Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 55
ISSUE 2
December
2012

iHFMS - an integrated system for predicting and monitoring up-to-date tool life status based on high-level CNC data

A.Z. Abdul Kadir [a,b,*], X. Xu [a]
[a] IIMS, Department of Mechanical Engineering, Faculty of Engineering, University of Auckland, New Zealand
[b] Department of Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, UTM, Malaysia
* Corresponding e-mail address: aabd115@aucklanduni.ac.nz

Received 13.10.2012; published in revised form 01.12.2012

Analysis and modelling

ABSTRACT

This paper presents an integrated High-Fidelity Machining Simulation (iHFMS) system with the intention to predict and monitor up-to-date tool information status based on high-level CNC data through the evaluation of historic Post-Machining analysis. The system consists of three components which include; tracking and recording mechanism of Cutting Tools Database (CTD) via barcode identification, remaining tool life predictive model, as well as development of a Machining History Database (MHD). A case study was designed to demonstrate how the system is utilised in tracking the remaining tool life of a mounted cutting tool, together with variety machining configurations. The outcome shows the integrated system may fasten the process planning activity and perform machining efficiently by providing dynamic tool life values based on the shop-floor status.
Keywords: Simulation; Tool life; STEP-NC; CNC; Machining

Reference to this paper should be given in the following way:
A.Z. Abdul Kadir, X. Xu, iHFMS - an integrated system for predicting and monitoring up-to-date tool life status based on high-level CNC data, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 421-430.

1. Introduction

As the 21st century has advanced, the manufacturing environment has become a highly scientific, customer-driven industry, involving a worldwide venture that is boosted and dominated by dynamic change. Products become more complex, industries become larger, and customer demands keep on growing. All of this has led to a greater and more prevalent need for simulation technology [1].

As the use and availability of simulation has grown, so has the understanding of the difficulties associated with simulation. Acknowledging, analysing and monitoring a real machining system's environment are becoming crucial to the development of a modern simulation system. By this means, the need to adjust and match the simulation output upon commencing machining activities is greatly reduced. This means that one can lessen the number of tasks that do not escalate the production's added value.

Today, data exchange and information flow from CAD to CAM still remain a sizeable challenge in manufacturing. most simulation applications still cannot share data with each other or with other manufacturing software systems [2]. Existing simulation software based on CAD/CAM systems usually stands alone and is not integrated. In addition, performing simulation without knowing the actual machining environment can be indistinct and may produce ambiguous results with lack of integrity.

Perhaps in today's manufacturing environment the main need for simulation, due to its very nature, will propagate the search for more information at all manufacturing levels. By this means, simulation could significantly improve system knowledge, shorten development lead time, increase utilisation and productivity and support decision-making by various parties throughout a product's life cycle [3].

The incompatibilities between the simulation environment and control systems most definitely demand a high-level of standardisation in dealing with design-production data exchange and communication [4]. As a result, it becomes obvious that efforts to define exchange standards must be unified at the international level. This effort is being led by the International Organisation for Standardisation (ISO). The emergence of STandard for the Exchange of Product model data (STEP or ISO 10303) [5] for Numerical Control, known as STEP-NC (ISO 14649) [6] has opened the door to providing a data structure that can act as a standard backbone for tying design and production together. The research outcomes of STEP-compliant systems have demonstrated promising scenarios in assisting process planning and machining tasks [7-9], though they are still at the early stage of industrial adoption. Nevertheless, most CNC systems can still only handle the outdated NC part programme with a limited scope of information defined by ISO 6983, also known as G-code.

High-Fidelity Machining Simulation (HFMS) system was developed with the intention to overcome the abovementioned issues [10]. STEP and STEP-NC were utilized as an enabler for the development of the system. The aim is to demonstrate the ability of the system to incorporate actual status of a real machining behaviour through monitoring of the shop-floor activities. Therefore, 'truthful' simulation environment can be performed with high degree of accuracy. The system composed of three operational phases; Pre-Machining, Machining Simulation, and Post-Machining. Machining Simulation phase was assisted with information from Pre-Machining data obtained from signals captured via sensors as well as evaluation of historic Post-Machining data analysis.

As part of HFMS fundamental concept, this paper focuses on the development of an integrated HFMS (iHFMS) system in portraying the capability of the system to monitor actual cutting tool information at shop-floor. It was known that tool information are influenced by a number of manufacturing functions such as machined features, its material, its life, workpiece material, machining strategy, etc [11]. All of these information are collected continually upon actual machine status activation which allows historic Post-Machining report to be generated providing a reliable and comprehensive statistics on tool usage and its remaining life. The remaining sections were organised as follows: Section 2 introduces the fundamentals of the integrated system which include the overview, description of Post-Machining analysis, extended STEP-NC data structure, Cutting Tools Database, remaining tool life predictive model and Machining History Database. Section 3 explains the tools identification approach that discusses the development tools and how the barcode scanner is integrated into the system. Section 4 introduces the prototype system of iHFMS together with demonstration of the system functions. Finally, conclusion is given in Section 5.

