4) ISO 14649 editing module, (5) ISO 14649 generation module, and (6) verification module. Each module is explained in detail.

The interpreter (A1) takes STEP AP physical file representing the final machined part or ISO 14649 part program as an input. Fig. 5 shows the functional diagram of the interpreter module. The interpreter module is composed of: (1) STEP interpreter (A11), and (2) STEP to geometric kernel data translator (A12).

In the case that existing ISO 14649 part program is edited, the output (A11) is a list of workingstep information. These workingsteps will be used as the starting information in edit workingsteps (A4). In the case that a new part program is created, A11 outputs either feature list, or geometry and topology information according to the input given by STEP AP physical files of AP203, AP214, and AP224. If the input is given by either AP203 or AP214, A11 outputs geometric and topological information, which is converted to geometric kernel data by A12. The geometric kernel (e.g. parasolid) data is used for storing and visualizing the part, and recognizing the machining features to be done by A2 (feature recognition). If the input is given by AP224, the output of A11 is feature list. Since the features of ISO 14649 are compliant with those of AP224, A11 simply converts the AP224 features into ISO 14649 by mapping. Thus, in this case, feature recognition (A2) is not necessary.

For the Geometric Kernel Data obtained from A12 feature recognition (A2) will be executed. The feature recognition module is decomposed into three

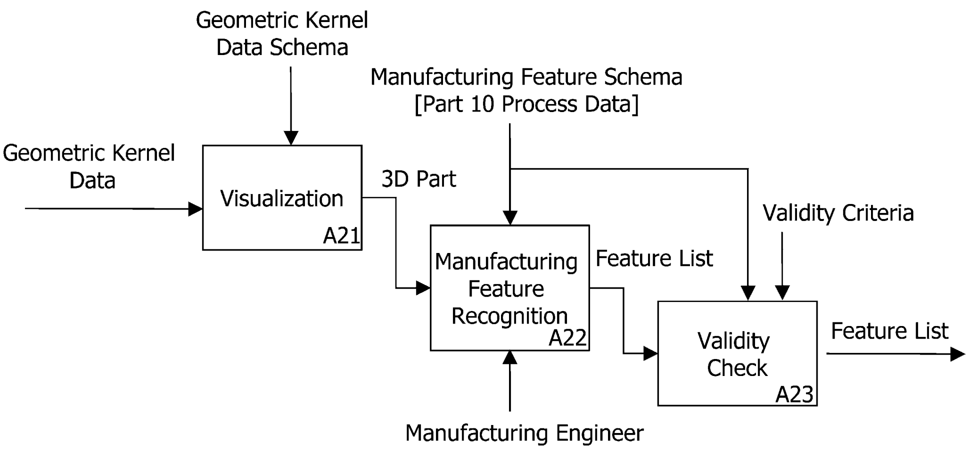


Fig. 6. Machining feature recognition module.

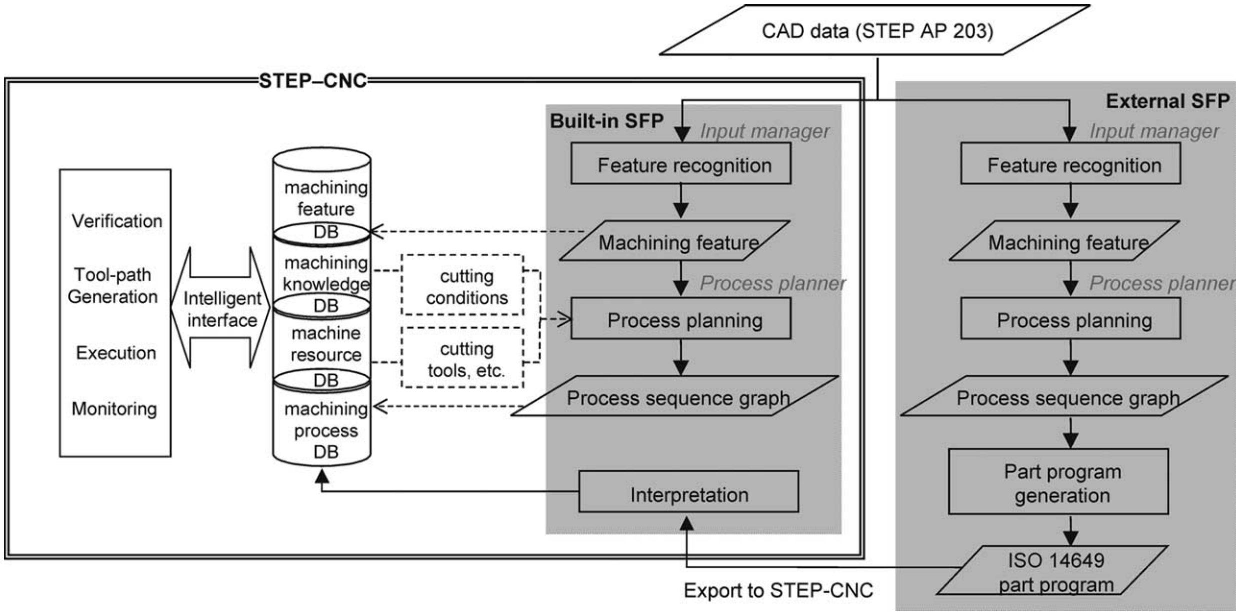


Fig. 7. Built-in SFP system and external SFP system.

sub-modules as shown in Fig. 6. The core module is the machining feature recognition module (A22), which recognizes the machining features in accordance with the manufacturing feature schema defined in ISO 14649. Feature mapping and extraction of feature attributes extraction are also critical functions. The details on feature recognition are given in Section 5. Each feature is inspected and checked before it is passed to the next step (A3 for process planning).

