MÄLARDALENS HÖGSKOLA
Department of Computer Science at Mälardalen University
Supervisor Rikard Lindell
Examiner Peter Funk

ABB Automation Technology Products
AB Robotics
Supervisor Ralph Sjöberg

Visual Programming

Simplified online programming of arc welding robots

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Authors: Mikael Johnsson
Andreas Örmo

ABSTRACT

This paper presents the result of our Master thesis work at ABB Automation Technology Products AB Robotics, performed late 2001 and early 2002.

ABB sees the potential in the visual programming field, and is interested in investigating if it is possible to develop something new or improved for manufacturers that have not got the possibility or knowledge to use RobotStudio[1]. These customers program in the old fashioned way; online.

The main purposes with this thesis are to show the principle of *visual* online programming by making an intuitive, robust, simple and usable prototype connected to present online programming methods, as well as to investigate the state-of-the-art in visual programming today.

The prototype has a straightforward, intuitive user interface, and the navigation is simple. Unneeded, advanced features are hidden and the use of necessary ones is simplified and automated to make it possible for a wider range of people to program arc welding robots. A user evaluation with people inside ABB is also carried out and the result about how these people understand the prototype is presented. The result from the user evaluation can be used as input for future development projects with focus on visual programming. Some of the comments from the test persons were “it is a very good idea and takes the programming phase in the right direction” and “if it works satisfactory, it is an opportunity to entice new customers to ABB robots”.

[1] http://www.abb.com/robots

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Andreas Örmo and Mikael Johnsson, January 2002.

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1 Introduction

Robotics has been an active area of research for more than three decades. Today various types of robots are thus in use in industry, in particular for manufacturing applications. Europe has a strong position in robotics manufacturing through major companies. ABB Automation Technology Products AB Robotics[1] is such a company that develops, manufactures and distributes industrial robots. An industrial robot is a complex computer aided system consisting of many parts. Ease of use and efficiency are strong user demands.

ABB´s robot simulator RobotStudio[2], that allows manufacturers to program their next job without interrupting the one currently in progress, is starting to attract considerable attention from both large and small companies. In some cases, it is halving the time for products to come to market and is cutting costs by up to 30 percent, according to customers[3].

This is the reality today. Customers, large or small, that have the funding, knowledge and technique use the latest technology. Virtual programming with RobotStudio allows companies to accept big contracts that would have taken a robot off the daily grind for long bouts of manual programming and testing.

In order to achieve simplification and efficiency in future use of arc welding robots, there is a need to investigate the possibilities to make use of a graphical description of the controlling program, as well as the process information. To create a graphical description, *visualization*, lies within the boundaries of something called Visual Programming[4]. VP research is a very wide concept with many concentrations, of which only a few are of interest in this case; fundamental research, industrial research in general and, if possible, special attentions towards the robot process industry.

1.1 Background

The majority of all visual robot-programming tools today are offline based. The big customers (e.g. car factories) are ready, and able, to invest money in expensive offline programming computers and programmers, and they have great use of pre-programming the robots for the big-scale production they provide. However, not all customers benefit from such systems. The smaller companies have maybe a single up to a few robots at their disposal, intended for a small-scale production. In their case, investing in expensive offline programming equipment is not really an option. Even if it was, once the equipment is in place, all work cells and materials need to be modeled, there must be an educated operator to do this, and so on. This gets very ineffective, considering the small quantities they produce, perhaps down to a single piece. The solution for them is to use online programming. Nevertheless, this also needs programming knowledge to perform. In relation to this, there are a large number of potential customers that also might use a robot if it was easier to program and maintain.

[1] For the remainder of this paper, ABB Automation Technology Products AB Robotics will be referred to as ABB Robotics
[2] http://www.abb.com/robots
[3] http://inside.abb.com (published 011119)
[4] For the remainder of this paper, Visual Programming will occasionally be referred to as VP for short

1.2 Purpose

The purpose with this thesis is not to create as much functional program code as possible, nor to build a fully functional application. Instead it is of importance to show whether it is possible or not to build an intuitive, simple and straightforward application using visual programming for the robot arc welding industry, and to make this process easier on the user. This is attempted with a prototype.

Another purpose is to present a summary of the best visually aided software applications available on the robot programming market up to date; in other words a state-of-the-art investigation.

1.3 Document description

The chapters are intended to be a chronological journey through our work. Starting at chapter 2 with a short background of different techniques used in robot programming today. Chapter 2 continues with the state-of-the-art investigation, followed by visual programming theories in chapter 3. Chapter 4 describes the prototype, including a user evaluation. The following two chapters are very important as they summarize, draw conclusions and give the reader ideas on future work in this subject.

Chapter 1 INTRODUCTION. This chapter introduces the reader to the thesis, background, purpose and limitations.

Chapter 2 ROBOT PROGRAMMING TODAY. This chapter describes the two main categories of programming techniques used in robot programming today. A brief description of how robots are programmed using RAPID is also presented. Finally there is a presentation of some visual programming tools on the market today.

Chapter 3 VISUAL PROGRAMMING. This chapter introduces the reader to the visual programming domain. It starts with a general discussion of advantages and disadvantages with visual programming, followed by a theoretical background.

Chapter 4 THE PROTOTYPE. In this chapter a prototype with the requested functionality is presented. It ends up in a few conclusions and a user evaluation section.

Chapter 5 FUTURE WORK. This chapter gives proposals on future work.

Chapter 6 CONCLUSIONS. This chapter draws conclusions over the thesis work.

2 Related work

The idea to this assignment is based on an earlier bachelor degree, “En studie av Visuell robotprogrammering” [27]. A free translation is “A study of Visual robot programming”, and it was intended to investigate the possibility to extend the textual programming phase with graphics and images.

A prototype was developed during this project as well. It uses a flowchart model to create arc welding programs, and a combination of buttons, icons and textual input in a windows-like environment to let the user set up necessary parameters.

2.1 Basic categories of programming languages

Virtually all robots are programmed with some kind of robot programming language. These programming languages are used to command the robot to move to certain locations, signal outputs, and read inputs. The programming language is what gives robots flexibility. When learning any programming language, be it a robot language or a computer language, one of the most difficult tasks is learning what the commands are and how to use them.

To get an overview of different types of robot programming languages, it is appropriate to put them in three basic categories:

1. **Specialized robot languages.** These languages have been developed specifically for robots. The commands found in these languages are mostly motion commands with minimal logic statements available. Most of the early robot languages were of this type, although many still exist today. VAL[1] is an example of such a robot language.
2. **Robot library for a new general-purpose language.** First creating a new general-purpose programming language and then adding robot-specific commands to it created these languages. They are generally more capable than a specialized language, since they tend to have better logic testing capabilities. KAREL[2] is an example of this type.
3. **Robot library for an existing computer language.** These languages are developed by creating extensions to already existing popular computer programming languages. Consequently, the robot languages resemble traditional computer programming languages, providing the same power as these widely used languages. RobotScript[3] is an example of this type of language.

[1] See [Appendix E - Table 1] for code example
[2] KAREL is a robot programming language from Fanuc Robotics, see [Appendix E - Table 2] for code example
[3] See [Appendix E - Table 3] for code example

2.2 Programming techniques

Today, arc welding robots are programmed in one of two possible ways. In reality, these techniques are often combined, which sometimes is referred to as hybrid programming. The two main techniques are described shortly below.

2.2.1 Online programming

Online programming means creating the control program directly on the robot's onboard computer, hence by manually steering the robot to different positions using a jog[1] or similar control mechanism. Each desired position contributes to the code as a number of coordinates. An advantage with online programming is exactness and few later corrections due to programming the actual robot in its actual real-world environment. Time consuming and long production stops are mentioned as disadvantages.

2.2.2 Offline programming

In contrast to online programming, offline programming means creating the control program on a detached unit, such as a PC. This involves either manual editing of code in a text editor, or automatically generated code using for instance a CAD-model in RobotStudio[2] [47] or corresponding environments. Once the program is ready for deployment, it is moved to the robot's computer for manual correction and tuning. An advantage with this method is that robots can be programmed before installation and stay in production while being reprogrammed, meaning production breaks usually are significantly shortened. On the other hand, manual correction sometimes gets very extensive, and a programmer is also required to write the code offline.