2. System fundamentals

2.1. iHFMS system - An overview

In general practice, there are essentially two trivial tasks that are carried out prior to machining; the first is to setup the workpiece on the machine tool worktable and the second is to set up the cutting tools. The former is acknowledged by HFMS main system through Pre-Machining data update [12]. This paper focuses on the latter aspect where Post-Machining computational platform is implemented and demonstrated by developing an integrated system named iHFMS. The platform allows the calculation of remaining tool life, using updated cutting tool data monitored via barcode identification approach. The updated tool life value is useful in increasing the accuracy of future simulation analysis.

2.2. Post-Machining analysis

Post-Machining analysis deals with knowledge-based data gathered and analysed during a machining operation. The intention is to feed the simulation data with updated information for subsequent machining simulation tasks. Some examples include remaining tool life, total machining time and machining history. A detailed explanation is given below:

- Remaining tool life: tool-life data is often provided by the tool manufacturer, considering the maximum allowable cutting hours of the tool, incorporating safety factors. It is defined as an expected number of hours that a given cutting tool can be used before tool wear significantly impacts machining performance. In this study, tool life is monitored and calculated based on the total cutting length that it has performed for a given operation. The information is stored in a database using the barcode system. In this way, the remaining number of hours of the tool can be calculated using only the actual machining time. Thus, future simulation can be performed, based on remaining tool life, to advise how many hours are left to perform certain cutting for a certain strategy used.
- Machining history: the data is continuously recorded and therefore machining history can be replayed and preserved for future simulation analysis. This can be useful for understanding the machining behavior of a particular part for future improvement. A database is developed to store all the data for easy extraction.

2.3. High-level CNC data (STEP-NC - ISO 14649)

As mentioned, STEP-NC was used as a data model of the system structured with high-level information. This information include machining workingsteps, features information, tolerances, machine tool description, kinematics representation and cutting tool description based on several Parts [13-19] defined under

STEP and STEP-NC. These combined Parts of the HFMS data model, may cater for several functions such as a milling simulation environment, up-to-date cutting tool information that includes remaining tool life data, requirements data for machine tool display and other milling operation functions. Unlike G-code, comprehensive machining information is stored in a STEP physical file called Part 21 file [20]. In order to track the remaining tool life data of a mounted tool at shop-floor, an entity called remaining_tool_life is extended into the available standard of Part 111 [14]. This additional attribute is used to store the number of hours left for a particular cutting tool used in milling operations.

For example, the data model written in EXPRESS showing remaining_tool_life being added as part of the attribute of cutting_component is shown below:

```
ENTITY cutting_component;
tool_offset_length:        length_measure;
its_material:              OPTIONAL material;
technological_data:        OPTIONAL
cutting_edge_technological_data;
expected_tool_life:        OPTIONAL time_measure;
its_technology:            OPTIONAL
milling_technology;
remaining_tool_life:       OPTIONAL time_measure;
END_ENTITY;
```

2.4. Cutting tools database

The introduced CTD is a complement to the evaluation of Post-Machining data in the machining simulation system and is used as a parameter to certify how tool availability at the shop-floor can be used for more effective machining. The main purpose of the CTD was to retain information from the available cutters for machining operation. For tracking purposes, these tools were marked by a unique ID (Table 1), using a barcode ID technique. The ID number represents all the information from the cutting tools specifications. A description of this specification is illustrated in Fig. 1.

Some of the basic information and values such as mill type, diameter, cutting edge length and overall length are given Table 2. The system control of the barcode scanner was configured so that the code ID and the code name transmission could be integrated into the integrated simulation system. The scanning process begins when the tool codes are illuminated by a transmission of red light. The sensor from the scanner detects the reflected light and generates an analog signal with varying voltages that represent the intensity of the reflection. The analog signal will then be converted into a digital signal and fed to a decoder. The decoder is responsible for interpreting the digital signal into ASCII text through a keyboard interface. The simulation system utilises the ASCII output and translates it into data values that contain all the cutting tool information.

Table 1.
Barcode identification labels

Labels	Cutting tools ID
30820	30820-EndmillShort
7100	7100-EndmillLong
7201	7201-EndmillBall
7404	7404-EndmillDouble
7413	7413-EndmillDouble
7430	7430-EndmillSingle
7400	7400-EndmillDouble

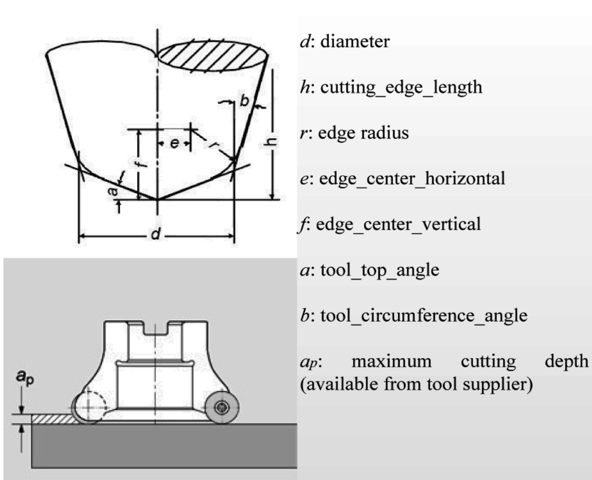

Fig. 1. Tool specification

2.5. Remaining tool life

Tool life was chosen as a criterion to demonstrate physical insight into how the Post-Machining data is employed in the entire system. In general, tool life is defined as cutting time in minutes to produce a given wear land for a set of machining conditions [21]. In any machining operation, it is essential to know the relation of tool life to the cutting parameters when determining the efficiency of the cutting process. Choosing a proper tool that satisfies the requirements of machining output in terms of production rates and minimum cost is a trivial task in machining operation. Several factors in machining might affect the tool life of a cutter. Tracking tool life with respect to various machining possibilities may assist the development of an optimum machining plan.