For the feature list obtained either from A1 or A2, process planning is done in A3 (process plan and operation generation). Process planning is to interactively input the machining operation (such as type of machining operation, machining strategy, cutting condition, cutting tool, etc.) for each of the machining feature. To ensure accuracy and efficiency of input procedure, A3 should be designed user friendly showing what he or she is doing. GUI and diagnostic message together with visual verification means are necessary (*design consideration #10*). Machining sequence of each feature is determined by sequential enumeration of *executables* or conditional statements; e.g. *if* or *while*. *Workplan* and *workingstep* are subtypes of *executable*. Machining sequence can be set manually by the user through graphical user interface or automatically by utilizing the stored knowledge in internal database (*design consideration #12*). In addition to sequential (linear) machining sequence, ISO 14649 also supports non-linear process sequences; e.g. *selective*, *parallel*, *nonsequential* by which alternative process plan can be specified. To the end, the Process Sequence Graph (PSG) [1] scheme should be used for clarity and preciseness of representation (*design consideration #11*).

Based on the workingstep information either from A3 or A4, ISO 14649 part program can be automatically generated in A5. Depending on SFPS is interfaced, there exist three cases. (*design consideration #7* and *#8*). The first one is when SFPS is used as an off-line CAM system for STEP-CNC; i.e. external SFPS in Fig. 7. In this case, A5 generates ISO 14649 part program in physical file according to STEP Part 21, and it is exported to STEP-CNC. The physical file will be interpreted and stored in the DB of STEP-CNC (see Ref. [4] for a detailed architecture of STEP-CNC).

When SFPS is installed in STEP-CNC (i.e. built-in SFPS in Fig. 7), ISO 14649 part program is in the form of internal data which can be directly used by STEP-CNC (i.e. conversion of physical file to ISO 14649 DB in

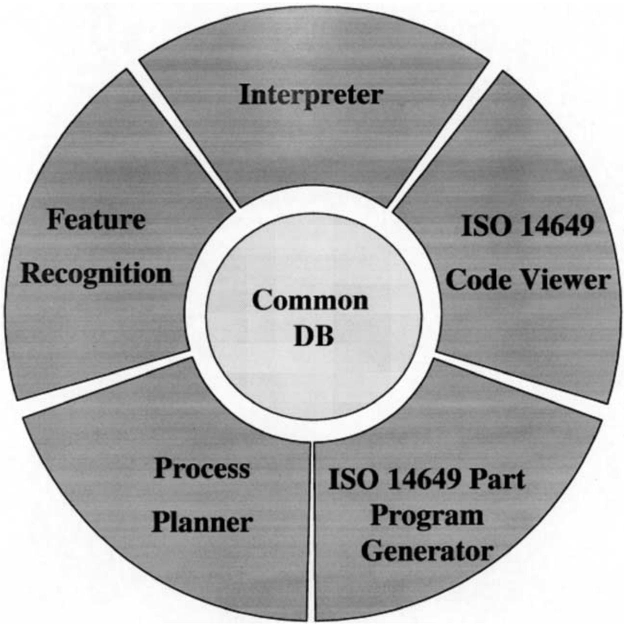


Fig. 8. Five modules in PosSFP.

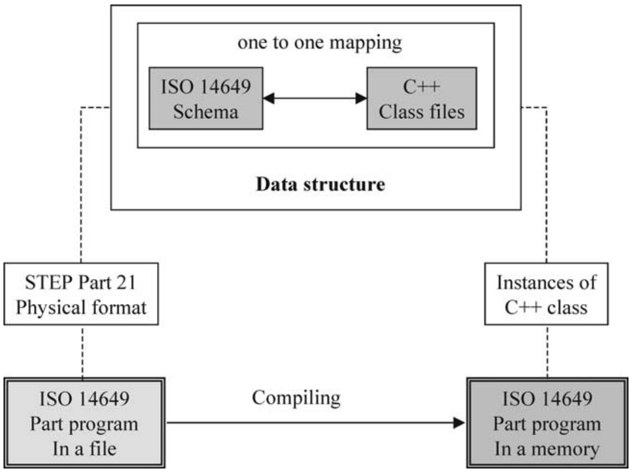


Fig. 9. Structure of ISO 14649 part program interpreter.

STEP-CNC are not necessary). In both cases, verification of ISO 14649 part program is done in A6. Since tool path is not included in ISO 14649 part program (it is done by Tool Path Generator (TPG) of STEP-CNC using actual cutting tools available in machine tools. See Ref. [10] for details on TPG), only the sequence and geometric shape of machining feature can be verified.

