# Supporting fault diagnosis through a multi-agent architecture

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**Abstract:** In the industrial environment a short down-time of computer numerical control (CNC) machine tools is increasingly important. One approach to counter the loss of production is to make the machines more reliable, thereby reducing their times of non-use. Another is to enable machine operators to locate and to remove machine faults and their causes themselves, in order to reduce delay until maintenance staff is sent from a location far away. Operators may be supported in the fault-finding process by a knowledge-based decision-support system. The questions as to how to avoid the negative consequences of using such systems and how to even increase competence on the job is addressed by ComPASS, a system based on a multi-agent architecture. A running, functioning prototype was developed and evaluated. Based on this experience the system is currently being extended and improved, first results of which are presented here.

**Keywords:** fault diagnosis, decision support, multi-agent system

## 1 INTRODUCTION

In the industrial environment a short down-time of computer numerical control (CNC) machine tools is becoming more and more important. Rather than making the machines more reliable and thereby reducing their down-times, the approach taken here is to enable machine operators themselves to repair the malfunction in order to avoid the delay until qualified maintenance personnel arrive to solve the problem. Operators may be supported in the fault-finding process by a knowledge-based decision-support system. However, diagnostic tools bear the danger of people relying too much on them and their capabilities, so that after a while formerly competent personnel lose their competence [**1**]. This can even occur with the use of an expert system, if it merely gives instructions on how to remove a fault rather than explanations on how the error was located or other possible causes for the errors and how to avoid a repetition of the same fault.

The development of ComPASS (competence promoting multi-agent system for support) is aimed at overcoming the problems mentioned above in the application area of fault diagnosis of CNC machine tools. A multi-agent structure was chosen because it makes it possible to distribute the knowledge concerning the problem-solving process over several agents [**2**], each supplying the user with a different view on the problem [**3**].

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## 2 APPLICATION DOMAIN AND SYSTEM ARCHITECTURE

ComPASS was developed to assist operators in the process of locating and remedying malfunctions occurring at a CNC machine tool. The support for the user during the diagnosis consists of the presentation of different views on the diagnostic problem and their likely solution. The alpha-version of ComPASS [**4**] consists of two deliberative, adaptive, loosely coupled agents, each furnished with its own inference strategies (Fig. 1). It lies in the user's determination to utilize just one agent or both. The two agents were named after their main direction of search for the source of a fault, the so-called horizontal agent and the vertical agent.

The horizontal agent searches along the functional dependencies between component parts and assemblies of the machine, whereas the vertical agent searches for fault dependencies at a single assembly or component.

ComPASS has the following further features, which help prevent a loss of competence on the side of the operator:

(a) forcing intense interaction with the machine;

  

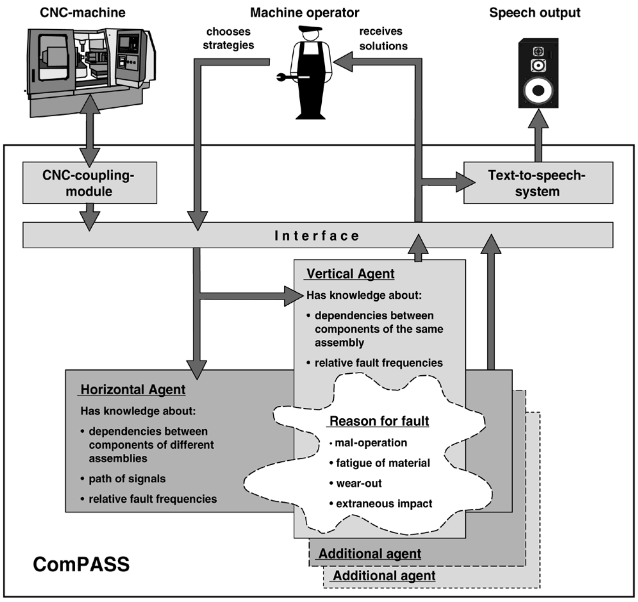


**Fig. 1** Components of ComPASS

(b) presenting different possible sources of a malfunction, where the user has to decide which path to pursue;
(c) offering strategies for finding faults, which might be new to the operator.