Table 2.
Cutting tools database

Tools ID	Mill type	Diameter (inch)	Cutting edge length (inch)	Overall length (inch)
30820-EndmillShort	End mills (Short) ¼” shank	0.125	0.1875	1.09375
7100-EndmillLong	End mills (Long), ¼” shank	0.0625	0.15625	1.09375
7201-EndmillBall	End mills, (Ball nose),¼” shank	0.09375	0.1875	1.375
7404-EndmillDouble	End mills (Double-Ended), 3/8” shank	0.250	0.5	3.125
7413-EndmillDouble	End mills (Double -ended), 3/8” shank	0.3125	0.75	3.5
7430-EndmillSingle	End mills (Single-ended), 3/8” shank	0.5	1	2.5
7400-EndmillDouble	End mill sets (Double ended) 3/8”	0.375	1.5	3.5

Since STEP-NC has the advantage of primarily documenting task-level information, the information regarding cutting tools is regarded as tool requirements. The existing tool available in the tool holder is fed into the simulation system and matched with the tool description provided by the STEP-NC file. This is done by tracking the tool updates through its code identification. Initially, the tool life value used in the planned working step is taken from the tool manufacturer’s catalogue. This value is logged as a new tool in the STEP file as well as the CTD, then tool life usage is calculated.

Subtraction of the tool usage value from the assigned tool life value defines remaining tool life. Finally, the calculated remaining tool life value is mapped to the main HFMS system, which determines whether the set of work plan provided in the original STEP file is adequate to perform machining of the particular feature described in the file. The procedure for remaining tool life calculation is shown in Fig. 2.

Based on Fig. 2, there are various tool-life criteria depend on the interrelationship of various scenarios. These criteria act as the basic procedure for how the simulation process is performed:

1. Set feature types - three types of features such as slot, open pocket and planar face were considered in the system. This feature will define the geometry for where the tool should remove material. Based on this feature, cutting length is calculated.
2. Set machining strategy - the system is able to work with three types of machining strategy (bi-directional, uni-directional and contour spiral), defined machining plan and style of the cutter movement. The strategy also defines its overlap or tool step over. This overlap is usually specified as between adjacent tool passes, in order to ensure complete cutting of the part. Table 3 shows the overlap values that are considered by the system, which fall in a range between the tool diameter (D) and 70% of the diameter of the tool (0.7D).
3. Set feature dimensions - basically, the feature dimensions are mapped from the value obtained from the STEP file. This value can be modified to test ‘what if’ scenarios. However, a maximum input for the features dimensions is restricted by considering the worktable working range for not exceeding value of 250 mm in the X-axis and 180 mm in the Y-axis.
4. Set machining parameters - a high number of studies have been conducted to determine the optimum relationship of machining parameters such as cutting speed, feed-rate and depth of cut with respect to tool life. The relationship between those parameters is best explained by Taylor’s tool life equation [21]. Mathematically, it can be expressed as:

$$V_c T^{\eta} = C \quad (1)$$

where V_c is the cutting speed, T is the tool life based on a new tool, η is the exponent depending on tool material, workpiece material, cutting conditions, and environment, and C is a constant also depending upon tool material, workpiece material, cutting conditions and environment. Typical values of tool life data for various tool materials are given in Table 4.

Table 3.
Overlap or step over of cutting tool

D	0.9D	0.8D	0.7D

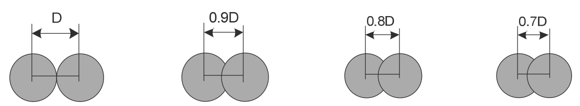

Table 4.
Typical values of constants for various cutting tool materials [21]

Tool material	η	C	Vc (m/min)
HSS	0.12-0.15	200-300	30-50
Cemented carbide	0.2-0.30	600-1000	50-200
Ceramics	0.5	1000-2000	>200