The third case is for conventional CNC taking ISO 6983 code. Strictly speaking, this is not within the scope of genuine SFPS, but just for the sake of transient need (*design consideration #8*). In this case, G-code conversion is done by A7. Converting ISO 14649 code to ISO 6983 code requires explicit tool path computation in which the cutting tool used should be the same as the one to be used for machining. In other words, the same cutting tools used in ISO 14649 part program should be available in the tool magazine. The computed tool path can be verified by A8. The tool path computation is followed by posprocessing.

5. Development of a prototype SFPS

Based on these design considerations, a prototype SFP system called PosSFP was developed. The program was written in C++ and operated in Windows platform. Parasolid was used for geometric modeling kernel, and graphical user interface was coded mainly using OpenGL. As shown in Fig. 8, the PosSFP is composed of five modules: (1) interpreter, (2) feature recognition, (3) process planner, (4) ISO 14649 part program generator, and (5) ISO 14649 code viewer. In what follows, technical details together with implementation status are given for each of the modules.

5.1. Interpreter for ISO 14649 and ISO 10303

There are three interpreters in A1; (1) ISO 14649 physical file to workingstep DB (A11), (2) ISO 10303 AP 203 physical file to geometry and topology information DB (A11), and (3) STEP to geometric kernel data translator (A12). The technology to develop these three are very similar, and they can be developed

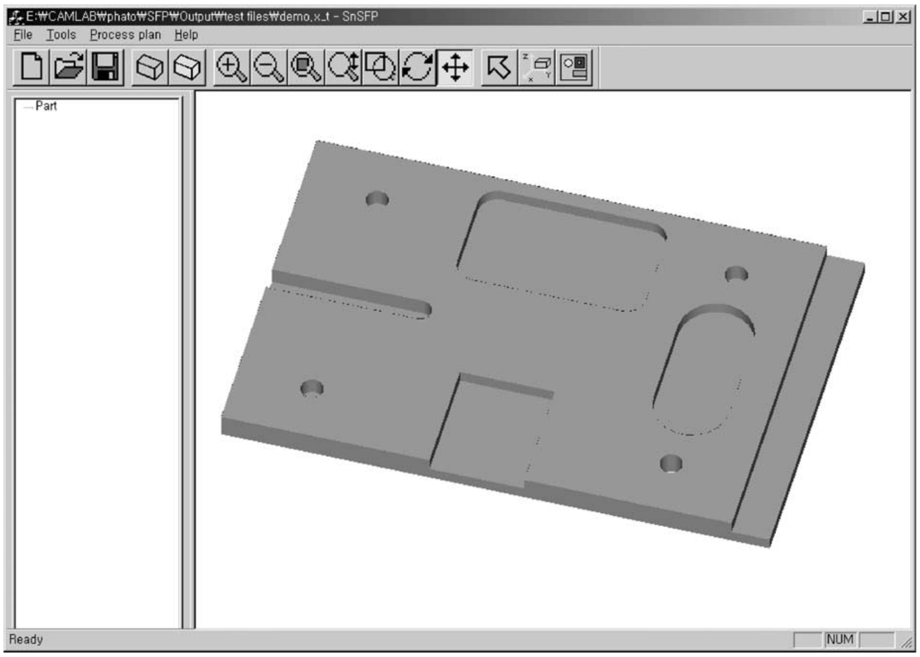


Fig. 10. An AP 203 file interpreted and visualized.

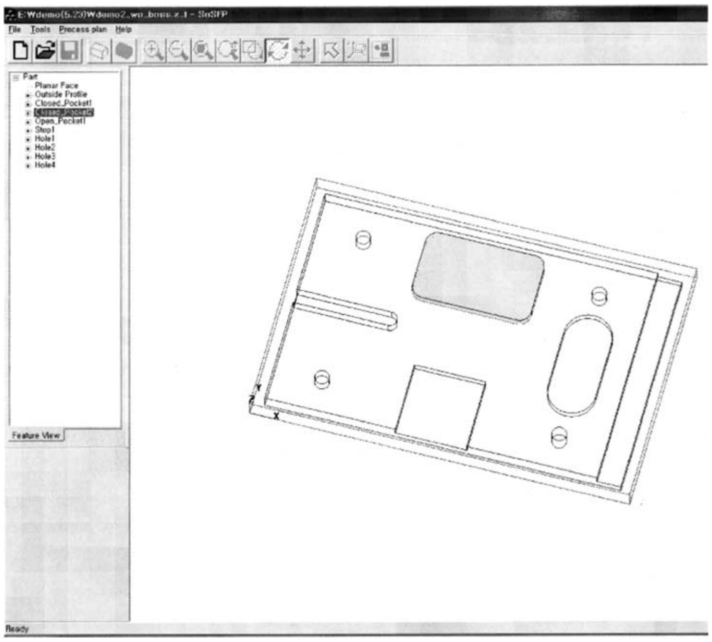


Fig. 11. Recognized features for the part of Fig. 10.

