Error Recovery Assistant

For

Operators Of Industrial Automation

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ABSTRACT
All industrial automation systems fail from time to time thus the costs of support increase at the same rate as these systems become more and more complicated. In order to cut the cost of support, the operators needs to be better informed on how to diagnose and recover from failures. By enabling the electronic user manual with interactive feature in a web browser interface, the error recovery process is simplified and easier to perform for operators with minimal training. Different techniques of presenting the instructions to the user are also investigated. These methods include the graphic and text interface as well as digital video format.

Keywords
Industrial Automation, Error Recovery, Web Browser, HTML, Computer-To-Plate (CTP)

1 INTRODUCTION
With the advance of computer technologies, many industries now heavily depend on industrial automation (IA) to produce their products efficiently and effectively. Since automation is best suited for repeated tasks, the error recoveries for IA typically require the interference and diagnostic of its human operators. This creates an economical dilemma in terms of operator training. On one hand, well-trained operators can diagnose and correct most faults in IA and thus reduce the cost of machine support. On the other hand, as IA become more and more sophisticated, the cost of operator training increase significantly to the point where the cost saving in support does not justify the extensive training for operators. Therefore, in addition to design foolproof IA, easy-to-understand error recovery tools which assist the operators to correctly diagnose and correct the problems should reduce both the support and training cost. This paper investigates the use of web browser as an Error Recovery Assistant (ERA) to provide the operator with interactive error recovery information as well as integration with the Internet such that the information is up-to-date and under version control.

To demonstrate and test the effectiveness of the web browser based ERA, a Computer-To-Plate(CTP) output device, Creo Products Inc.’s Trendsetter Spectrum (Fig 1) is used as a target system for evaluation.

2 TARGET SYSTEM OVERVIEW
A typical CTP system consists of three components: workflow software, RIP, and output device. The workflow software manages the post-script files from the customers and fixes problems with these files. In the same time, the workflow software may add features to these post-script files to improve the quality of the final printed products.
Some workflow software may also schedule the RIP to optimize the throughput if multiple RIPS are connected. The RIP is used to convert the "vector based" post-script files into "dot based" raster files. The raster files are sent to the output devices such as the Trendsetter Spectrum for imaging. The RIP also controls the output device to synchronize raster file download as well as handling any exceptions generated by the output device. The RIP typically is a software application that runs on a multi-processor workstation. The output device receives control commands and raster data from the RIP for imaging onto the media. In the case of the Trendsetter Spectrum, the raster data is received via a SCSI link connected to the RIP workstation while the control commands are received via Creo Open CTP Interface (COCI). COCI ensures that the Creo CTP devices are compatible with RIP software from different vendor running on different OS. The COCI uses serial communication with ASCII protocol, which means any computer with a serial port can control the Creo’s CTP device (Fig 2). Since the COCI has been in service for more than 10 years [1], it is important that any changes made to the COCI must be backward compatible. This is due to the fact that the RIP software is produced by various vendors and it is impossible for all vendors to update their control software to accommodate the changes to the COCI.

3 ERROR RECOVERY MODEL

The error recovery can be done in forward or backward manner [2]. In forward error recovery model, the device and the operator attempt to continue from an erroneous state by making selective correction to the system state. Although forward error recovery can be efficient, it requires the device and the operator to accurately predict the location and cause of the error. In addition, forward error recovery is system specific.

The backward error recovery model relies on restoring the system back to a safe state previous to that in which the error occurred. It has the advantage that the erroneous state has been cleared and that it does not rely on the finding the location or cause of the fault. Thus, backward error recovery can be used to recover from unanticipated faults including design errors. The ERA uses backward error recovery model.

Sample Error

One of the common errors that occur on the Trendsetter Spectrum is "Media Jammed". This error occurs when for various reasons, one or both of the leading edge clamp and the trailing edge clamp that hold the media on the spinning drum is unable to hold the media. Thus, the media flies off the drum and triggers the laser beam that ensures the media sits on the drum properly. The device then stops all actuator movements, switch to the suspend state, and reports an exception "Media Jammed. Please remove the media manually" to the RIP software.

To recover from this error, the operator has to interact with the machine extensively. In addition, each recovery step requires the decision from both the operator and the machine. Fig 3 shows the error recovery steps.