This tool life equation can also be extended to include feed-rate in minutes. This study incorporated the extended Taylor’s tool life equation, which incorporates the relationship between feed-rate and cutting length. This can be expressed as:

$$V_c T^{\eta} V_f^{\alpha} a^{\beta} = C \quad (2)$$

where, V_f is the feed-rate, a is the depth of cut, α and β are both exponents for feed and depth of cut (α = 0.19 to 0.61 and β = 0.3 to 0.4), and C is a constant value for α and β that has to be established by test procedures. By rearranging Equation (2), tool life, T, can be expressed as:

$$T = \left\{ \frac{C}{V_c V_f^{\alpha} a^{\beta}} \right\}^{\eta} \tag{3}$$

The total cutting time expression for a milling operation is denoted as:

$$T_{total} = T_c(i-1) + T_c(i) \tag{4}$$

where T_c is the cutting time that can be derived from the tool trajectory length generated by the tool-path, L_t, with respect to its feed-rate, V_f, expressed as:

$$T_c = \frac{L_t}{V_f} \tag{5}$$

Here, the feed-rate is given as:

$$V_f = fnz \tag{6}$$

were f is the feed per tooth (mm/r), z is the number of effective cutting teeth and n is the spindle speed, expressed as:

$$n = \frac{1000V_c}{d\pi} \tag{7}$$

Combining Equations (3) and (4) leads to the remaining tool life, which can be calculated from the expression:

$$T_R = \frac{T - T_{total}}{T_m T} \tag{8}$$

where T_m is tool life value, obtained from the manufacturer's catalogue.

The contribution made by each decrement is a life reduction rate, which is the ratio of the life consumed over its total available life, and can be called fraction remaining. This fraction in percentage, or fraction remaining, can be derived by the equation:

$$\Delta T = \frac{T - T_{total}}{T} \cdot 100 \tag{9}$$

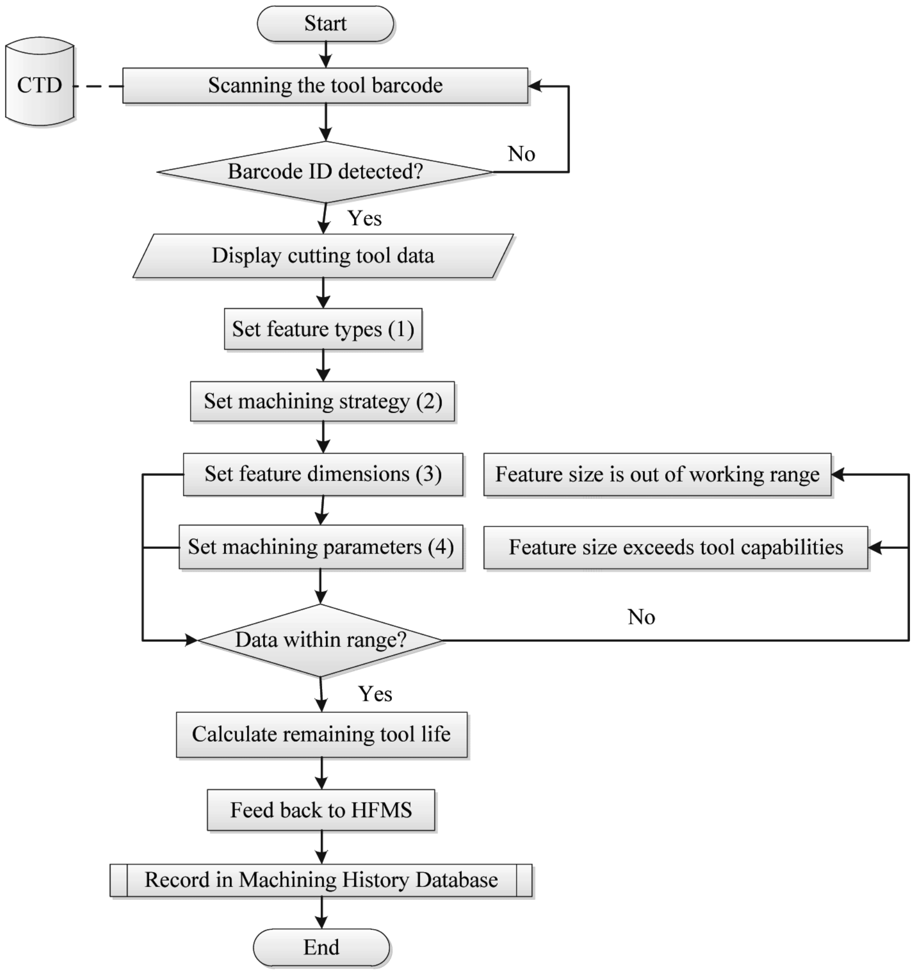

Fig. 2. Procedure for remaining tool life calculation

2.6. Machining history database

The MHD is an essential part of the simulation system, in particular the Post-Machining phase of the HFMS main system. This is due to the fact that cutting tool information needs to be recorded to track tools' current status, in terms of their remaining tool life. The database is integrated into the system using Microsoft Office Interlop assemblies. It is used to read and write machining data to a database in EXCEL format. Data such as simulation start and finish time, total machine length, spindle speed and remaining tool life are recorded and stored in an updated STEP file. For every STEP file loaded, a new worksheet is created to avoid duplicate files. This is done by reading the ID name of the STEP file and a new row of data is recorded every time the DAQ is activated. The updated MHD is considered a robust link provided by the Post-Machining phase. Not only can it be used for archiving purposes but it also provides adequate information for subsequent simulation analysis.