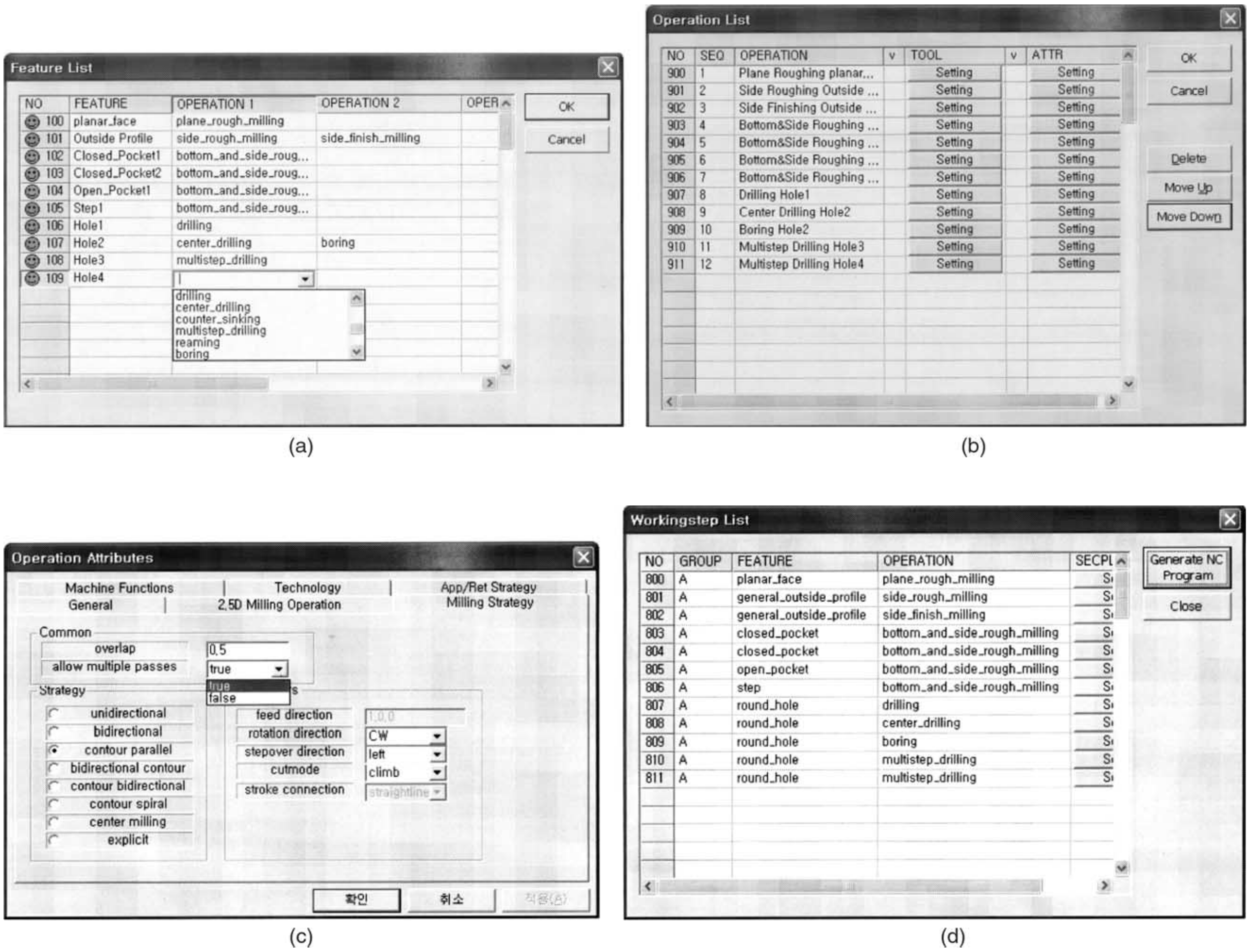
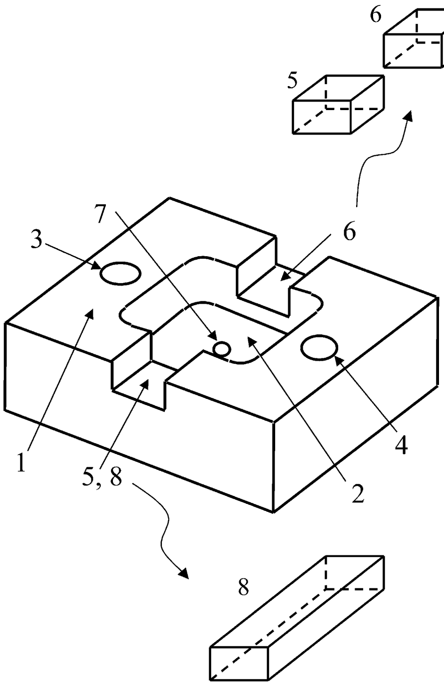


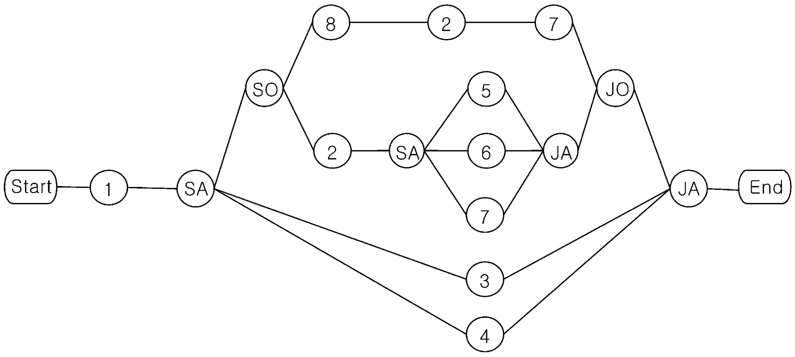
Fig. 12. Screens showing process planning in PosSFP. (a) Feature list and operation assignment, (b) operation list, (c) setting up operation attributes, (d) working step list.