[1] A jog is a joystick for manual control of a robot
[2] RobotStudio is a software environment created by ABB for program development, simulation, code generation, etc

2.3 How an ABB arc welding robot is programmed today[1]

This section of the chapter works as a short introduction to understand the principles of how to program an online arc welding robot today, and is not a complete step-by-step guide. However, before this introduction it should be mentioned that today there are complete solutions that simplify the programming and use of robots. These solutions are called work cells (e.g. FlexArc Compact) and consist of a robot, welding equipment and software, integrated in a steel cage with complete safety functionality.

Before starting to edit arc welding instructions, the arc welding system and external axes must be configured. The arc welding data that is to be used needs to be defined as well. This data is divided into three types:

- **seamdata:** describes how the seam is to be started and ended.
- **welddata:** describes the actual welding phase.
- **weavedata:** describes how any weaving is to be carried out.

The exact components of the above data depend on the configuration of the robot at the time.

Now the arc welding instructions can be added. This can be done in the following way:

1. Jog the robot to the desired destination position.
2. Open the instruction pick list by choosing **IPL1: Motion & Process.**
3. Select the instruction *ArcL* or *ArcC*.

The instruction will be added directly to the program, as illustrated in Figure 1. The arguments are set in relation to the last arc welding instruction that was programmed. The instruction is now ready for use. However, if an argument needs to be changed, it can be replaced by another.

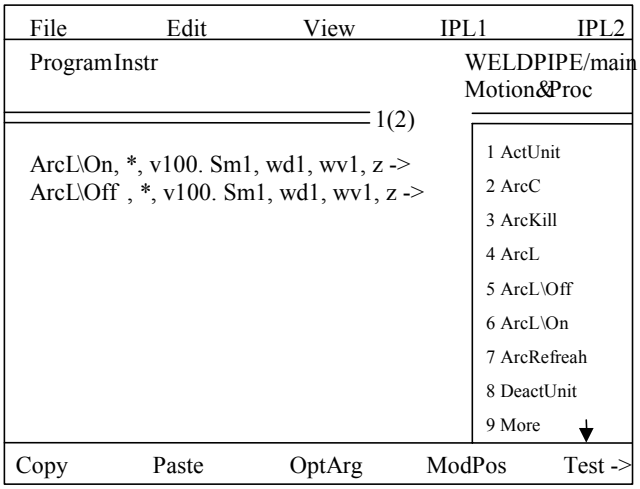


Figure 1 RAPID instructions on the teach pendant

[1] See [43] for further information

When finished adding arc welding instructions, it is time to go on with the arc welding topics. The topics contain parameters that define the arc welding functions:

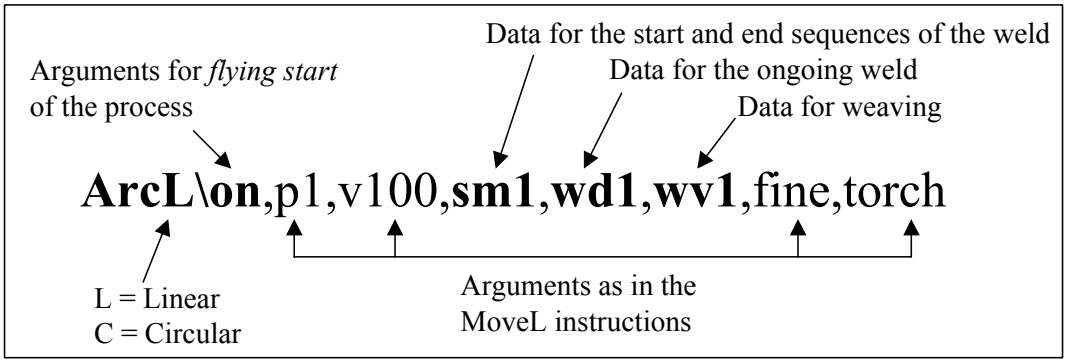
- The units used when the parameters are entered
- The process functions used
- The current equipment
- The weldguide sensor being used

When the setup is complete, and the program is running, there are two ways of tuning the weld data components. A short description of how to do it both ways follows.

Manual functions when program execution has been stopped
Certain weld data components (*weld_speed, weld_wirefeed* and *weld_voltage*) can be tuned using the weld data tuning function. When tuning this way, it is always the present value that is changed, however the original value can also be updated (i.e. it can be set to the same value as the present value).

Manual functions during program execution
Certain data can also be tuned while it is active (i.e. when the program is executing), however only the present values can be tuned. The original values can be altered only when program execution has been stopped.

Example of arc welding instructions




```
MoveJ p10, v100, z10, torch;
ArcL\On, p20, v100, sm1, wd1, wv1, fine, torch;
ArcC, p30, p40, v100, sm1, wd1, wv1, z10, torch;
ArcL, p50, v100, sm1, wd1, wv1, z10, torch;
ArcC, p60, p70, v100, sm1, wd1, wv1, z10, torch;
ArcL\Off, p80, v100, sm1, wd1, wv1, fine, torch;
MoveJ p90, v100, z10, torch;
```

Figure 2 Arc welding instructions in RAPID

2.4 State of the art

2.4.1 Approach

As mentioned earlier, VP is a rather wide concept. In this case however, state of the art visual programming systems are only interesting if they are applicable to robot programming. This approach turned out to present two types of applications, hence dividing the topic into two larger subcategories: general-purpose visual programming software and VP tools concentrated towards the robot process industry.

2.4.2 Compilation of visual programming software and tools

SW package	*Company Web-site*	*General description*
Sanscript	Northwoods Software Corporation (USA) www.trulyvisual.com/sanscript/index.htm	Visual dataflow programming language
Dymola	Rapid data (GB) www.radata.demon.co.uk/dymola.html	Modeling program and language
Amira	KUKA Roboter GmbH (GER) et al. www.cee.etnoteam.it/amira/frameset.html	Advanced Man-machine Interface (project before KIE)
KIE	KUKA Roboter GmbH (GER) www.kuka-roboter.de	Online visual programming language
UltraArc	Delmia (WorldWide) www.delmia.com	Simulation, offline program
CimStation Robotics	Silma (a division of Adept Technology Inc.) www.adept.com/Silma/products/pd-cimstationrobo.html	Simulation, offline program
ROPSIM	Camelot (DK) www.camelot.dk/english/historie.htm	Simulation, offline program
RobotScript	Robotic Workspace Technologies Inc. (WorldWide) www.rwt.com/RWT_Content_Files/articles/RWT_A Jan99IR.html	Macro-like robot program, visual / textual robot language
Grasp2000	Bygsystems limited (GB) www.bygsystems.com/robotics/robotics_index.htm	Simulation, offline program
Cosimir	Institute of Robotics Research (GER) www.irf.uni-dortmund.de/cosimir.eng/prospekt.d/welcome.htm	Simulation, offline program
ActWeld	Alma (FR) www.alma.fr/cgi-bin/charge_frame.pl	Simulation, offline program
RobotStudio	ABB (WorldWide) www.robotstudio.com	Simulation, offline program

Table 1 Compilation of visual programming software and tools

2.4.3 General purpose prototypes and software

Applications presented here are to be considered general-purpose visual programming tools. They are intended for various industrially related tasks, such as the robot industry, but need not be used specifically for programming robots.

2.4.3.1 Sanscript

Sanscript[1] [4] is a visual dataflow programming language and development environment. Scripts (called "flowgrams") are assembled from graphic functions connected together in dataflow-like diagrams. Sanscript is for professionals that aren't programmers, but "need to throw a script together now and then to get their job done". Functions are the primary components of Sanscript. Functions are represented by icons that include labels, inlets (data-entry points), outlets (where data leaves the functions) and other appropriate symbols. The icons indicate the action of the function. The pre-made functions include drive, path, directory and file management, text and string handlers, integer and decimal number tools, system utilities and user-interface components. There are also functions for working with the Windows Registry, data lists, and compound data records. Sanscript also includes functions for OLE/DDE that provide a mechanism to work with objects in other applications. There are over 200 functions provided.