3. Tool identification approach

3.1. Development tools

LabWindows/CVI 9.0 was used as the development programming environment. LabWindows/CVI provided a platform with the ability to read input signals from the barcode scanner. It also allowed simple GUI development for displaying cutting tools information and providing an interface for simulating the remaining hours of the cutter's life. The system is also able to detect if the tool specification value, such as cutting edge length, h, and maximum cutting depth, a_p, (Fig. 1), is within the confined values of the machining parameters. The relevant modification can then be fed to the HFMS main system for MHD recording.

3.2. Barcode scanner setup

The scanner is programmed by scanning barcodes from the operation manual and successful scanning shall be obtained by tilting the scanner with respect to the barcode labels representing the tool ID that contained tool information. The right interface of the scanner was set according to the host. The interface protocol to optimise the scanner with the host was also configured. Other variables such as system control options, code option and format option were all set up accordingly to enable the configuration settings to be stored in the non-volatile memory of the scanner.

4. System implementation

4.1. iHFMS prototype system

The integrated system for tool life analysis was constructed based on the available Cutting Tool Database, where its specifications were updated using barcode identification. This platform was developed to perform remaining tool life simulation and the system interface is shown in Fig. 3. The integrated system comprises four parts labelled from item 1 to 4, and their functionalities are described as follows:

- The machining strategy panel consists of various types of milling strategies (uni-directional, bi-directional and contour spiral), milling features (pocket, slot, and planar face), feature dimensions and machining parameters that can be selected by the user to perform a variety of strategy combinations.
- Once the Start button is clicked, the DAQ is activated to begin Actual Machine Status data acquisition process. The Enter barcode button is used to detect the scanned barcode identification and the CTD is updated based on the tool barcode ID. It also contains a Reset button to reset all the tools specification into default mode.
- The Cutting Tools Database consists of all the cutting tool specifications including their ID, diameter, cutter material, allowable maximum depth of cut, cutting edge length and the current tool life as recorded by the system.
- The summary of results panel was developed to display simulation results such as the calculated cutting length, the new tool life value, current tool life value and remaining tool life. The Calculate button is used to start the simulation process and when the Execute button is clicked, the system will advise the HFMS main programme of the simulation activities to allow changes to be updated. The Machining History Database can also be recorded for archiving purposes.

4.2. Demonstrations of iHFMS system functions

This case study was designed to demonstrate how the iHFMS system is utilised in tracking the remaining tool life of a mounted cutting tool, together with its machining configurations. Three example parts; closed pocket, open pocket and slot were used as the part models. Each part was pre-specified with information such as machining parameters, tooling requirements and geometrical data extracted from Part 21 files. The summary of the simulation criterions are given in Table 5 and the calculation procedure is based on the algorithm discussed in Section 2.5. From Table 5, four different cases were designed, with conditions marked A, B, C, and D. Every case represents different types of parts where each feature varies, depending on a set of candidate tools detected by the scanner. Every type of tool is marked by a unique identification number. When the tool is scanned, a specific CTD based on the identified barcode is generated. If the tool ID is not recognised, an alert (Fig. 4) will appear indicating that the tool barcode was not detected.

Case A tested the situation when the tool ID is identified and the CTD displays the tool specification successfully. However, calculation cannot be further processed since the detected machining parameters, such as the cutting depth, exceed the allowable maximum depth of cut. Here, the system will detect the error and display a warning as shown in Fig. 5 (a). Another notable criterion, as considered in Case B, is related to the feature placement and dimensions of the part with respect to the worktable working range of the machine tool. When, for example, wrong dimensions for a feature's length are entered, the system will again display a warning message to indicate that the feature is out of range, as described in Fig. 5 (b). In Case C, the criterion is set so that the feature size exceeds the depth of cut. Here, the system will advise the user to modify the feature size accordingly before proceeding with further calculation. The warning for this is shown in Fig. 5 (c).