(a) Part geometry

WORKINGSTEP		
ID	FEATURE	OPERATION
1	planar_face	plane_rough_milling
2	closed_pocket	bottom_and_side_rough_milling
3	round_hole	drilling
4	round_hole	drilling
5	slot	bottom_and_side_rough_milling
6	slot	bottom_and_side_rough_milling
7	round_hole	drilling
8	slot	bottom_and_side_rough_milling

(b) workingstep list



(c) Process sequence graph

Fig. 13. Example for feature intersection and non-linear process plan.

by using tools kits, such as ST-developer (that we used for A12).

The interpreter for ISO 14649 physical file was developed based on the structure shown in Fig. 9. C++ files corresponding to ISO 14649 schema were designed and coded. Note that the schema represents the structure of data file based on the physical file format of STEP Part 21, and the class file represents the structure of instance of a class. Physical file data can be transformed into instances of classes by: (1) reading/compiling the physical file, (2) creating instances of classes corresponding to the entities defined in the schema, and (3) setting the member values of instances by referencing the attributes of the entities. The interpreted input is stored in DB and visualized. Fig. 10 shows an example part of AP203 interpreted and visualized by PosSFP.

5.2. Feature recognition

The function of feature recognition (A2) is to generate the feature list as defined in ISO 14649 from the input given by geometric kernel data (A12). Feature recognition from a solid model has long been the subject of research since the seminal work of Kyprianou [11] and is still studied vigorously. Graph pattern matching, convex hull decomposition, cell-based decomposition, and hint-based reasoning are four distinct BRep-based approaches that have attracted attention. In this paper, we do not propose any new approach or modified algorithm for feature recognition, but to discuss how to apply it for recognizing the features as defined in ISO 14649.

A critical issue in feature recognition is the capability of recognizing intersecting features. This issue is still an object of active research. As is often the case with

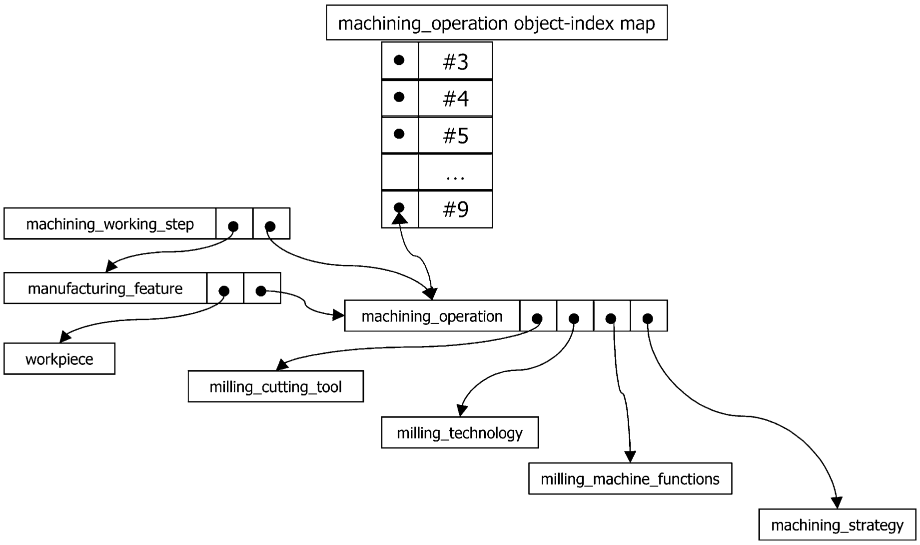


Fig. 14. Structure of entity-index map.

realistic design part, there are some intersecting features in the part. But none of the known approaches provides the perfect recognition result as far as intersecting features are concerned. Moreover, there are compound features made up of more than one simple feature in ISO 14649. It is impossible to recognize them automatically because the current recognition approach can recognize only one feature. For SFPS of STEP-NC, all machining features should be extracted by all means. In this research, we adopted automatic feature recognition for simple features and interactive recognition for compound features, and we focused not on how well a recognition module works but on how robust it is.

It should be mentioned that features of ISO 14649 are defined implicitly or explicitly. In either case, it is required to know the type and value of feature attributes.

