CAD of a Motion Control Package: A User Centred Approach

M. G. King

School of Acoustic and Electronic Engineering, University of Salford, M54 WT
Tel: 0161 2955952 Fax: 0161 295 597

Abstract: This paper presents the work of a programme which developed a simple two axis linear motion control package and the parallel development of its supporting environment for use in manufacturing systems. The emphasis was upon a User-Centred-Design approach and focused on producing a solution that was simple to use for both external customers and internal sales staff. This was achieved by adopting methods and tools familiar to both sets of users whilst combining them to form a complete package and supporting environment from initial sales enquiry through to installation and support of the package. *Copyright © 2000 IFAC*

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1. INTRODUCTION

This paper presents the work of a recent TCS programme that developed a simple two-axis linear actuator motion control package and the parallel development of its supporting environment for use in manufacturing systems. Taken together these developments provided a systematic approach to bespoke motion control packages that was unique in the market place.

This paper does not focus on the many new and mature CACSD tools available, instead it considers extending the focus to the incorporation of such tools into a wider, pragmatic design and development environment. Demonstrating how even relatively small companies can take advantage of the standard but powerful computer tools already available to them.

The emphasis was upon a User-Centred-Design approach and focused on producing a solution that was simple to use for both external customers and internal sales staff. This was achieved by adopting methods and computer based tools familiar to both sets of users and by combining these to form a complete motion control package and its supporting environment. By taking this holistic, systems engineering approach the final solution was capable of supporting staff from initial enquiry through to installation and support of the motion control package itself.

2. BACKGROUND

2.1 Pragmatic Use of Computer Tools

Many computer aided techniques for control system design are mature in their application and the availability of powerful PC's on the desktop of almost every employee along with company wide networking and shared data base connections is now taken for granted. This wealth of readily available computer resource (which was the perceived panacea only a few years ago) is often overlooked in the spiralling drive for the latest technologies and ever-increasing computing power. Whilst the latest tools may be required within the sphere of higher end applications for motion control packages there are a wealth of applications which require levels of technology readily available today, but in forms which make them more accessible, or in short more useable.

The motion control package described in this paper is one such example of a more usable approach. However, the industrial partner for this TCS project (a local motion control equipment distribution company) wanted the same ethos of ease of use to extend from the customer using the package to include those internal to the company and its extended enterprise (Szegheo and Petersen, 1999). The need was not just for a product that was easy to order and easy to use for the customer but also easy to receive enquiries for and which made the final solution easy to specify for the internal staff.

The final result was the development of a two axis linear motion control package, including actuators, motors, drives, controller with built in Human Machine Interface (HMI), its associated innovative software and a supporting environment developed in parallel for internal technical and sales staff.

2.2 The Overall Aims

The overall aims for the project were to develop a motion control package for an identified market segment of the manufacturing systems industry which was easy to order, easy to install and easy to use.

It was decided that the customer should not have to be an expert in motion control systems just to order the package, after all that is often why the customer comes to a supplier for a package solution. The package had to be supplied in a form that would make it possible for the average factory technician to install and the package had to be easy for the customer to use, so that they would not have to go onto a course or learn a programming language.

The elements of risk had to be greatly reduced for the customer; the risk of buying the wrong solution, the risks of complex installation and the risk of taking too long to get the package to do the job it was supplied for.

2.3 Design Approach

To achieve this a User Centred Design approach was adopted. User Centred Design is an integrated design method closely related to Concurrent Engineering (CE) approaches in which traditional down stream information from the design development process is incorporated into the early conceptual design stages.

Whilst it is accepted that user concerns should always be included in good design they are often not considered until after the technical concerns have been addressed (Lee-Mortimer, 1994). The mechanisms and electronics are considered first then some interface for the user is added towards the end. For a good example of this interface-at-the-end approach consider where the button for closing the draw of your CD ROM drive is located. (Namely; immediately below the draw, making it difficult to reach once the draw has been opened.)