## 3 DIAGNOSTIC STRATEGIES

Not all the 15 diagnostic strategies defined in the literature (Table 1) were implemented in the alpha-version of ComPASS, but will be added step by step. The strategies implemented so far were chosen according to the ease of comprehensibility and application, the coverage of the whole machine and the distribution over the agents.

**Table 1** Diagnostic strategies according to Konradt [**5**]

| Number | Strategy | Frequency distribution |
|---|---|---|
| 1 | Historical information | 29.0 |
| 2 | Least effort | 11.5 |
| 3 | Reconstruction | 9.8 |
| 4 | Sensory checks | 8.7 |
| 5 | Systematic narrowing | 6.6 |
| 6 | Signal tracing | 6.0 |
| 7 | Conditional probability | 5.5 |
| 8 | Relative frequency | 4.9 |
| 9 | Exclusion | 3.3 |
| 10 | Manuals | 3.3 |
| 11 | Pattern of symptoms | 2.7 |
| 12 | Topographical search | 2.2 |
| 13 | Diagnosis software | 1.6 |
| 14 | Split half | 1.1 |
| 15 | Information uncertainty | 1.1 |
| 16 | Other | 2.7 |

The strategies were distributed over the two agents considering the whole machine so as to give the most detailed information about error dependencies but also to have overlapping domains. Examples of strategies implemented are given in the following:

### 3.1 Horizontal agent

(a) *Path of signal*: frequently applied strategy, suitable to follow a symptom to its source (types of signals: electrical, mechanical, hydraulic, pneumatic).
(b) *Patterns of symptoms*: fast, goal-oriented search for faults, without the need for further input to be calculated from a database.
(c) *(Relative) frequency*: easy to understand, easy to apply, suitable especially for novices.
(d) *Document-based search*: support by agent trough online documentation.

### 3.2 Vertical agent

(a) *Path of signal*: often applied strategy for unknown difficult problems, searches in depth along the component tree.
(b) *(Relative) frequency*: easy to understand, easy to apply, suitable especially for novices.
(c) *Document-based search*: support by agent trough online documentation.

## 4 COMPASS SUPPORT FOR THE USER

Error messages can be input by the operator or are received by the CNC-coupling module of ComPASS and are analysed by the agents. There are two different starting points for the analysis of possible causes for a malfunction. The fault is described by either naming the component and having the system show possible malfunctions for it or by choosing the malfunction and letting the system add the function and component (top area in Fig. 2). The user may choose the agent(s) and the strategies for them to pursue. After selecting main and secondary strategies, the horizontal agent, for example, may follow the given type of signal (here, mechanical) until either the source is found or it is clear that the fault must pertain to other types of signals. In the latter case, search has to be continued on another signal or started anew with different parameters. The actions and results of the agents are shown in scrollable windows. Figure 2 shows a screenshot in the situation where the agents, having been given strategies to follow, produce the shown results of their information processing.

Once the agents have come up with the results, explanations may be presented. ComPASS offers hints for control and correction measures. To achieve a larger