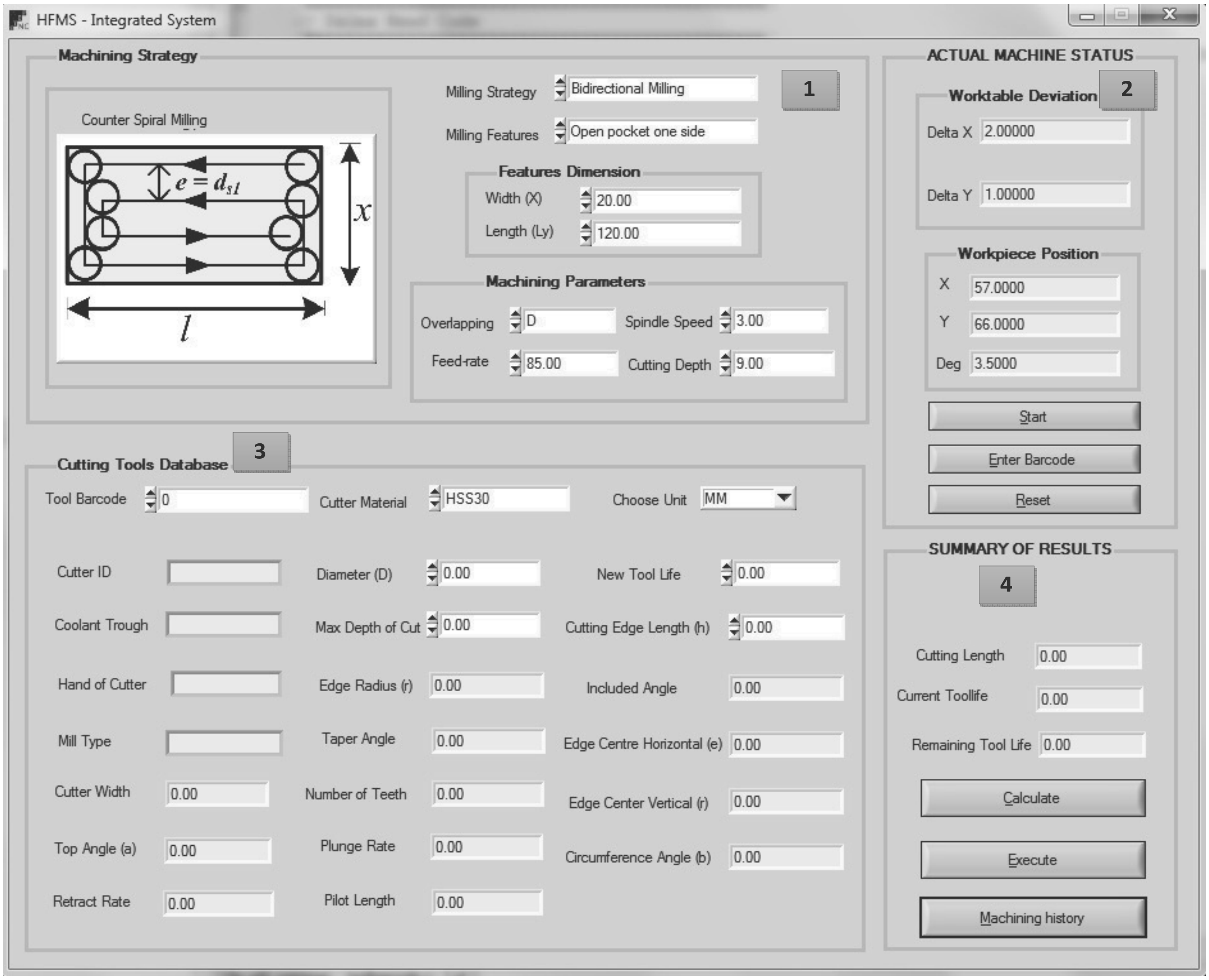

Fig. 3. iHFMS prototype system

Table 5.
Summary of simulation criterions

Case	ID	Part	Strategy	*f* (mm/rev)	*L (mm)*	*D* (mm)	*h (mm)*	*d (mm)*	d_{max} *(mm)*
A	7100	Closed pocket	Bi-directional	15.00	40.00	10.00	0.3968	4.5	0.5
B	7400	Open pocket	Bi-directional	100.00	140.00	2.42	0.24	0.1	0.1
C	38020	Slot	Uni-directional	120.00	80.00	3.175	31.00	5.0	12.0
D	7100	Closed pocket	Counter milling	85.00	80.00	1.5875	0.3968	0.1	0.6

Fig. 4. CTD without scanned barcode identification

The criterion set in Case D demonstrates how the remaining tool life can be successfully calculated with all the parameters assigned correctly. Information such as cutting length, total cutting time, depth of cut, feed-rate, cutting speed, tool life and fraction remaining were utilised and processed in tracking the remaining tool life values. The current tool life value is also displayed to indicate whether the tool is adequate to machine a certain feature. The results indicate continuous tool life value of a current mounted tool was able to be monitored. These values were then sent to the HFMS main system for updating the information via Part 21 file. The system then updates the Part 21 file with current data from the cutting tools. An excerpt of the updated Part 21 file for the part in Case D is as follows:

```
#390=MILLING_CUTTING_TOOL('7100-
Endmill',#455,(#450),80.0,$,$);
#450=CUTTING_COMPONENT(18.0,HSS,$,2400,$,2399.9);
#455=BULLNOSE_ENDMILL (#500,4,$,.F.,$,18.0);
#500=MILLING_TOOL_DIMENSION
(1.59,9.0,4.0,0.3968,3.0,3.0,63.0);
```

Line #390 describes the basic information needed for a cutting tool description, which includes its unique label to exactly identify the tool, the type of tool body, its cutting edge, total assembly length, direction for spindle orientation and tool holder diameter for spindle orientation. The detailed description of the tool body is defined by Line #455. Here, the information includes the dimensions, number of teeth, hand-of-cut, coolant availability and pilot length.

Line #500 gives the relevant data to describe the dimensions of tool body such as diameter, top angle, circumference angle, cutting edge length, edge radius, edge centre vertical and edge centre horizontal. Line #450 is used to specify the cutting component data, composed of the tool offset length, its material, technological data regarding cutting edge, expected tool life, the technology and finally, the remaining hours of tool life.