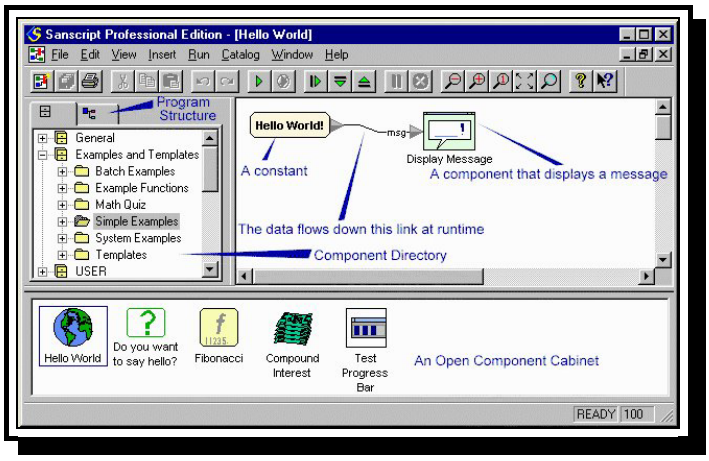


Figure 3 Sanscript (www.trulyvisual.com/sanscript/tour/sample.htm)

[1] Developed by Northwoods Software Corporation (USA)

2.4.3.2 Dymola

Dymola[1] [5] is described as both a general purposes modeling program and language, appropriate for building all sorts of mechanical and electrical systems. It has an object-oriented approach, enabling several of the powerful characteristics of such languages, e.g. hierarchical structures, model classes and even inheritance.

Dymola is built on using equations for describing modeling details. The equations are automatically solved and interpreted to symbolical representations. These models and symbols can then be generated on different formats. Supported at the moment are, amongst others, C and Fortran.

Dymola is available for the UNIX and Windows platforms.

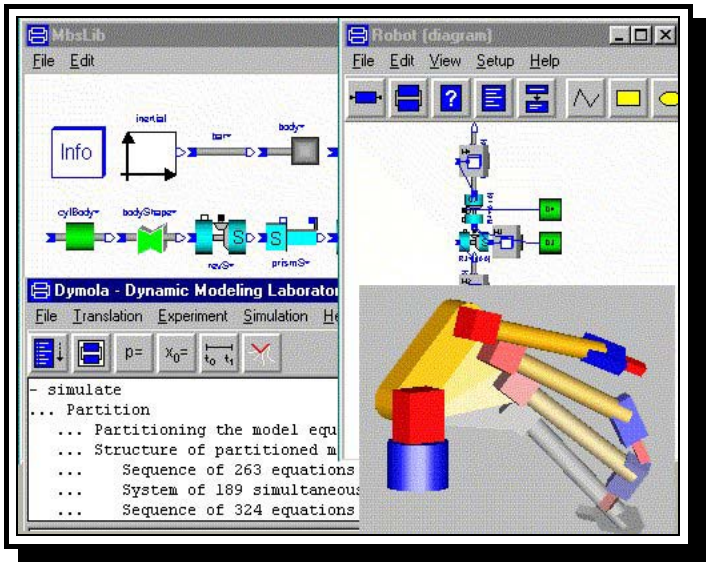


Figure 4 Dymola (www.radata.demon.co.uk/dymola.html)

[1] DYnamic MOdeling LAnguage by Rapid Data (GB)

2.4.4 Visual programming software concentrated towards the robot process industry

This section contains visual programming software directly aimed for the robot process industry.

2.4.4.1 AMIRA – Esprit project 22646

In November 1996, KUKA[1] lead the way for cooperation among five European companies, with the intention "to develop the next generation of advanced man-machine interfaces for robot system applications". The project was called Advanced Man-machine Interfaces for Robot System Application, or AMIRA [6 & 46] for short, and proceeded until spring 1999. Some of the keywords were "a visual language for robot programming", i.e. a tool that allows the end-user to create programs on a higher level than with the usual commands and instructions used in text based languages like e.g. RAPID. The result was a visual programming environment on a point-and-click basis that was "tested and verified in industrial environments", and thus created the foundation for the KIE[2].

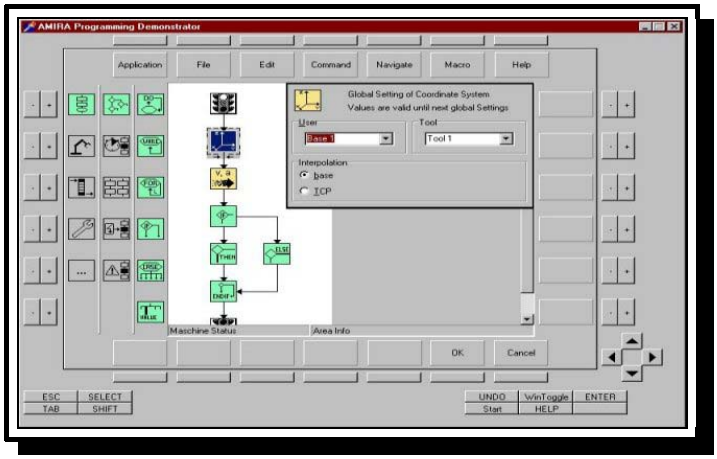


Figure 5 Screenshot of AMIRA - the precursor of KIE

[1] KUKA Roboter GmbH (GER), founded 1898 in Augsburg
[2] [2.4.4.2 KIE – KUKA Icon Editor]

2.4.4.2 KIE – KUKA Icon Editor

Based on the AMIRA project, KUKA developed an online visual programming system called KIE [7]. As with its successor, the idea is to relieve the end-user from syntactic work, and focus on the higher-level logic and task goals.

Instead of writing lines of code in a text editor, the 'programmer' selects the proper icon and inserts it in a flowchart-like environment. KIE also allows direct manual (textual) manipulation of the code to satisfy needs of both beginner and experienced programmers.

Considering that KIE uses icons to represent programs, there is a risk (as with all visual graphic environments) that the working space might become very immense and detailed. In an attempt to maintain the overall picture no matter the complexity of a program, KIE also features an overview window with zooming functionality.

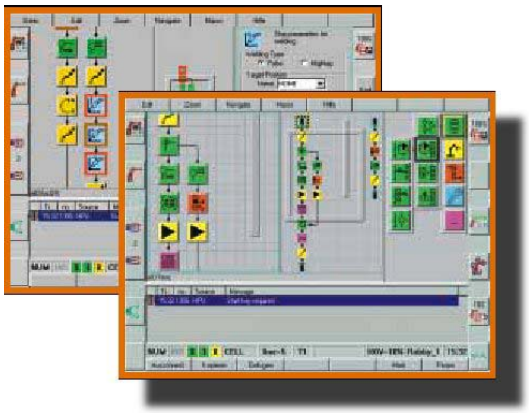


Figure 6 KIE - The KUKA Icon Editor (www.kuka-roboter.de/webc/re_engl/index.html)

2.4.4.3 UltraArc

UltraArc[1] [8] is a simulation and offline programming solution, with calibration tools that let users adjust the simulation model to accurately reflect real world device relationships. The interface lets programmers easily modify robot devices to achieve very accurate robot motion results.

UltraArc holds a library of arc welding robots and weld guns, including the latest robots from ABB, Fanuc and Motoman. It also includes a built-in CAD package to create custom work cell components and supports direct import of CAD files via IGES, DXF and direct translations. Robot programs can then be automatically generated from information contained in weld details. There is also support for robot controller-specific weld process information (seam tracking, seam searching, speeds, currents, voltages, etc).