The development of the motion control package described in this paper is particularly interesting from the User Centred Design point of view because two groups of users had to be considered, namely the external customer and the internal staff and a solution found which addressed the needs of both groups. Also the design had to take into account the wide range of potential applications for which the package was required to provide a solution. An overall design method was selected which utilised the approaches of Concurrent Engineering and thus facilitated the parallel development of all the software, hardware and procedural elements along with placing an emphasis on the early reconciling of the multiple viewpoints of the users (King and Gray, 1999). These viewpoints included marketing data and information from customers and staff concerning the types and ranges of potential applications as well as identification of problematic issues and areas of difficulty.

3. THE MOTION CONTROL PACKAGE

3.1 Setting the Initial Hardware Specification

Rather than take the more usual approach of selling each package as a bespoke solution, a standard off-the-shelf motion control package was developed. This off-the-shelf package was developed to cover a wide range of potential applications. Something, which, in itself was relatively unique in the market place.

From marketing information a broad outline for the package was set, one or two axis of linear motion, with control flexible enough to allow the package to be configured to a range of applications. The marketing information was also used to set the wide specification within which the package would have to perform in terms of the range of speeds and loads it needed to be able to handle.

By taking an extended enterprise approach and working closely with suppliers the format for the package, in terms of specific component selection was set based on the combined experience of those involved. A middle range, belt driven linear actuator was selected for the package and held on the shelf in a choice of three standard working strokes. Similar choices of three standard gearbox ratios were available enabling a range of loads and speeds to be provided whilst maintaining the same motor drive combination. And finally a controller with built in interface was selected consistent with the aim of keeping the number of components in the package to a minimum, thus reducing complexity in assembling and installing the final package.

3.2 The Control Software

The unique feature of the package was the ease of use of the control software. Normally to program a motion controller requires attendance on a course or having to learn a large manual of commands. Which means in practice to change the sequence of operations of the machine a new programme has to be written. This is usually just long enough after the course has been attended that everything learned has been forgotten, leaving the customer ringing for technical support with a large manual in front of them, whilst simultaneously trying to download a new programme from their lap-top PC to the machine's controller. All of this can be required just to make simple changes of speed or distance. This was not an approach that was felt consistent with ease of use.

By working closely with the supplier of the controllers flexible but simple to use software was developed. This software enabled the customer to build up motion sequences using plain English commands from a drop down menu. The number of available commands was limited to reduce the learning curve for the customer, but provided enough flexibility to develop relatively complex sequences.

The basic commands were as follows: An INPUT command enabled any one of the available digital inputs to be specified. Once specified the execution of the sequence of commands paused at this point until that input had been triggered. This enabled the package to be linked to other hardware such as additional controllers, separate operator push buttons and additional sensors. The INPUT command supplemented dedicated inputs for safety features such as start-circuit-disable interlocks. An OUTPUT command enabled up to eight digital outputs to be configured via a simple bit pattern. The user simply toggled between on or off states for each output via a simple 'Output Wizard' without the need to calculate hexadecimal values for the bit pattern. A PAUSE command allowed users to enable a pause in the command sequence execution for a specified number of seconds. A MOVE command allowed the user to specify a distance to move in millimetres accurate to one decimal place. All MOVE commands were entered as absolute moves. However, with a simple change to a software menu prior to shipping the option of entering MOVE distances in relative mode was also available if the customer required it. A SPEED command enabled the speed of each move to be specified. However, it was found that this was not as simple as it first appeared. In entering a speed the user is really concerned with setting the length of time within which a move is to be completed. This is not a straightforward calculation for the customer since in order to calculate the time taken to complete the move the customer must also allow for acceleration time to reach the specified speed and similarly the associated deceleration time. Consultation with potential customers led to an approach that allowed SPEED to be specified as a function of the maximum available. Since in most cases it was found that as long as the package was capable of achieving the rapid section of the application within a given time, users were happy to express slower speeds, such as those for return values, as a function of the maximum available.