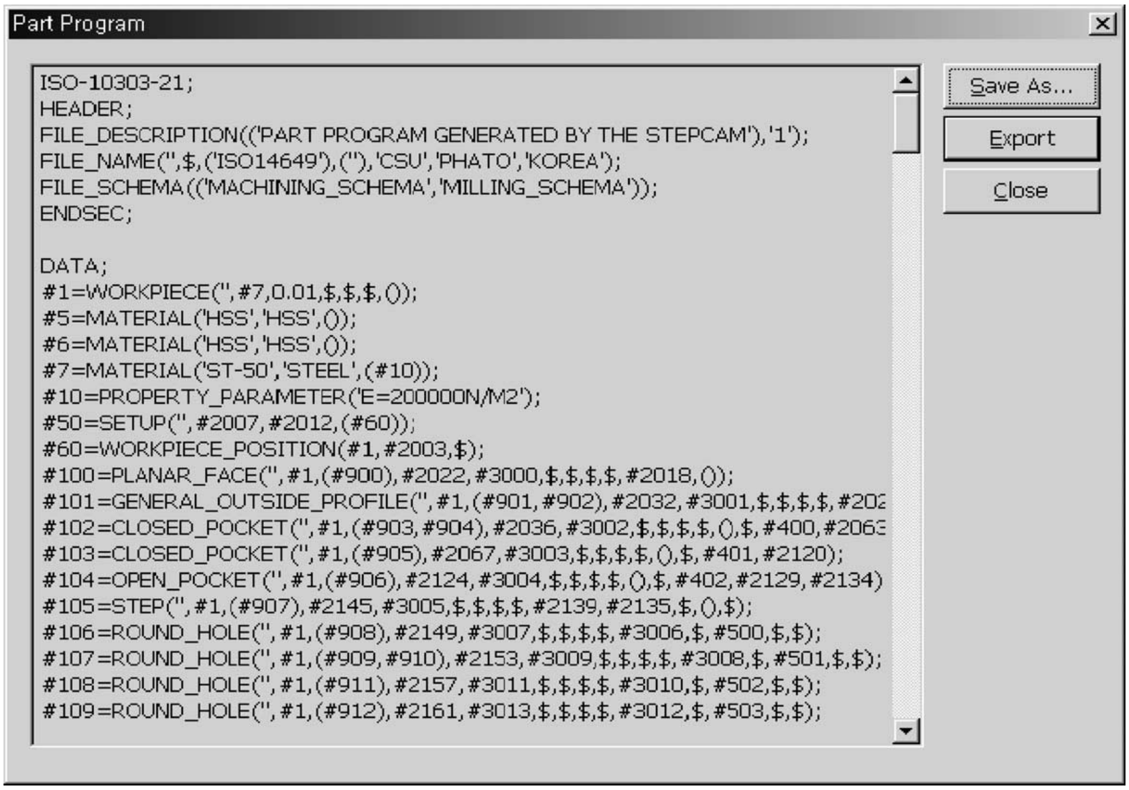


Fig. 15. Generated ISO 14649 part program.

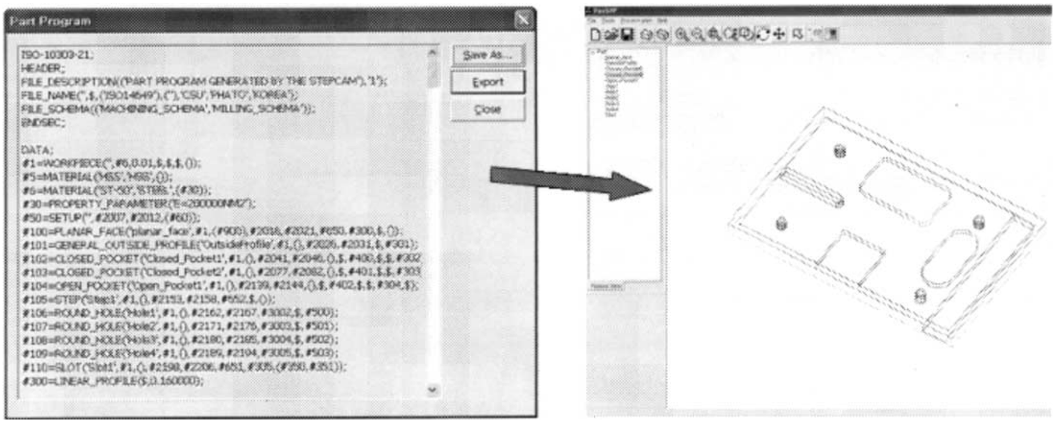


Fig. 16. Code Viewer.

For example, the end type of a slot can be one of *woodruff_slot_end_type*, *radiused_slot_end_type*, *flat_slot_end_type*, *loop_slot_end_type*, or *open_slot_end_type*. So it is essential to map the recognized feature in terms of the feature defined in ISO 14649. This feature mapping makes the recognition algorithm for ISO 14649 a little different from the general purpose one.

Fig. 11 shows a PosSFP implementation, showing the feature recognition result for the part of Fig. 10. In this part, a total of 11 features (1 *planar_face*, 1 *general_outside_profile*, 2 *closed_pocket*, 1 *open_pocket*, 1 *slot*, 1 *step*, and 4 *round_hole*) listed in the left of the screen, are successfully recognized.

5.3. Process planner

A process plan is organized in the order of: (1) assigning machining operation to each machining feature, (2) setting up process data for the assigned machining operation, (3) setting up *workingsteps* with tuples of features and operations, (4) classifying the *workingsteps* into several groups according to the setup, and (5) sequencing the *workingsteps*. Fig. 12 shows the screens of PosSFP implementation for these procedures.