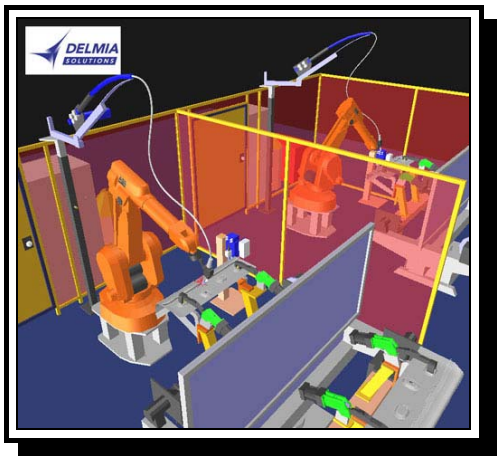


Figure 7 UltraArc (www.delmia.com)

2.4.4.4 CimStation Robotics

CimStation Robotics[2] [9] is a program much like RobotStudio. The major difference between these two products is that CimStation supports many different robot suppliers and their products.

[1] Developed by Delmia (worldwide)
[2] Developed by Silma (a division of Adept Technology Inc.)

2.4.4.5 ROPSIM

This virtual production system is a result of a research environment at DTU[1] and IKS[2], after further development by Camelot[3].

ROPSIM [10] is a PC based, model driven robot simulation system with 3D visualization. The simulation is performed virtually and allows production simulation on screen. It is a robot programming system for use in design, layout, production and maintenance of work cells in integrated production systems.

ROPSIM is:

- Developed for Microsoft Windows
- Able to reuse CAD models and simulate 3D robot programs
- Drag 'n drop programming
- Robot supplier independent

The program has been developed with the focus of simplifying offline programming of robots. Programming is graphical and supported by CAD models. It has a project-oriented approach. Models and robot programs are combined in projects for easy program usage. ROPSIM is open for integration with third part software. In ROPSIM, programs can be built in two different ways: interactively graphically or textually. Interactive programming is utilized for programming of movement, while program logics are programmed using the latter.

ROPSIM has interfaces for several robot vendors' controllers. The interface can consist of a text file on a disc, a network connection or through direct communication via the serial port of the PC. In other cases a post processor is used so that robot programs developed in ROPSIM can be transferred to the robot's controller.

2.4.4.6 RobotScript

RobotScript[4] [13] should get a category of its own, since it is not really a graphical environment for visual programming itself. Code is produced textually, but because it operates in a Windows environment, the end-user has the advantage of using any third-party software to enhance the operation of the robot cell. It also provides an intuitive, graphical user interface to reduce operator training and minimize errors. It can easily be customized using the Software Development Kit to provide a standard, enterprise-wide operator interface.

RobotScript is a macro-like robot programming language that employs the Microsoft ActiveX-technology, and is actually based on Microsoft's Visual Basic Scripting programming language. Consequently, RobotScript can be used in a variety of Microsoft development environments, including Visual Studio, Office or any Windows development environment.

[1] The Danish Technical University
[2] The Institute for Construction and Controlling technique
[3] Camelot Development (Denmark)
[4] Developed by Robotic Workspace Technologies Inc.

RobotScript is used to program virtually any robot model that is being controlled by the URC[1]. It runs in online mode in the Windows NT environment on a company's URC, or in offline mode on any PC running Windows NT/95.

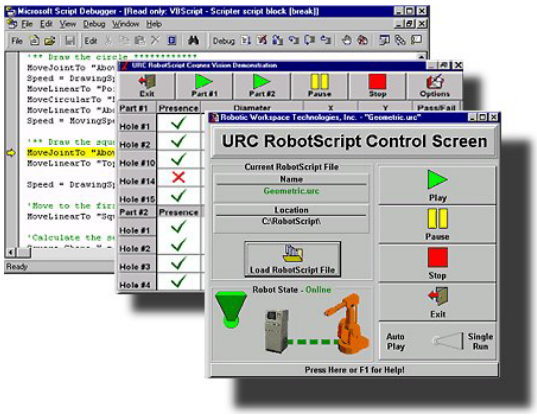


Figure 8 Robotscript (www.rwt.com/RWT_Content_Files/articles/RWT_AJan99IR.html)

2.4.4.7 *Grasp2000*

Grasp2000[2] [15] is another software application in the vast category of visual robot programming systems that support 3D models created with CAD tools. The system exists in two versions; one basic version supporting most common robots and robot programming languages, and another version developed together with Toshiba specifically for their robots.

In addition to 'standard functionality' among this kind of products, such as collision detection, reach validation and numerous system checks, Grasp2000 claims to be offering features that other offline programming systems do not; extraordinary calibration software for calibrating the 3D model and mapping it onto the real world. Further it needs no external measuring equipment to be set up, but requires only a few robot poses as input for calibration and analysis.

Grasp2000 is available for the Windows and UNIX platforms.

2.4.4.8 *COSIMIR*

COSIMIR[3] [11] is a 3D-robot simulation system much like RobotStudio. It can be used to check position reachability of all positions, as well as plan and simulate whole work cells. This means that not only robot motion, but also the interaction of the robot with the environment (e.g. gripper and transport actions) is realistically simulated.

COSIMIR supports several robot programming languages, for instance IRL, V+, KRL, RAPID, MRL[4] etc, and can generate programs in the chosen programming language automatically.

[1] Universal Robot Controller is an open-architecture, PC-based robot controller
[2] Developed by Bygsystems limited (GB)
[3] Developed at Institute of Robotics Research (GER)
[4] Industrial Robot Language, Kuka Robot Language, MovemasteR Command

Its structure is modular and can be configured with different packages and modules, making it possible to extend COSIMIR for new requirements, e.g. by adding additional modules for further programming languages or for the up- and download from/to specific robot controllers.

2.4.4.9 ActWeld

ActWeld[1] [14] is an offline programming development environment that, similarly to amongst others RobotStudio, imports CAD/CAM-models to allow for the programmer to program the robot graphically. ActWeld supports basically "all robots in the market", and claims to be able to take all necessary parameters into consideration.

2.4.4.10 RobotStudio

RobotStudio is ABB's own software tool for simulation and offline programming of robots. It is built on the ABB VirtualController, an exact copy of the real software that runs the robots in production, and hence provides very realistic simulations, using real robot programs and configuration files.

2.5 Conclusions

The extensive search for different modern visual robot programming environments provided a voluminous number of interesting software applications, that confirm what was stated in [1.1 Background]; a majority of them are offline based. A closer look at each one of them shows that many of them are very similar to each other, in many respects. The use of imported CAD/CAM-models with possibilities to simulate movements and generate code by graphically manipulating the model is a popular approach, as seen in RobotStudio, ActWeld, CimStation Robotics, UltraArc, etc. These different products could basically have been put under one headline, which is why not all of them have been described in detail.

Visual online arc welding programming tools on the other hand seem to be rare, the Kuka Icon Editor[2] excepted. A probable explanation is that successful research within this new, "hot" area is not presented to the public, at least not on the Internet.

[1] ActWeld is developed by Alma (FR)
[2] [2.4.4.2 KIE – KUKA Icon Editor]

3 Visual Programming

3.1 Introduction

VP has been an area of interest for quite some time. Research can actually be said to have been going on since the sixties, depending on exactly what is meant by 'Visual Programming'. What is really meant by the expression? For instance, autonomous robots (agents) that are able to interpret information gained through a camera are considered being visually programmed among some people. The expression itself often, and incorrectly, leads the thoughts to textual programming using visual environments, as for instance in Microsoft Visual Studio.

True visual programming researchers refer to VP as a method for creating whole programs using nothing but visual building blocks, implying nothing less should be called visual programming; no textual editing necessary, because there is often no generated code at all to edit. Menzies suggests a definition for what *pure* visual programming is: "A pure VP system must satisfy two criteria. Rule 1: the system must execute … Rule 2: the specification of the program must be modifiable within the system's visual environment … more than just (e.g.) merely setting numeric threshold parameters" [16]. Gorgan ignores the execution rule and defines visual programming like "the visual programming notion means the developer or programmer uses visually built up expressions in the programming process … For example, the syntactic forms are built by picking up the terms from graphics scene. If the syntactic forms and generally all program entities (i.e. statements, expressions, data structures, flow control structures, and so on) have visual presentations, then the programming language is visual programming language" [23]. Another idea of difference between visual and textual languages is multidimensionality, as expressed by Burnett [29].