As shown in Fig 3, it takes 8 to 10 operator actions to recover form this error. Therefore, some sort of offline, step-by-step instruction is required.
Therefore, more and more systems are providing the operator manuals in electronic HTML form. Since HTML files can be downloaded from the Internet, the cost of distribution is minimal. Furthermore, the hyperlink function can provide information with scalable detail. On the other hand, HTML manuals do not interact with the target system and thus its usability is limited. For example, assuming the following error recovery procedure:

If sensor reads TRUE
Goto Step3
Else
Goto Step4
Without interaction with the target system, the operator has to read the sensor via some diagnostic interfaces and decide on whether to follow the hyperlink to step 3 or step 4. With interaction, as soon as the sensor reads TRUE, instructions for step 3 is displayed.

Finally, traditional instruction manuals consist of text and graphics. The use of video has often been omitted.

4 ERROR RECOVERY ASSISTANT
The error recovery assistant specified in this paper consist of three parts: hardware, workstation software, and device firmware.

Hardware
The hardware for ERA is shown in Fig 4.

Since the ERA shares the same hardware with CTP system, in order to ensure the ERA does not interfere with the normal operation of the CTP system, a separate communication connection is used. This also provides backward compatibility where if any ERA command were sent to an older firmware, which does not support ERA, would not cause the device to behave unexpectedly. Similarly, if an older version of workstation without ERA support were connected to an ERA-supporting firmware, the CTP system would still operate properly.

The connection between COM2 of the workstation and the ERA port of the device shall be identical as the connection between COM1 and COCI port. The connection is ASCII based serial link at 9600 baud with 8 data bit, no parity bit, 1 stop bit, and no flow control.

Workstation Software
The components of the ERA workstation software is shown

Fig 3. Error recovery Steps for Removing Jammed Media

Previous Work
The conventional way to provide operator instruction is via operator manual on printed-paper. Although printed manual are used widely in many industries, there are significant disadvantages. One of shortcoming of printed manual is the cost of distribution. Since IA systems are updated from time-to-time, the out-of-date manual needs to be recalled while the up-to-date manual needs to be issued at the time of update. In addition, it is environmentally unfriendly to publish manuals that would be obsolete in a short period of time.

The popularity of the Internet and the computerization of manufacturing floor have made the web browser and computer terminal widely available in the IA environment.
ERA User Interface
The ERA user interface is an html page with a java script that polls the status of the ERA extension handler every 500mS. When the device encounters an error, an ERA command is sent to the ERA extension handler with the error ID and the ERA user interface script uses the ID and search the corresponding error recovery pages in the error recovery database. When the search result is found, the pages are displayed on the web browser. Each page shall be divided into three frames. The top frame shall display the current status of the device, the ERA extension handler status, as well as hyperlinks to the CUA forum and the online response services. The left frame shall display the progress of error recovery process. The main frame shall display the error recovery page.

Error Recovery Data Base
Since there are more than 5000 possible errors for the Trendsetter Spectrum, a database of error recovery pages shall be designed such that it can handle search and query efficiently. In addition, this database shall be available offline and can be synchronized with the latest update via Internet or distributed CD-ROM since not all workstations are connected to the Internet.

For the purpose of academic study, only one error recovery page – “Media Jammed. Please remove the media manually” – is implemented. This page can be made available offline by either saving the page locally or use the “offline browsing” feature of the web browser.

CUA Forum
The CUA forum is an Internet news group where all users of Creo products can discuss issues about operating Creo systems. The forum is monitored by Creo service so the system experts can answer customer’s questions. On the top frame of the ERA user interface, a hyperlink points to the CUA Forum such that when the user click on the link, the CUA forum is displayed on a new browser window (or newsgroup reader window) to avoid interference with error recovery process. Obviously, this function requires the workstation connection to the Internet. This feature is reserved for future development.

Online Response Services
The Creo response centre provides 24x7x365 product support via telephone. However, if the support staffs are able to view or control the content on the workstation monitor as well as provide live feedback to the user, the error diagnostic and correction can be more effective. In addition, the cost of service may be reduced in terms of lower long distance phone charges.

On the other hand, there are concerns of users on the privacy and security issues with online response services. Thus more study on user acceptance on this feature is required. Nevertheless, a hyperlink shall be placed on the top frame of the ERA user interface and the online response services shall be launched ion a separate window when the users click on the link. This feature is reserved for future development.

ERA Extension Handler
The ERA extension handler is a collection of function calls that send and receive ERA extension commands via COM2. Fig 6 shows the available ERA commands.