As far as workingstep sequence input method is concerned, the PSG scheme is used. PSG scheme is similar to AND–OR graph, which is convenient to represent

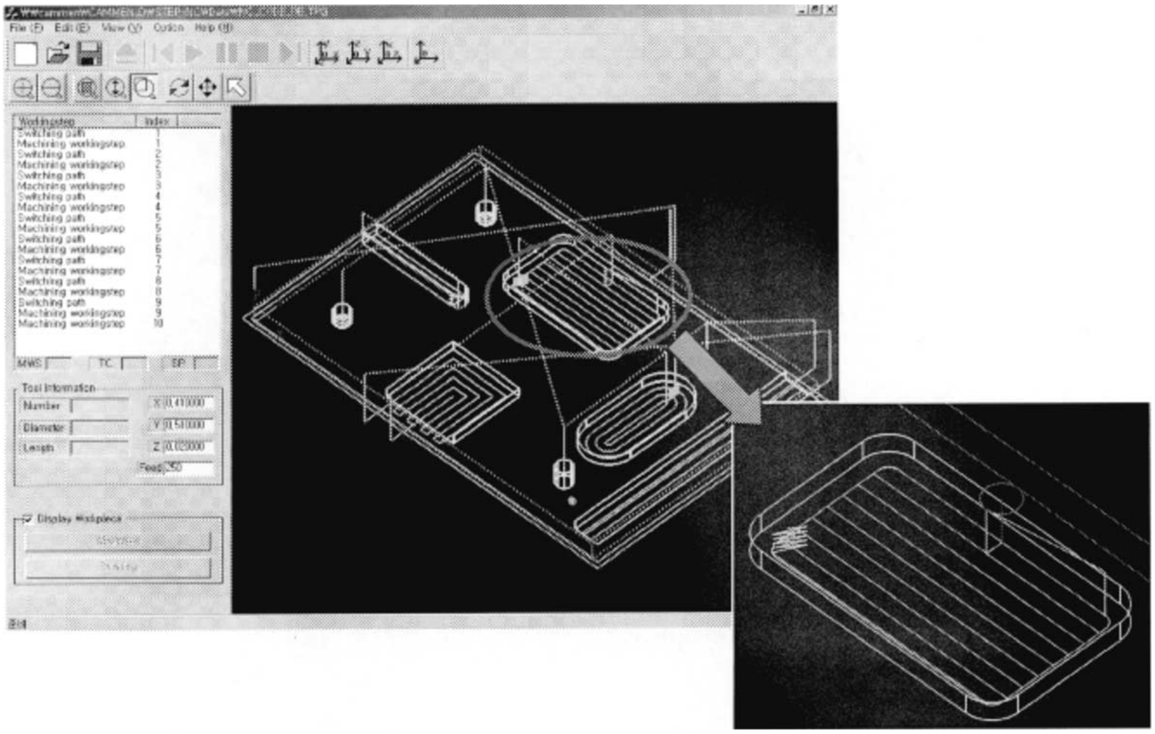


Fig. 17. Tool path generated by TPG of Korea STEP-NC.