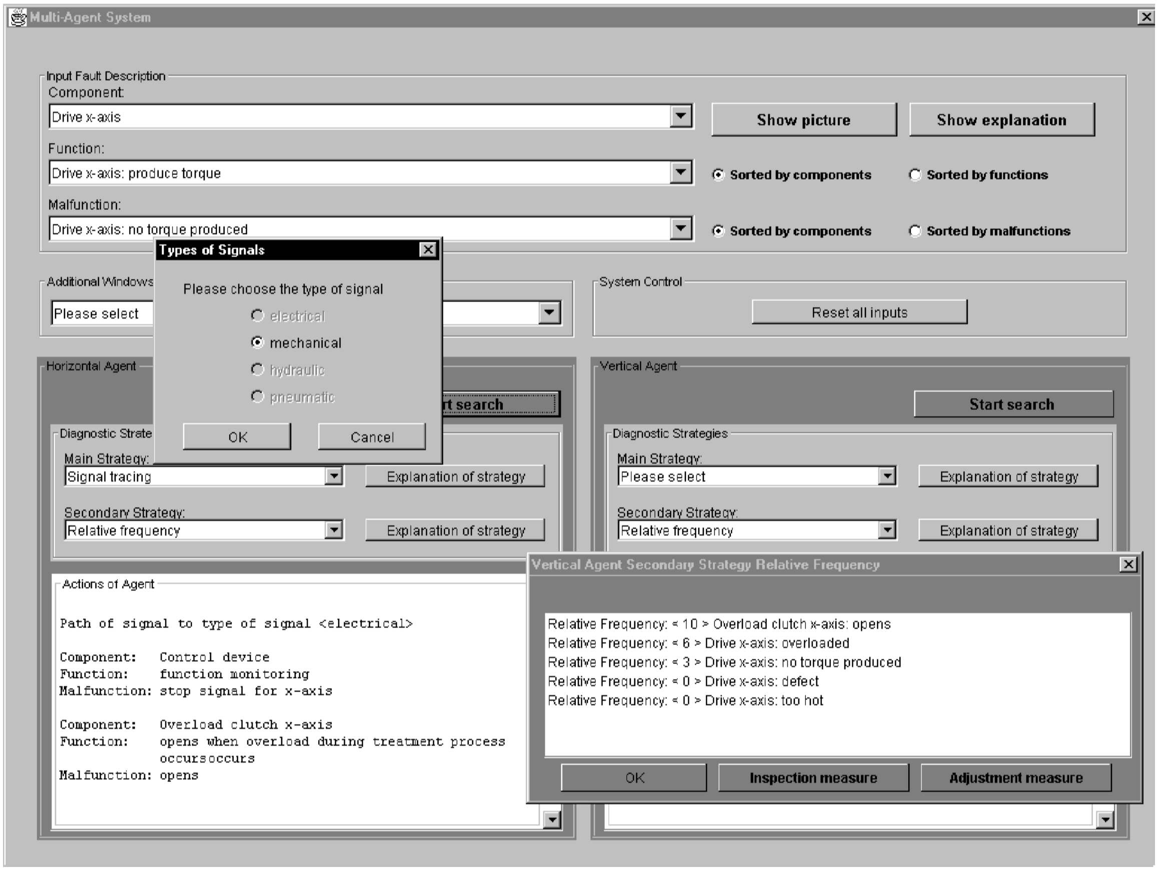


**Fig. 2** Fault diagnosis with ComPASS

comprehensibility, a component tree, which contains the components of the machines in a hierarchically structured way, is integrated into the system (Fig. 3, left). Furthermore, photographs (Fig. 3, top right) or explanations concerning the affected components and assemblies (Fig. 3, bottom right) are shown. Information about the function and possible malfunctions are available via an online help function.