Other functions of the software included the ability to set a fixed number of repetitions for any sequence using a 'LOOP' command. To further reduce the potential complexity of using the software for the customer if both axis were given moves starting at the same time interpolation of the two axis was automatic, and set to coincide with the axis which would take the longest to complete its specified MOVE.

Having selected a command from the drop down menu the customer could then enter values for the command such as 'MOVE 480 mm.' Instead of having to make changes and download them from a laptop PC. The sequence of commands could be edited directly on the controller, enabling the customer to stop a sequence whilst it was running, make changes and then start the sequence again giving instant feedback on those changes.

Since the solution was being supplied as a complete package the physical limitations of the elements was known prior to shipping. This allowed each package to be configured with limits of travel, speed and acceleration profiles, which the customer could not exceed in configuring the command sequences. If the customer tried to set a move distance or speed which exceeded the capability of the package a warning was displayed on the screen and the user was given the option of selecting the maximum achievable value. This aspect combined with a high degree of software reliability made the package safe for the customer to use, it was not possible for the customer to crash the software or the hardware.

This ability for the customer to learn by experimenting directly and safely with the package was a key factor in establishing the package's overall ease of use. When combined with an easy to follow colour coded user manual incorporating simple set-up and tutorial exercises the average customer could learn to use the package in less than an hour.

In developing the controller software the concerns of the internal technical staff who configure the motion control packages prior to shipping also had to be considered. A similar approach was adopted which enabled all the changes required and values to be specified to be made via simple menus directly upon the controller itself so that no download from a separate PC was required for configuration. Configuration issues included entering a scaling factor for the gearbox ratio used and the setting of maximum parameters, such as the maximum distance of travel.

An important aspect of configuring the package was the tuning of the package required for the servomotors used to drive the actuators. A novel and robust tuning algorithm was utilised, which when combined with the information supplied concerning the customer's application enabled the package to be pre-tuned prior to shipping. This negated the need for any knowledge of servomotor tuning on the part of the customer or the requirement for an 'on-site' visit from an experienced technician. This was further enhanced by careful setting of the specification of the package well within its performance parameters, which reduced the critical elements to the tuning and enabling the package to operate within a band of parameters with the same tuned setting.

As an extra measure all the configuration parameters could be triggered with individual passwords via a hidden password entry screen. This made it possible for informed customers to make changes to specific pre-configured parameters, whilst being prevented from changing others. Since the configuration software used the same simple menu approach the customer could be talked through any changes over the phone by the technical support staff.

Installation of the package was simplified with the use of a standard cable kit with coded plugs and leads. Considerable time was spent in designing the wiring layout to minimise the number of interconnecting leads required. Originally the concept of supplying the electronics for the package in a standard pre-wired cabinet was proposed but no standard cabinet design could be derived from the differing requirements of customers and their applications. The standard cabling kit provided a good compromise allowing the customer to install the package in the cabinet layout of their choice without the need for undertaking the relatively complex task of making up the interconnecting cables for themselves.

3.3 Variations to the Standard Package

In order to produce software that was easy to use at its front-end levels for both the potential customers and the internal staff who had to configure the packages prior to shipping considerable time and resource had to be employed. In order to capitalise upon this and widen the sphere of potential applications for which the controller and its software could be used the configuration level software also enabled, via further simple menus, the controller to be set to work with a number of standard variations.

These variations included abilities such as using a range of ballscrew driven actuators rather than belt driven actuators. This simply required a calibration value to be read from a table and entered into the software when prompted. The scaling for each axis could also be set independently enabling rotary axis, or a combination of rotary and linear axis to be utilised. This was linked to the MOVE command, which could then be configured so that values could be entered in degrees of rotation or as linear distances. Lower levels of configuration enabled the same controller and software to be used with stepper motors, or for analogue inputs and outputs to be provided.