In the case of investigating visual programming as a method for programming industrial robots, the pure visual programming approach seems tempting. However, at present time that is a very difficult goal to achieve, and a more realistic path would be a combination: a robot program is created using visual programming exclusively, but the programmer still has the opportunity to make necessary, final corrections on a lower (textual) level.

Without taking any of these thoughts into consideration, visual programming could probably be summed up with one word: usability. Usability is a word with many definitions. However, its basic meaning is about making it easier and faster for a user to learn, use and master something, in this case a software tool. Hence, making it easier on the end user, perhaps by creating an interface between computer and human that is more appropriate to us than the classical console/textual standard, is basically what visual programming is all about.

3.2 Outline

3.2.1 Is Visual Programming always better?

Whether programming visually really helps programmers or not has been lively debated. Results from studies and reports show very differing, at times even contradictory results [16]. Some researchers mean that they help to some extent, but are far from always superior to textual languages [19]. Others mean that TLs[1], including fairly new object-oriented ones like Java, already are on the edge of being obsolete, due to being to C-like, low-level and complex, suggesting they should be replaced by flowchart-like programming methods [20].

3.2.2 Known Visual Programming difficulties

There are a number of problems with programming visually that are known to VP researchers. One is the lack of desktop space, meaning visual representations of programs tend to quickly become very big. In addition, many visual environments use arcs to connect nodes (flowchart-style), resulting in lines going back and forth across the screen[2]; the combination of the two makes overviewing hard.

An issue that VP researchers often have to struggle with, is the difficulty of proving any of their theories in real life; it is hard to do reliable surveys to back them up, leaving a great need for empirical results on whether visual representations improve the programming process or not. This is a well-known problem in the VP community, also referred to as the evidence problem [24].

Another problem, that might seem peculiar and irrelevant, is the classical resistance among programmers to adapt to new programming techniques, and in particular the use of visual ones. Brooks writes, regarding graphical and visual programming for software development: “Nothing even convincing, much less exciting, has yet emerged from such efforts. I am persuaded that nothing will.” [17]. O’Brien agrees by writing “…beware the claims of visual programming. Drawing lines between objects becomes bafflingly web-like. Purely visual programming is not yet and may never be viable.” [18]. These extracts are just examples to show a bigger picture, so on the contrary, it is of great importance to take this issue into consideration when developing visual programming environments.

3.2.3 Why Visual Programming?

Despite present difficulties and problems to solve with VP, it is still necessary to consider the opportunities in a longer perspective. In the perfect case, the programmer’s job is made significantly easier. With syntactical problems removed, the programmer can focus on program design and what the program is supposed to do – the semantics. This should lead to a reduced development time, but at the same time improved software qualities.

[1] For the remainder of this paper, textual languages might be referred to as TLs
[2] This problem is sometimes referred to as the spaghetti plate syndrome

3.3 Theoretical background

There are a few difficulties doing theoretical research on VP. To begin with, there seems to be almost an inner circle of researchers, who seem to attend every meeting or conference available, and whose names are repeatedly cross-referenced from each other's papers and journals. Put differently, a majority of the documents concerning visual programming tend to be influenced by a minority of people - in one way or another. It is hard to tell what impact this may have on the results presented. Moreover, many of the theories stated do not have proper experimental studies to back them up (also implied by [21 & 22]); they are merely opinions or visions of the author[1].

Based on these conditions, the theoretical research presentation is presented as actual studies results on one hand, and authors' theories on the other.

3.3.1 Programmer survey

"The Outlook from Academia and Industry" is an extensive survey from 1997. It presents some interesting differences in opinion among different categories of people, including professional traditional programmers who are known to dislike new programming techniques, and especially visual ones.

Three different categories of *intended* VP users participated in one survey each: academic VP researchers with vast knowledge of visual programming languages, professional programmers with none or small VP knowledge and strict LabView[2] programmers. The three different surveys were constructed to provide comparable results (but here the LabView part is left out[3]), presented in 15 categories with regards to visual programming. These were of type *learnability, productivity, readability, etc.* A summary of the most interesting categories follows.

General impact refers to whether visual programming languages[4] are easy to use. The academic VP researchers agreed that is the case, while half of the programmers claimed VPLs do not make a difference on the matter, or are even more difficult to use.

Learnability is how easy something, in this case a VPL, is to comprehend and learn how to use. The difference of opinion showed once again, when the researchers repeatedly pointed out this VPL-benefit. The programmers however stated the time that would be required to learn a visual programming language, if they at all mentioned it.

Productivity. The paper says (quote) "…productivity improvements are the only justification for any investment in new programming techniques."

Both categories agreed that visual programming could increase the amount of code produced. However, unlike the VP researchers, the programmers disagreed that there also were advantages to design, debugging and maintenance as well, implying that the overall project benefits were less.

[1] See [3.2.2 Known Visual Programming difficulties]
[2] LabView is a visual programming environment
[3] The third survey questions were directly aimed at LabView and can be misleading in this theoretical discussion
[4] Visual programming languages might be referred to as VPLs

Readability. Both categories more or less agreed in this matter, that the structure is easier to follow in visual than textual programs. This may be worth noticing, since the programmers have little or no experience of VPLs. They referred to flow-chart diagrams and models in general, while the researchers more specifically pointed out the advantages of specific languages.

Documentation effects. Respondents from both categories stated that visual representation works directly as documentation, as well as a communicating medium between developers and customers. This is in line with Baroth and Hartsough's opinion several years earlier, quote "The most important advantage … in using visual programming is the support for communications among the customer, developer, and hardware … Without the visual component, the support for communications is not present" [28].

Syntax reduction and modularity. Although the researchers did not seem to think about less syntax problems as a big benefit with VPLs, it was pointed out clearly by several of the programmers. However, a few worried about syntactic problems using visual programming languages as well (e.g. the spaghetti plate problem).

The surveys were summarized using different codes, to get both numerical and theoretical conclusions. The overall picture confirms the well-known classical resistance and skepticism among traditional programmers against new programming techniques, no matter the advantages they may contribute with. Less powerful, less readable and less enjoyable to use were a few of their strongest arguments. The academic researchers had almost exclusively good things to say about VP, using positive influence on the mental process of the programmer as their best argument.

3.3.2 Researchers' theories

The following chapter describes different researchers' theories from the VP literature. The intention is to reproduce their theories as good as possible so that the reader can get a good overall picture about the different thoughts reported in the vast VP literature.

As mentioned before, there are very different opinions whether VP really improves programming in the ways that are claimed. There are three camps of researchers in the matter; those who are truly devoted to VP and all of its benefits, those who are very suspicious, skeptical and critical, and then the people in between, merely reporting others' statements.

Hirakawa belongs to the positive group, claiming "When we use visual expressions as a means of communication, there is no need to learn computer-specific concepts beforehand … which enables immediate access to computers even for computer non-specialists… ". He continues by stating that pictures are superior to texts by being more easily comprehensible and universal [30]. This is in line with Gradman's thoughts. He thinks the mind does not have to interpret a picture, since it already is in terms the mind can comprehend. He goes even further than Hirakawa when stating that "VP is such a powerful paradigm that a user does not even have to be a programmer to learn how to write applications. The universality of visual language ... makes programming something anyone can learn and do" [26]. Others oppose statements like these, and refer to the lack

of evidence supporting them [40 & 41]. Still a decade later, that is an unfortunate truth; hard evidence is rare.

Other typical statements are that VP is more user friendly, helpful, satisfying, intuitive readable, familiar, appealing, accessible, reliable, pleasant, straightforward, alluring, immediate and obvious than other programming techniques. Some researchers even believe that VP is easy to learn, easy to use, to write, understand and modify even without training. However, as with VP in general, there is little research that has investigated the relative speed of learning to program, and a claim of competence without training whatsoever seems unlikely [25].

According to Chang et al it was often stated that people find it easier to deal with the concrete than the abstract; solutions are easier to perceive if abstract information is converted to a concrete (i.e. visual) form [39]. Brown and Schiffer agree to this by pointing out that pictures are good at showing abstraction [38], or communicate a higher level of abstraction [36]. In addition, there is extensive general research showing that concrete words are easier to remember than abstract ones [31], while others say that abstract data is challenging for visual programming exactly because it is not naturally visual [37].