The generated MHD that contains recorded data such as simulation start and finish time, cutting length, spindle speed, tool life, remaining tool life, tool ID and the feature used for the particular tool used is shown in Table 6. The database archive shows several recorded simulation results of various criterions. This Post-Machining information is continuously recorded to assist decision-making in subsequent simulation activities. If, for example, when a certain feature is about to be machined using an identified tool on the shop-floor that has almost reached end of life, the system will indicate that the tool is insufficient to perform the cutting operation and advise another tool that is available, according to the recorded information in the CTD. Other substantial analysis such as tool management, tool requirement analysis, tool breakage analysis and surface quality analysis may also be performed.

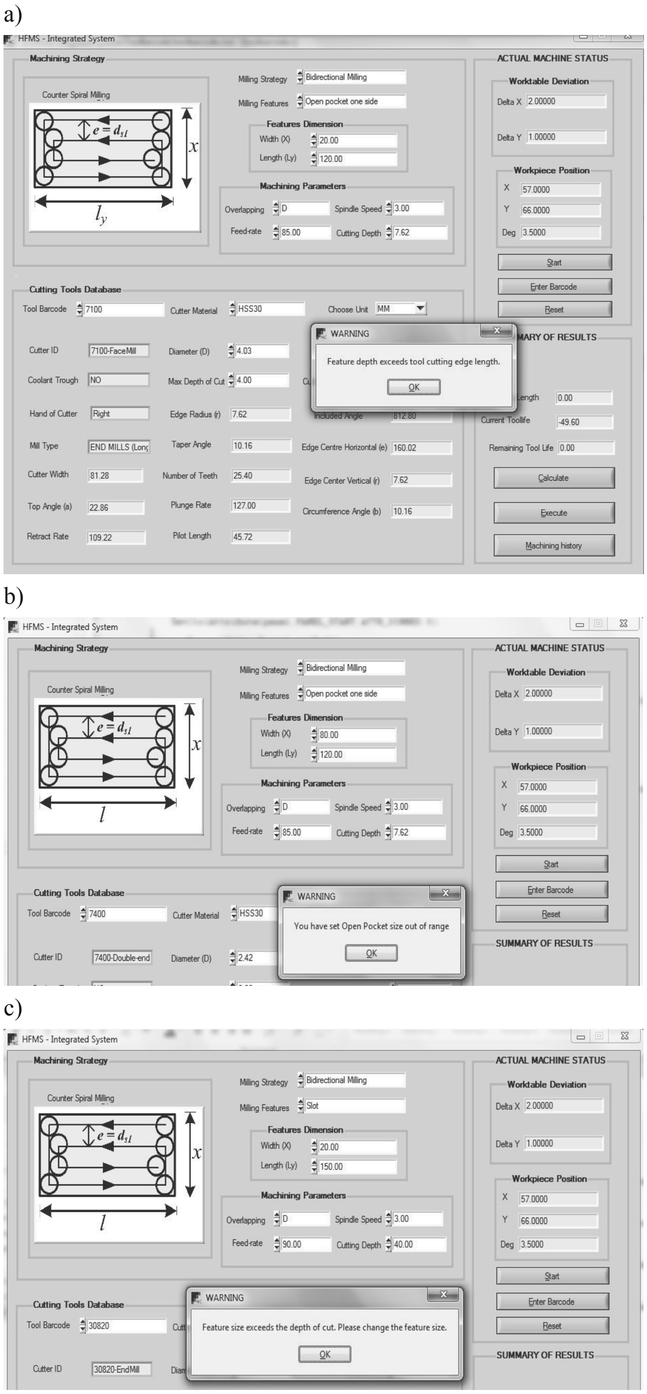

Fig. 5. Warning messages for: a) Case A, b) Case B and c) Case C

Table 6.
Machining history database

No.	Time Start	Time Finish	L_t (mm)	S (rpm)	T (hours)	T_R (hours)	Tool ID	Feature
1	2/01/2012 11:03	2/01/2012 11:13	1101.56	3157	2400.00	2399.904	7100	Closed pocket
2	2/02/2012 9:03	2/02/2012 11:28	984.55	3100	1850.00	1849.925	7404	Slot
3	3/02/2012 3:48	3/02/2012 4:21	425.33	2800	1500.00	1499.980	7201	Slot
4	4/02/2012 10:33	4/02/2012 10:58	1101.56	3157	1849.925	1849.845	7404	Round hole and pocket
5	4/02/2012 2:02	4/02/2012 2:12	122.01	2877	2399.904	2399.878	7100	Round hole
6	5/02/2012 3:22	5/02/2012 3:37	984.55	3157	1849.845	1849.744	7404	Open pocket
7	5/02/2012 5:08	5/02/2012 5:23	984.55	3157	1600.00	1599.657	7430	Open pocket
8	5/02/2012 7:00	5/02/2012 7:20	455.34	2800	1499.980	1499.976	7201	Slot
9	6/02/2012 11:03	6/02/2012 11:28	465.33	2800	1499.976	1499.851	7201	Slot
10	6/02/2012 8:04	6/02/2012 8:28	455.34	2800	1499.851	1499.842	7201	Slot
11	7/02/2012 9:03	7/02/2012 9:17	984.55	3157	1499.842	1499.574	7201	Open pocket
12	7/02/2012 9.30	7/02/2012 9:48	984.55	3157	1499.574	1499.304	7201	Closed pocket