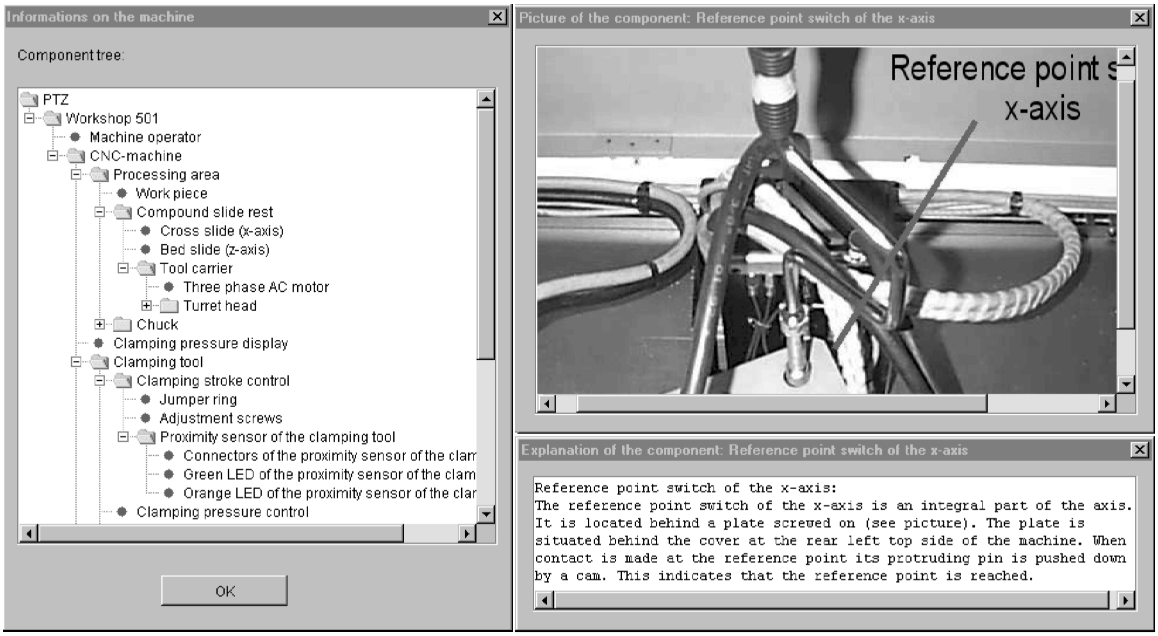


**Fig. 3** GUI for user support

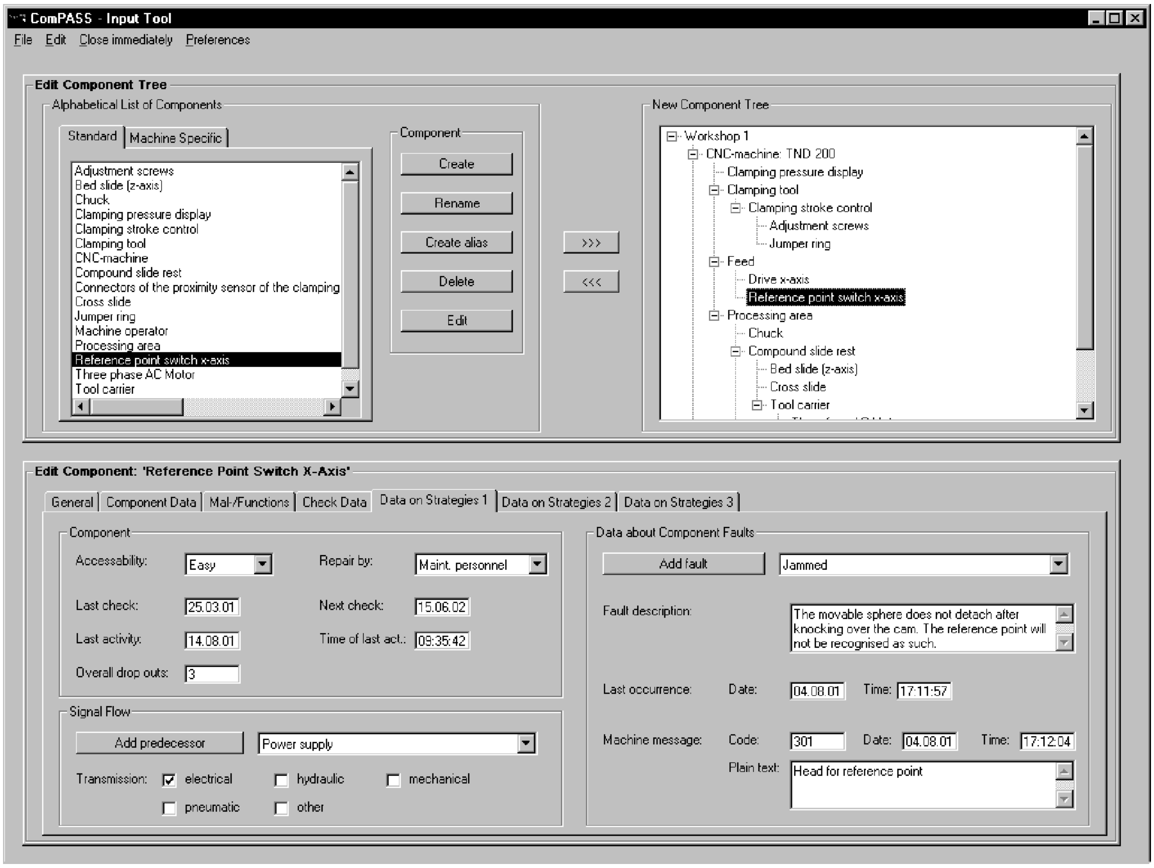


**Fig. 4** GUI of input tool for the developer of an application

## 5 SUPPORT FOR THE DEVELOPER

The developer of an extension or modification of ComPASS is the person responsible for the data input concerning a specific machine. For ComPASS to work properly, all data regarding a machine and the inference processed have to follow a specific format. Therefore, to support the developer, a tool is provided that allows for comfortable recording of the required input. Data concerning information on other machines or assemblies may be included. The forms offer the developer fields to input all the necessary information on specific machine parts (Fig. 4). They also let him or her add the photographs and explanations, which are presented to the user at run-time, as shown in Fig. 3.

## 6 PERSPECTIVES FOR THE EXTENDED SYSTEM

The prototype of ComPASS was evaluated [**6**] and any hints for improvements were taken into consideration for an upgrade of the system version. The ultimate goal of the development is to implement the system in SMEs that are using CNC machine tools. For this to be feasible, several modifications are made.

### 6.1 Source code

It was considered necessary to reimplement the system in large parts. The original system was programmed in Java, making a fast prototyping easy. The final system will be built in C++ to be faster, more reliable, and independent of additional interpreter software.

### 6.2 User interface

The user interface will be redesigned using self-explaining icons and more comprehensible expressions for terms like ‘horizontal agent’. To allow a multi-lingual use of the system, a change of language at run-time is facilitated by requiring all data necessary for outputs on the screen to comply to the UNI-Code standard.