In a study, Blackwell noticed that several writers have mentioned how VP helps to express problem structure [25]. This was implied earlier by Schiffer, stating that relationships are more explicitly represented and easily recognized in pictures than in text [36]. These theories have further support in Larkin and Simon´s cognitive model of diagram use in problem solving, where locality and topological connections between elements reduce the need to label corresponding items [35].

Another thing Blackwell points out is that graphical information is more intuitive than text, that it enables use of “native intelligence” [34] and provides for “intuitive interaction” [33]. The fact that something is intuitive will make it easier to understand, in other words meaning that *graphical* presentations are more comprehensible [32].

4 The prototype

4.1 Background

ABB[1] recently finished an investigation among 250 ABB customers in ten countries worldwide. Although the customers seem to have confidence for the company, the results show that ABB is not generally associated with user friendliness.

To get an objective idea as possible about robotic arc welding, robots in general, robot programming, usability, problems and other important background facts, we have tried to get input from different points of views. This means we do not only want to know what people in the robot developing business think, but also what the end user on the factory floor has to say about it.

A field trip to Laxå, with the intention to hear about their development, goals, visions and expectations, also gave us an opportunity to see arc welding in their laboratory. A number of issues and problems regarding tuning and welding results became obvious during the demonstration.

This was followed up by a visit at Corporate Research in Västerås. They are developing a way to simplify the welding process as well. This relieves us from a few parts, since we now can assume these already exist. In addition, we were inspired by the way they presented the program information visually. However, once again we were reminded about the difficulties in robotic arc welding.

To balance these experiences, we visited Segerström&Svensson in Eskilstuna. They have a number of welding robots from ABB and Motoman. We made an interview with one of the people involved in programming/maintaining the weld robots. In addition to this interview, a small end-user survey was performed. The results provided us with a few interesting thoughts and even some concrete programming problems. A compilation of these can be viewed in [Appendix A].

It should be mentioned that an effort was made to get a demonstration of the "revolutionary" KUKA Icon Editor[2]. Contact was made with Peter Herbrich at DEFAC in Germany, but unfortunately nothing could be arranged.

[1] The investigation was commissioned in late 2001
[2] [2.4.4.2 KIE – KUKA Icon Editor]

In addition to this input, we have discussed these issues with several people at ABB Robotics. To summarize, there seems to be a general opinion that online programming of ABB arc welding robots today is unnecessarily difficult. A few main aspects of what these difficulties include (in no particular order):

- The programmer needs extensive knowledge about RAPID. Commands, syntax, function parameters, semantics and so on.
- The programmer needs to know how all parameters affect the welding result, which means he/she also needs to know a lot about welding.
- A company might be using several different robot fabricates. This means a robot operator would have to know several totally *different* programming languages as well.
- Tuning of welding parameters such as voltage, welding speed and wirefeed speed during welding means walking through several drop-down menus. Once the tuning menu is reached, the parameters can only be tuned one at a time. By the time all parameters are tuned, there is a good chance the robot is done welding a long time ago.
- The interface on the teach pendant[1] is generally not very usable (user friendly). There are several steps that should be avoidable in doing simple tasks such as programming and tuning.
- To change certain data for a welding program, such as the burnback time in the seam data or the wire diameter, the programmer has to walk through all files in the program and set it at every single location.
- Defining welding points by manually ”jogging” the robot is not easy, nor effective. Even so, this is still the most common way to do it.
- Today a program can be created by up to three different people. The following could be a totally possible scenario: one man defines a rough path, making sure the robot will not collide with any objects. The next one creates a more exact path, setting coordinates and angles the way they should be. The third person has vast knowledge about welding, so he/she sets up all welding parameters, such as weld data, seam data, weave data, etc. The natural reaction to this is that one person could do all of it if it would not demand him to know everything about both programming and welding.

All of this implies that there is a need to create a simple tool to let smaller customers program robots with extreme ease. The everyday user has a need for approximately 20 percent of all programming functionality available. The rest is considered unnecessary and even confusing. One approach to supply this might be to create a much simpler and more limited tool that allows for visual programming, and that has enough power to perform all actions needed for the small user.

[1] A teach pendant is the operator’s handcontroller to program and operate the robot

4.2 Visions

Visions on how to program an arc welding robot in the future are many and of different natures. Many of the thoughts are about how the programming phase can be simplified for the end user. It does not matter if you are running a multinational company with production all over the world, using advanced off-line programming tools in your production, or if you run a smaller business that generally programs the robot online; a demand these customers have in common is the possibility to handle and program the robot in the easiest possible way.

In relation to this, ABB Robotics wants to offer their customers innovative, advanced products that are experienced as user friendly, in the meaning that they are very easy to learn to deal with and use. The simplification is intended to substantially decrease the programming- and startup time considerably for the customers; an improved programming time from e.g. 3 weeks to 3 days, or 3 days to 3 hours is by no means impossible.

The bottom line is that a robot that is not working properly, or not working at all, means losing thousands of dollars every minute for a multinational company and is not acceptable in any way.

4.3 Goals

The best way to describe arc welding-robot programming today and what part of it this thesis focuses on, is perhaps with an overview relation chart:

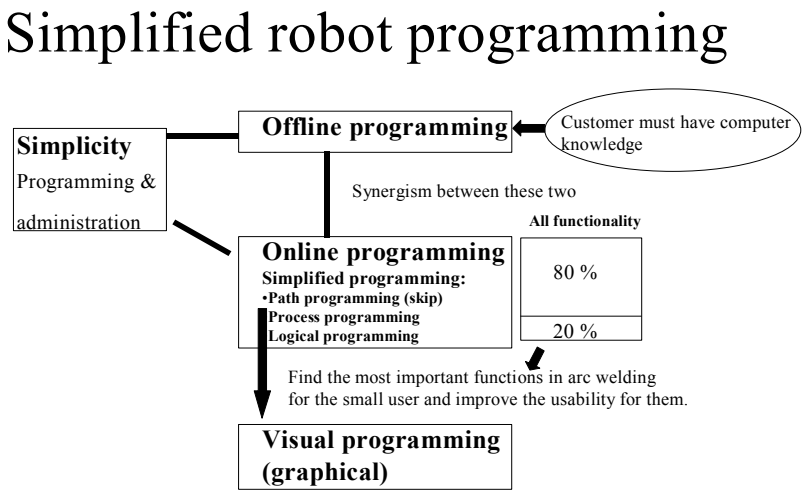


Figure 9 Schematic overview of the thesis project

The nodes “Offline programming” and “Online programming” describe the two ways of programming arc welding robots today. This thesis focuses on the process and logical programming parts in the “Online programming” node, not including path programming issues. From these parts, one objective is to extract the most important robot programming functionality and provide a new, visual interface. This could improve usability and widen the user clientele to include non-programmer welders on one hand, and non-welding programmers on the other. Another possible outcome might be to point out some sort of synergism between offline and online programming in general.

4.4 Approach

4.4.1 General description

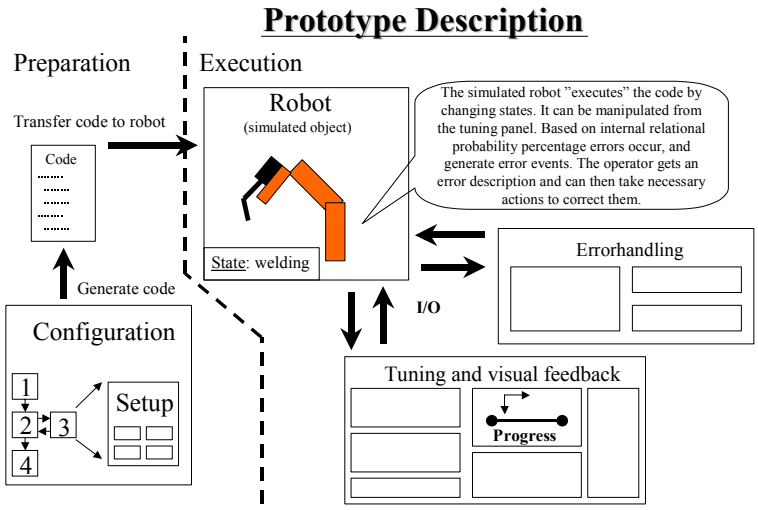


Figure 10 A comprehensive prototype description

The prototype can be thought of as five parts:

1. The first part is a weldpoint editor that really has nothing to do with the prototype itself. Its only purpose is to create a few virtual points in 3D-space that are necessary for testing of the following parts of the prototype.