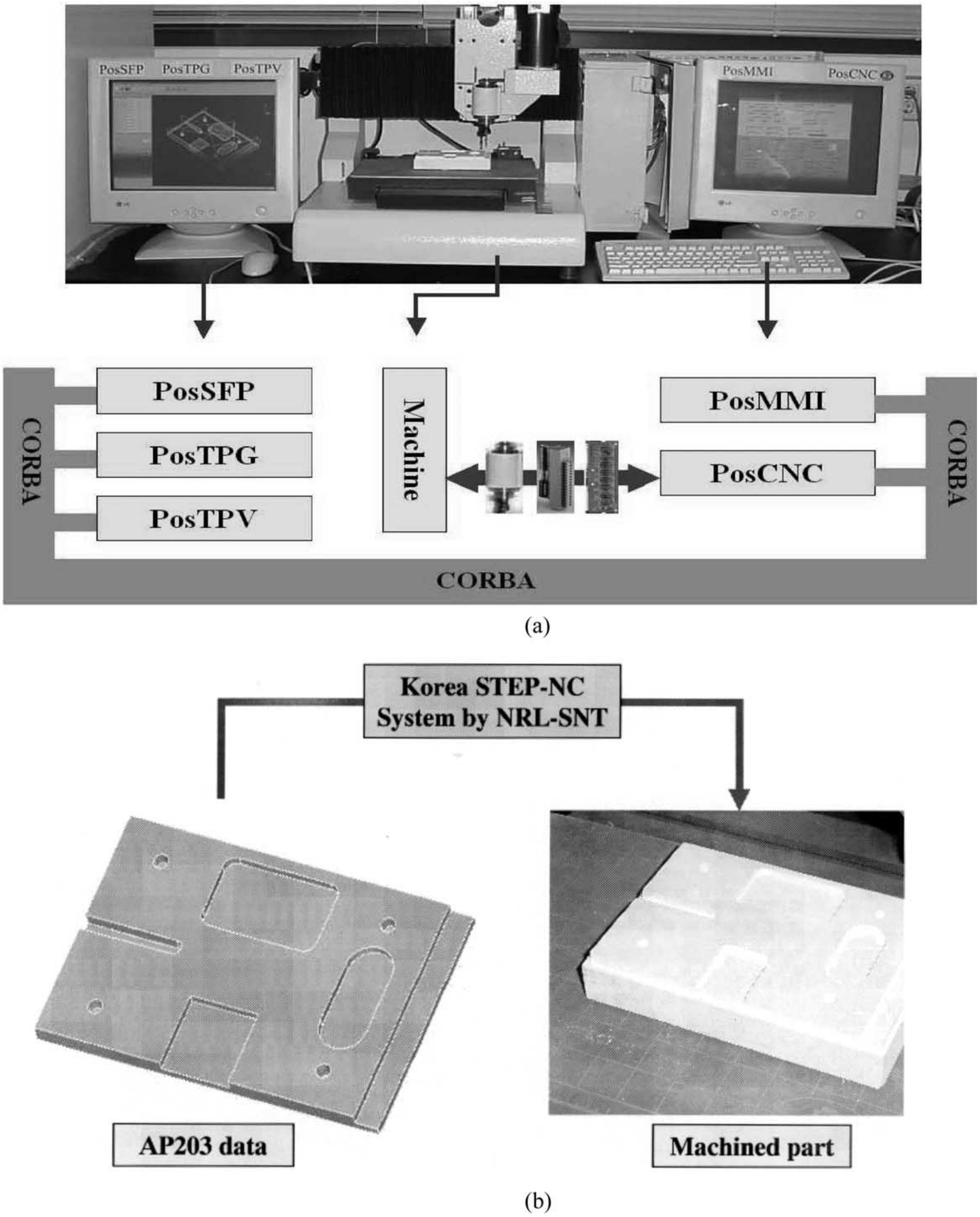


Fig. 18. The prototype Korea STEP-NC and the machined part. (a) Korea STEP-NC prototype, (b) the designed part and the machined part.

alternative process sequence. This gives rooms for flexibility to STEP-CNC to accommodate unexpected occurrences (e.g. unavailability of resources such as cutting tools due to tool breakage), or optimization of process sequence (e.g. in the case of making tens of holes, machining sequence is not matter. In this case, its machining sequence is not necessarily specified by the part program but to be optimized by the CNC at the time of execution). Fig. 13(c) illustrates the PSG including alternative process plans for the part (Fig. 13(a)) whose shape can be interpreted as either two short slots (Feature #5 and #6 in Fig. 13(b)) or one long slot (Feature #8).

5.4. ISO 14649 part program generator

Part program is generated by writing the addresses of entity instance and entity-index map to the file. There are several entity-index maps for each group of features, operations, strategies, and cutting tools. DATA section of a part program is made up by writing up the contents of all the entity-index maps. HEADER section is treated in a separate way with the additional information input by the user. Fig. 14 shows the structure of entity-index map, and Fig. 15 shows the generated part program for the example part of Fig. 10.

5.5. ISO 14649 code viewer

When a manufacturing engineer verifies or modifies the ISO 14649 part program through workingsteps, visual identification of the machining features through GUI centering around is necessary. A visual identification module named Code Viewer reconstructs the machining features in 3D object in order to: (1) enable the user to select the features, (2) check the parameters of features, and (3) modify them if necessary. The modified result can be directly reflected and visualized in 3D geometry. Fig. 16 is an example screen of Code Viewer showing the contents of the ISO 14649 part program (Fig. 15) in terms of 3D graphics. Note that the tool path cannot be displayed by Code Viewer, as the tool path information is not available in this stage (it is done by the STEP-CNC). In addition to the workingstep details, the workingstep sequence can be verified through PSG by the Code Viewer; i.e. by editing the nodes and arcs of PSG on the screen.

6. Integration and verification with Korea STEP-NC

The developed PosSFP was integrated with Korea STEP-NC [10]. For the example part of Fig. 10, the SFP operation was done as summarized from Figs. 11–16. The generated ISO 14649 part program was exported to Korea STEP-NC via CORBA communication. Then: (1) the part program is interpreted (by interpreter of Korea STEP-NC) and stored in the workingstep DB, (2) the tool path is generated (by TPG of Korea STEP-NC) with tools available in the machine tools (optimal tool is selected by tool selector of Korea STEP-NC), and (3) the generated tool path is executed by NCK/PLC of Korea STEP-NC). Fig. 17 shows the tool path generated by TPG, while Fig. 18 is the machined result, showing that the ISO 14649 part program was successfully generated by PosSFP, and executed by Korea STEP-NC.

7. Conclusion

STEP-CNC will surely be the next generation CNC controller interfacing with the new CNC data model formalized by ISO 14649. It will replace the conventional controller working with the old language. To realize the true benefits of the new interface scheme for CAD–CAM–CNC chain, the architecture and implementation technology for STEP-NC should be established. At the moment, worldwide efforts are being made for the new data model, and detailed technology is emerging. In this paper, we for the first time, dealt with the SFP system in detail, which is one of the core elements for implementing the STEP-NC.

A special emphasis was placed on the architecture of SFPS. The presented architecture was derived from systematic analyses aiming to fully support the STEP-NC to be interfaced and exploit its practical gains. The IDEF modeling and implementation methodology were given in detail. Based on the architecture, a prototype system called PosSFP was developed and integrated with Korea STEP-NC. Through an operational scenario, the validity and effectiveness of PosSFP was verified. Although PosSFP is a prototype, it includes crucial component technology, and hence it can work as a reference system for the SFPS for STEP-NC. To realize the true meaning of intelligent CAM system (operated completely based on 'push-button' operation), however, intelligence and optimization (discussed in *design consideration #10*) together with robust and interactive feature recognition capability should be further incorporated.

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