4. THE SUPPORTING ENVIRONMENT

4.1 The Switch from Applications Engineers to Technical Sales Staff

Whilst the design of the package itself helped ensure ease of use and installation for the customers the issues for the internal sales staff also had to be considered.

Normally the internal sales staff dealt only with customers who already know what components they want, such as a specific servomotor, namely an understood solution centred approach. Enquiries for package applications were dealt with by skilled applications engineers who made decisions about the components the customer needed derived from a problem centred understanding. However, these applications engineers represent a valuable resource to the company and rather than dealing with relatively simple package enquiries their expertise needed to be centred on the execution of larger and more complex projects.

Since the new package could address a wide range of applications all that needed to be determined was that the customer's application could be addressed with the new package. A standard enquiry procedure based around a questionnaire was developed. The questionnaire was structured to take the information from the generic towards the specific, starting with simple questions of the nature of the application, through to questions concerning the environment within which the package was to be utilised and then through to specific questions concerning loads and speeds. The questionnaire was developed based on the expertise of the applications engineers and was structured into plain, easy to understand language. The sales staff could simply take the answers to the questionnaire and compare them to the capabilities of the package. If the application could not be achieved with the standard package the enquiry complete with detailed information could be passed directly to the applications engineers with any risk areas clearly identified i.e. the aspects of the application that caused it to fall outside of the scope of the standard package. If the application fell within the capabilities of the standard package the sales staff could move on to provide a quotation.

4.2 The Platform for the Supporting Environment

The standard enquiry questionnaire was held as a document on the shared network, the key answers to the questions could then be entered into a standard form also held on the network which, over time built up to form a valuable database of market information.

The answers to the questionnaire could then be ported directly into a standard quotation form laid out in the same format and also held on the shared network. Putting out a standard quotation was a simple matter of filling in the blanks using the information gathered from the questionnaire, and calculating the cost from a standardised table.

Establishing the supporting environment was perhaps the most straightforward of the development aspects of the whole project. Standard office software was used for the questionnaire, enquiry logging and quotations. By using this standard software and by capitalising on the network connection a powerful approach was developed which did not even require the sales staff to learn how to use any new software.

4.3 Outcomes of the Supporting Environment

The questionnaire effectively captured the expert knowledge of the experienced applications engineers in dealing with enquiries and made it available to the other staff to utilise.

Rather than having to address each enquiry as a bespoke package and quotation, it was now possible to standardised, resulting in a reduction in the time used to go from enquiry to quotation for simple 1 and 2 axis packages of up to 80%. This integrated approach had the added advantage of providing automated tracking of enquiries and of collating market information.

5. CONCLUSIONS

Producing motion control software that is pragmatic for the customer requires considerable forethought of how the customer will utilise the software and an understanding of the problems customers experience in learning to use such software in the first place. This, combined with the need to have a similar level of simplicity for the internal technical staff who configure the packages prior to shipping, required considerable resource to be utilised in building a detailed overall picture of the problems which had to be solved. This had to include identifying the many and sometimes conflicting viewpoints of the problems. However, the overall result for these two groups of users was highly successful and greatly reduced the potential level of expertise required by them to use, or to configure the motion control package.

Getting the design right and developing a standard package enabled enquiry, quotation and costing procedures to be similarly standardised. Greatly reducing the company resource employed in these tasks for each enquiry. This aspect of developing all elements of the solution in parallel highlighted the effectiveness of Concurrent Engineering approaches in providing holistic solutions to complex problems.

The above presents an overview of the factors involved in extending control system design to incorporate user concerns and the wider supporting environment. Demonstrating that innovative products and improvements in business procedures as a whole can be stimulated with the use of broader design techniques. It also demonstrates that achievements can be made by taking a pragmatic approach and by utilising the wealth of computer based tools and the expertise of suppliers that is proven and available today.

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