L_t - Cutting length S - Spindle speed T - Tool life T_R - Remaining tool life

5. Conclusions

It was noted that in recent research trends, there is a recognised need to incorporate real environment knowledge and experience to assist process planning in simulation systems. One example is to monitor tool information at shop-floor for assisting efficient machining as well as guiding operators with up-to-date tool status. General practice usually realise static tool information using available tool catalogues employed during process planning activities. This is indeed a time-consuming routine task. Furthermore, this activity hinders the possibility of more intelligent simulation analysis being established. The integrated system (iHFMS) developed in this study is able to monitor dynamic tool life values based on the shop-floor status. Continuous tool updates were fed to the simulation system by updating the NC programme codes based on high-level CNC data (STEP-NC). A Cutting Tool Database (CTD) was generated based on barcode identification of each tool and updates the remaining tool life of a particular tool. Following that, Machine History Database was generated to allow advanced analysis to be performed for future simulation analysis. The results show that the approach can furnish all the information required to analyse any machining performance.

Acknowledgements

The work was funded jointly by Ministry of Higher Education (MOHE) Malaysia and Universiti Teknologi Malaysia (UTM). The authors would also like to express a special acknowledgment to Mr. Jimmy Bao for his contribution in the enhancement of the Post-Machining interface and Dr. Firman Ridwan for the insightful advice.

References

[1] F. Hosseinpour, H. Hajihosseini, Importance of simulation in manufacturing, World Academy of Science, Engineering and Technology 27 (2009) 285-288.

[2] C. McLean, S. Leong, The role of simulation in strategic manufacturing, Proceedings of the 2001 International Working Conference on Strategic Manufacturing, 2001, 239-250.

[3] J. Heilala, Use of simulation in manufacturing and logistics systems planning, Proceeding of the VTT Manufacturing Technology, Finland, 1999.

[4] X.W. Xu, Q. He, Striving for a total integration of CAD, CAPP, CAM and CNC, Robotics and computer-integrated manufacturing 20 (2004)101-109.
[5] ISO 14649, International organization for standardization, data model for computerized numerical controllers, Part 1, Overview and fundamental principles, 2003.
[6] ISO 14649, Industrial automation systems and integration physical device control-data model for computerized numerical controllers, Part 10, General process data, 2003.
[7] F. Ridwan, X. Xu, G. Liu, A framework for machining optimization and process control based on the STEP, Journal of Intelligent Manufacturing 23 (2012) 423-441.
[8] R. Laguionie, M. Rauch, J.Y. Hascoet, Simulation and optimization in a multi-process environment using STEP NC, Proceeding of the IEEE International Conference on "Control and Automation", Christchurch, 2009, 2384-2391.
[9] R. Liu, C. Zhang, R. Wang, Data processing and simulation platform development for STEP-NC, Computer engineering 31 (2005) 179-181.
[10] A.A. Kadir, X. Xu, Towards high-fidelity machining simulation, Journal of Manufacturing Systems 30 (2011) 175-186.
[11] G.C. Vosniakos, A. Daskalopoulos, N. Straggas, A web based integrated cutting tool management system, Proceedings of the 7th Biennial Conference on "Engineering Systems Design and Analysis" ESDA'2004, Manchester, 2004, 19-22.
[12] A.A. Kadir, X. Xu, Smart NC code generation via high-fidelity machining simulation, Proceeding of the 15th International Conference on "Mechatronics Technology" ICMT'2011, Melbourne, 2011.
[13] ISO 14649, Part 11, International organization for standardization, Data model for computerized numerical controllers, Process data for milling.
[14] ISO 14649, Part 111, International organization for standardization, Data model for computerized numerical controllers, Tools for milling.
[15] ISO 10303, Part 105, STEP product data representation and exchange: integrated application resource: kinematics.
[16] ISO 14649-201, International organization for standardization, automation systems and integration, physical device control, Data model for computerized numerical controllers, Machine tool data for cutting process, 2011.
[17] ISO 10303, Part 41, Industrial automation systems and integration - Product data representation and exchange - Part 41, Integrated generic resource, Fundamentals of product description and support, 2000.
[18] ISO 10303, Part 42, Industrial automation systems and integration - Product data representation and exchange - Part 42, Integrated generic resources, Geometric and topological representation, 1994.
[19] ISO 10303, Part 43, Industrial automation systems and integration - Product data representation and exchange - Part 43, Integrated generic resource, Representation structures, 2000.
[20] ISO 10303, Part 21, Industrial automation systems and integration-product data representation and exchange-part 21, Implementation methods, Clear text encoding of the exchange structure, 1994.
[21] M. Blair, T.L. Stevens, B. Linskey, Steel castings handbook, Steel founder's society of America ASM International, 2007.