<table>
<thead>
<tr>
<th>Command</th>
<th>Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA READY &lt;error ID&gt;</td>
<td>From Device</td>
<td>When the device is suspended due to an error of &lt;error ID&gt;, the device sends this command to the workstation. This indicates the device is ready to receive additional ERA commands from the workstation.</td>
</tr>
<tr>
<td>ERA ACT &lt;actuator ID&gt; &lt;parameter1&gt; &lt;parameter2&gt; …..</td>
<td>To Device</td>
<td>When the error recovery requires the device to move certain actuator, this command is sent with the actuator ID and a list of parameters.</td>
</tr>
<tr>
<td>ERA ACT &lt;actuator ID&gt; COMPLETE</td>
<td>From Device</td>
<td>When the actuator command is completed without error, the device returns this message.</td>
</tr>
<tr>
<td>ERA ACR &lt;actuator ID&gt; ERROR</td>
<td>From Device</td>
<td>When the actuator command cannot be completed without error, the device returns this message.</td>
</tr>
<tr>
<td>ERA READ &lt;sensor ID&gt;</td>
<td>To Device</td>
<td>When the error recovery requires the device to read certain sensor, this command is sent with the sensor ID.</td>
</tr>
<tr>
<td>ERA READ</td>
<td>From</td>
<td>When the sensor read</td>
</tr>
</tbody>
</table>
The ERA User Interface calls these functions to access and control the device.

Service Log
All commands processed by the ERA Extension Handler are copied to a log file with time stamp for future analysis and diagnostic. Fig 7 shows a few lines in a typical service log file.

```
6Mar00 5:44:41.906
Host Received Device String: ERA READY 15436
6Mar00 5:44:42.004
Host Send Device String: ERA ACT LEC 0
6Mar00 5:44:45.145
Host Received Device String: ERA ACT LEC COMPLETE
6Mar00 5:44:53.250
Host Send Device String: ERA READ DOOR2
6Mar00 5:44:53.905
Host Received Device String: ERA READ DOOR2 0
```

Fig 7. Typical Lines in a Service Log File

Device Firmware
The firmware of the CTP device controls various functions of the device including sensor reading and actuator movements. Fig 8 shows the block diagram of the integration of ERA to the existing firmware.

**Fig 6 ERA Extension Protocol (Version 0.1)**

- **ERA READ**
  - **Type:** Command
  - **Description:** When the sensor read command cannot be completed without error, the device returns this message.
  - **Message Format:** `<sensor ID> ERROR`

- **ERA NOT READY**
  - **Type:** Command
  - **Description:** When the workstation sends a ERA command to the device when the device is not ready (not in error suspend state), this message is sent.
  - **Message Format:** `<sensor ID>`

- **ERA ERROR**
  - **Type:** Command
  - **Description:** When the device is unable to accept certain ERA commands (i.e. due to syntax error), this message is sent.
  - **Message Format:** `<sensor ID>`

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**Fig 7. Typical Lines in a Service Log File**

**Device Firmware**

The firmware of the CTP device controls various functions of the device including sensor reading and actuator movements. Fig 8 shows the block diagram of the integration of ERA to the existing firmware.

**ERA Extension Interface Layer**

The ERA extension interface layer provide checks all incoming ERA commands which shall be of the proper syntax or the ERA ERROR message will be sent back. In addition, it also checks whether the device is in a state where it is ready to accept an ERA command. Thus, any ERA command passed to the ERA Command Processor is a valid ERA Command in term of proper syntax and proper timing.

**ERA Command Processor**

ERA Command Processor parses and re-packages all incoming ERA commands of the proper syntax into the internal firmware-messaging format and passed to hardware access layer. The respond messages from the hardware access layer are re-packaged to the proper ERA syntax and sent to the ERA Extension Interface Layer. The reasoning behind accessing the hardware layer directly is to ensure that any ERA operation does not interfere with the
normal CTP operation of the device. However, there might be potential danger to perform certain ERA operation when the device is under certain situation. Therefore, for full implementation, a safety guard layer shall be designed such that the ERA operation does not cause damage to device or injury to operator. For the purpose of this study, the safety layer is omitted for simplicity reasons.

5 ERROR RECOVERY TECHNIQUES

In addition to the traditional graphic and text, digital video is also used as means to provide the error recovery instructions to the operator.

Graphic and Text Interface

The graphic and text interface is used in most of the recovery steps. The main advantage of this interface is in its simplicity. Since graphic is readily obtained from digital camera and text is available in existing user manual, to generate graphic and text content can be done in a short period.

The graphic is edited such that a wide-angle photo shows the locations of the switches and a close-up photo shows the detail of the switches. This is to address the common problem of the operator being unable to locate the appropriate component indicated in the instruction.

For item definition, hyperlinks are embedded in the text and once the user click on the link, the definition text is displayed on a new window. This is to focus the operator on the main error recovery task while providing detail information if needed.