2. The second part consists of four steps, of which three are unavoidable to the user. These steps let the user set up the weld process parameters as well as robot specific data, such as work angles, torch distance, speed and so on.

3. The third part of the prototype comes into action once the welding setup is completed. This is the robot simulation phase, that is used only to show how the tuning and error-handling modules are intended to work, and is actually just a small state machine representing a few actions of a very simple robot.

4. The fourth part is the real time tuning[1] module that is part of the robot simulation phase.

5. The last part of the prototype is the error-handling module. This is also a part of the simulation phase.

[1] See [Appendix D] for a screenshot of the prototype real time tuning module

4.4.2 Requirements

Although the prototype is to be seen as an experiment to point out the possibilities and obstacles with using a combination of words and pictures, the thoughts behind the design should be of some interest. The final requirements used in the prototype are developed with the help of discussions and meetings with people at both ABB Robotics and Mälardalens Högskola. These demands actually consist of three parts: requirements, restrictions and assumptions, however they all concern the prototype.

Taken all in all, it is implied that the prototype shall strive to fulfil some important parts of the usability concept, such as being intuitive, effective and easy to use[1].

The following model inspired the process of determining requirements:

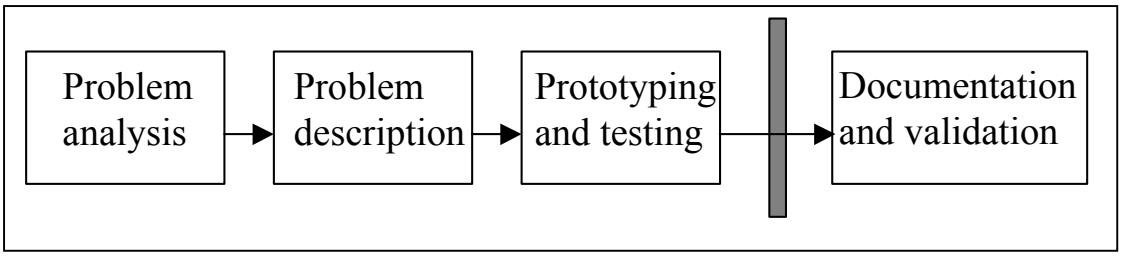


Figure 11 Requirement elicitation, analysis, definition and specification

[1] See [Appendix B] for a detailed description of the requirements

4.4.3 Work method

The overall development method was inspired by "the waterfall model with feedback".

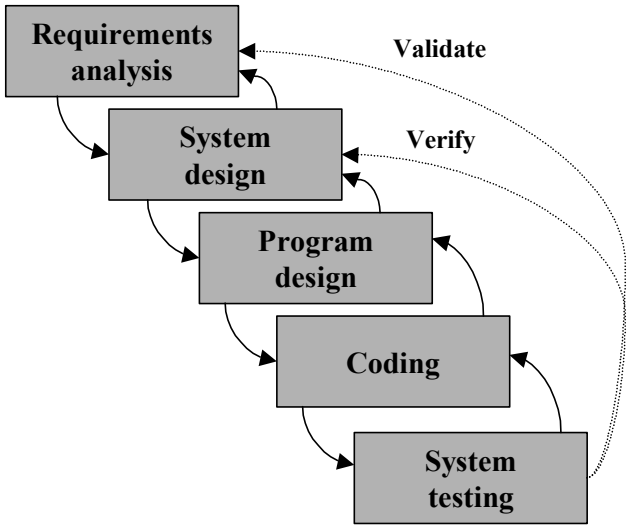


Figure 12 The waterfall model with feedback (authors' interpretation)

The interface and logics were designed first. A storyboard was complemented by numerous power point slides, describing the approximate appearance and interaction with the user. The design drafts were tested on people at ABB Robotics as well as Mälardalens Högskola. The slides were then redesigned, and tested again, until all major drawbacks were eliminated, and the program design stage was reached.

Once the logics were in order, the internal prototype design could be put together, providing a very good ground for the next step, the prototype implementation. The development approach was of an iterative nature.

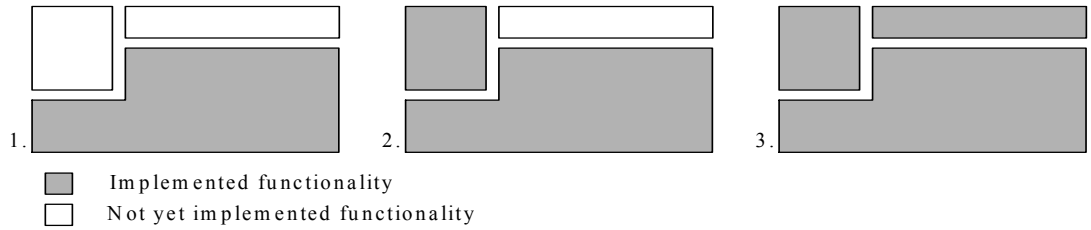


Figure 13 The iterative model

The requirements were then portioned into modules by functionality. The base for the prototype was created, i.e. a shell consisting of all the steps described in the general description[1] was put together, but without any contents. Functionality was then added to the different steps in gradual stages.

[1] [4.4.1 General description]

Along with added functionality, the prototype was repeatedly tested on the same people at ABB as the design sketches were. The testers' comments were then taken into consideration when modifying the prototype.

4.4.4 Graphical User Interface design

4.4.4.1 Issues when creating a prototype for programming arc welding robots visually

There are a lot of things to take into consideration when trying to make the programming phase easier on the end user. For starters, we should think about who the end user is; what is his/her background like? Did he or she know about programming or welding before he/she started using this workstation, or is he/she working on a self-teaching-basis? Can he/she read? That might seem like a stupid question, but the truth is that not all countries have well-educated labor. Anyway, depending on the answers, the user has totally different needs and demands on the system. An advanced and experienced user may, and this was discussed earlier, prefer having access to every programming detail there is, in order to create as fast and accurate welding cycles as possible. The user might also be an ”old school programmer”, and be very resistant to using a visual programming technique. On the other hand, the beginner might be overwhelmed by all the functionality provided in the programming language or the user interface.

Once decided to make the programming easier by using visual programming, there are well known issues to think about. Can pictures replace all textual parts? Probably not. Not all words can be described by concrete objects, and making abstract pictures can make things even more difficult for the user. Also, if a picture replaced every word, the screen would soon be filled with pictures high and low, making a detailed mess, incomprehensible to the user. A related question is if a picture always makes actions more intuitive, even if there really is an appropriate image for a word, or bunch of words?

The image alone requires a paragraph of itself. Depending on what the system is to be used for, there are of course different demands on the picture. For instance, one could ask how many/what colors are available on the target system. In the case of this thesis, the fantasy is the limit, and hence such specific obstacles are removed. On the other hand, there are more general issues that apply to all applications. What happens if the user is colorblind? What colors or symbols are inappropriate to use for a certain culture? How detailed should the image be to provide exactly the amount of information needed/intended? Is the picture ambiguous?

A more concrete difficulty with a visual programming technique, is that the environment does not fit the purpose. Weld robots usually work in very noisy and dirty environments, and the air can be very dusty. Hence touch screens can get very difficult to interact with if the components are too small or detailed, and the visual feedback may be difficult to grasp.

These and other questions need to be considered when creating a visual programming tool. This prototype gives one suggestion for a solution, however there are countless possibilities.

4.4.4.2 Approach

Considering the aim of this project, to create a visual tool for programming robots, the GUI[1] design became very important.