### 6.3 Further agent

The characteristics of a third agent have not yet been fully defined. The options are to use it for protocolling sessions, for tutorial purposes or as an assistant giving advice, if and when so desired by the user. Any other form of agent does not contribute directly to the diagnosis of malfunctions by offering new strategies or perspectives, but supports the learning with the system. A protocol agent will be employed for reconstruction and historical information. Even though all the options could be helpful in making the system more supportive of the diagnostic task, one has to be chosen over the others due to restrictions and limitations in a project.

### 6.4 Acoustic output and remote control

One result of studies in working environments was that a diagnostic system such as ComPASS may not be in the same room as the CNC machine tools, due to soiling or dusting the PC. Here, a solely graphical output forces the operator to print on paper the suggestions of the system as to the source and location of the problem. This sheet of paper has to be taken along to the site of the machine, where the operator starts working. Acoustic output could help concentration on the task instead of switching attention between the printed suggestions and the machine itself. The speech output can be realized using a text-to-speech system [7], allowing varying texts to be output according to the situation. The distance between the system and the operator requires a remote control to enable the repetition or continuation of the spoken instructions. The interaction will be performed either with an infrared remote control or a wireless telephone connected to the system via an integrated application programming interface (API).

ComPASS is being enhanced to include the described features in the near future. The suitability of the approach will be investigated in two environments, an SME in the Berlin area and—considering the multilingual aspect of the system—in Chile. The knowledge elicitation is continuing in these two environments, thereby leading to continued improvement of the system.

## ACKNOWLEDGEMENT

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