Digital Video Interface

Using digital video to provide instruction has several benefits. Unlike photographs, video shows action in progress. The operator is able to see the required error recovery step from its initial state to the finishing state. Rather than using wide-angle photo and close-up to indicate the location of a certain component, a single video clip can achieve this by starting at the wide-angle shot and zoom in to the component. In addition, the audio components of digital video instruction provide an additional sensory feedback to the user. However, digital video production is time consuming and requires more skills than still photography to produce effective content.

Other Issues

Each error recovery step must be simple and to the point. Avoid complicated logic at all cost. This is to ensure the operator understand what need to be done for a certain step and can perform the step accurately. For example, rather than using:

```
Step3()
    If A and B
       Goto Step5
    Else IF A and not B
```

A simpler alternative is:

```
Step3()
    If A
       Goto Step4
    Else
       Goto Step7

Step4()
    If B
       Goto Step5
    Else
       Goto Step6
```

The key is to allow the device to make programming logic decision while let the operator to make "fuzzy" or "human" decisions.

6 INFORMAL USABILITY EVALUATION

Three users from Creo Products Inc. are recruited to evaluate the usability of the ERA. 2 of the 3 users had previously operated the Trendsetter Spectrum while the third user has no experience with operating the device at all. The evaluation is conducted in an engineering lab with a Trendsetter Spectrum and the RIP workstation connected. The device is place into the "Media Jammed" erroneous state prior to the user starts the error recovery. Each user is asked to perform the error recovery steps according the instructions from the user manual on paper. The device is then place into its "Media Jammed" erroneous state with a different cause and the user is asked to follow the instructions from the ERA. Following the evaluation, each user is asked to fill out an evaluation form (Fig 9) and rank on a 1(Lowest)-5(Highest) scale.

<table>
<thead>
<tr>
<th>User Manual</th>
<th>Web Based ERA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of Use</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td></td>
</tr>
<tr>
<td>Navigation</td>
<td></td>
</tr>
<tr>
<td>Comment?</td>
<td></td>
</tr>
</tbody>
</table>

Fig 9 ERA Usability Evaluation Form
All users rank the ERA being easier to use than the user manual (4.5 vs. 3), provide clarity to the error recovery steps (4.5 vs. 2.5), and easier to navigate and find the information they need (4 vs. 3). On average, the ERA is ranked to be more efficient than the user manual (3.5 vs. 3). However, one user did point out that since the ERA is on the workstation, it is difficult to bring the instruction near the device to recover error efficiently.

All users commented on the video segment of the ERA. All users reported that the audio is very inefficient due to the background noise in the lab. Experienced users reported that the video flow "too slowly" while the novice user reported the video flow "too quickly". All users like the interactive aspect of the ERA so they don't need to switch to a different application to issue commands for error recovery.

7 COMPARISON OF ERA TECHNIQUES
Comparing the graphic and text interface with the digital video interface, the graphic and text interface clearly is better in terms of economics; the cost of producing the digital video is significantly higher than the graphic and text. The costs are due to longer pre-production (video shooting) time, more costly equipment, and longer post-production time. Furthermore, based on the informal usability evaluation, the digital video format is not as effective as the graphic and text one.

The shortcoming of the graphic and text interface is the need for two separate photos (one with wide angle view and one with zoom-in view) to assist the user to locate a particular switch on the device. The number of photos cluttered the workspace and may mislead the user. One possible solution is to incorporate a zooming feature (such as the ZOOM server from MGI Software Inc.[3]) so the user can zoom in and out of the wide-angle photo. Further work is needed.

8 FUTURE WORK
Further work is needed to refine and improve the ERA functionally. Areas worth investigating include:

- Implementing the CUA forum such that one can share tips and hints with other users.
- Implementing the online response services and studies the effectiveness of the services. In addition, the costs of integrating online services and telephone support shall be investigated.
- Investigating the use of ZOOM-able images to reduce the cluster of the interface.

9 CONCLUSION
The present work has demonstrate that by placing error recovery information on the web with the integrated command processing feature can improve error recovery process for industrial automation in terms of accuracy and ease of use. The electronic documentation aspect of the ERA reduce the cost of distributing instruction manual while ensures the users can obtain the most up-to-date information via the Internet. The interactive aspect of the ERA can improve the usability such that the user works in one familiar interface of the web browser rather than having to switch between different applications to achieve the error recovery. The present work also indicated that the use of digital video is not an economically sound method due to the high cost of production while the effectiveness of digital video instruction is limited in the industrial automation environment.

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REFERENCES