The basic ideas were

- big, clear components that are hard to misunderstand and easy to interact with
- not too much detail
- no unnecessary information showing if not wished for
- combine images with text as often as possible

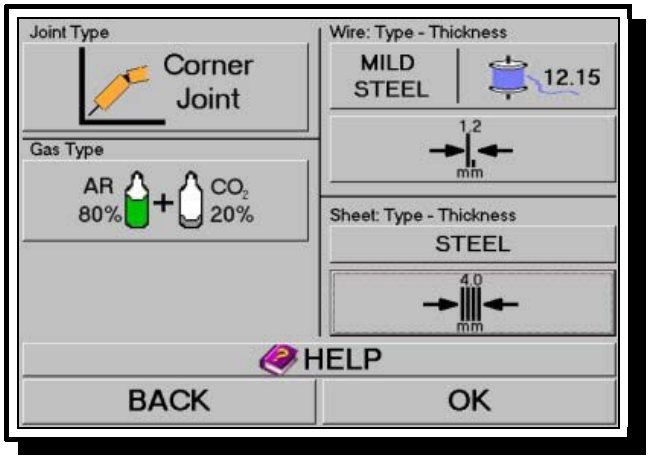


Figure 14 Example screenshot of the process data setup design

The other part of the visual design was about creating logic steps for the user.

The basics here were

- minimize the number of steps to enhance availability and overview
- easy navigation back and forth between the steps
- spare the user from unnecessary walking through levels and menus

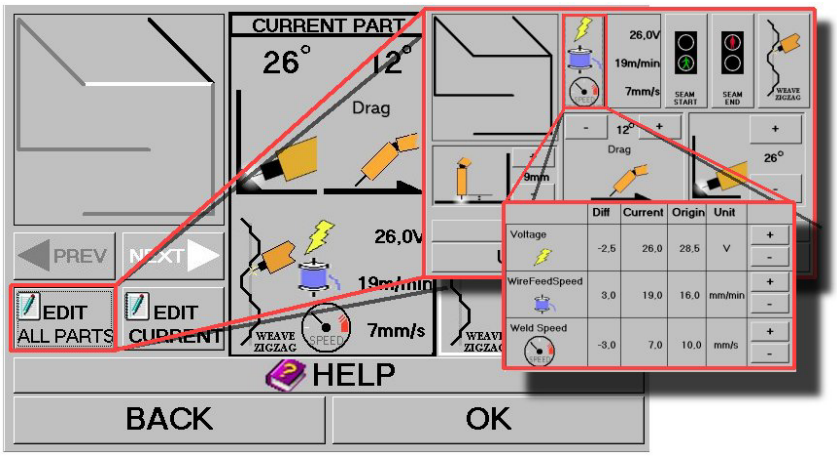


Figure 15 Manipulated example screenshot of the welding configuration design

[1] Graphical User Interface

4.4.5 Internal design and implementation

A basic, informal design of the main objects and their connection to each other could be made at an early stage, thanks to inspiration of how real welding robots work. A detailed schematic design of the whole prototype looks like this:

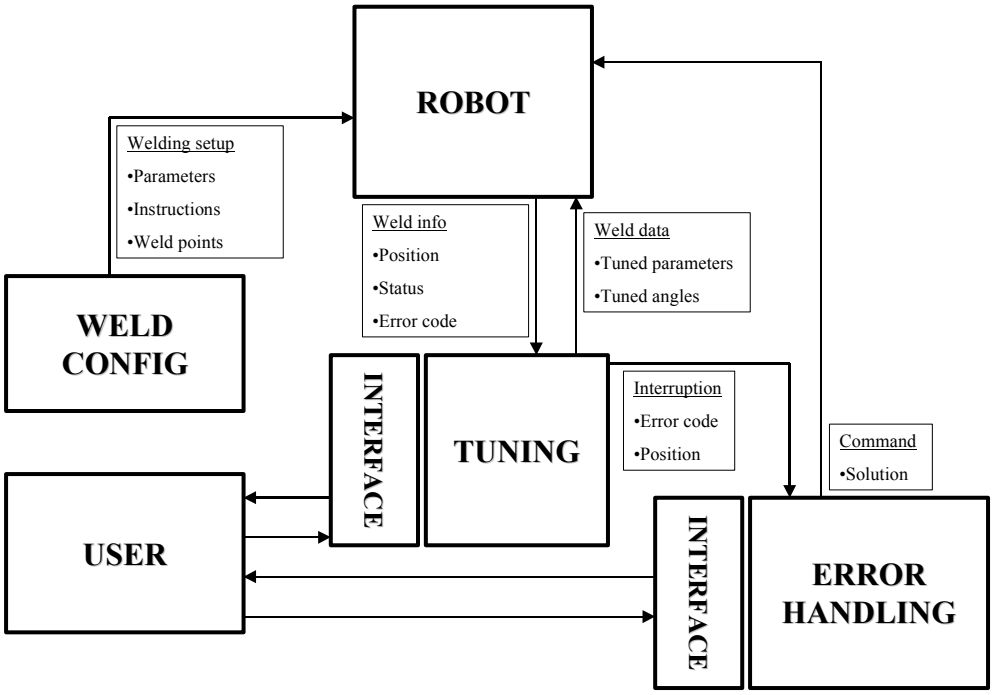


Figure 16 A schematic overview of the internal design

Not included in the schematic is the weld point editor, since it really is not a part of the prototype. At least it has no other connection to reality than to simulate the insertion of weld points in 3D-space, and for that reason the implementation details are not of interest in this section. However, for each and every weld line the user added in the weld point editor, an object is added to a list. The programming phase that then follows (named "weld config" in the schematic above) is implemented as a wizard.

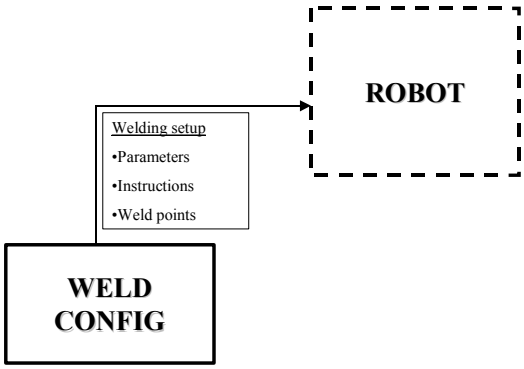


Figure 17 Schematic of the welding configuration

The user can modify the objects in the list by changing the process parameters. These process data also lie as a ground for the automatic generation of weld data. These data are generated using a database object, and are also stored in the object list. The object list is then used to generate proper RAPID code for the weld setup. The RAPID code instructions are then stored in a separate data type.

The simulation phase consists of the robot, the tuning and the error-handling modules.

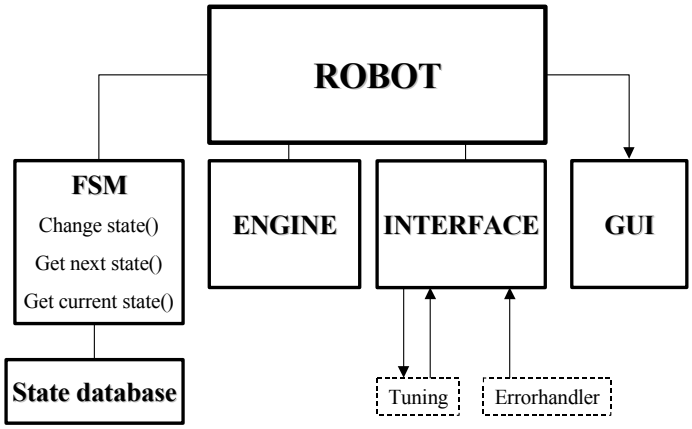


Figure 18 Schematic of the robot in the simulation phase

Similar to real life, the robot has an engine. In this case, it creates an interrupt at even intervals, depending on the simulation speed. At each interrupt a number of calculations and other operations are performed, before the GUI is updated and a signal is sent to the tuning module. The robot is implemented as a simple finite state machine consisting of seven states.

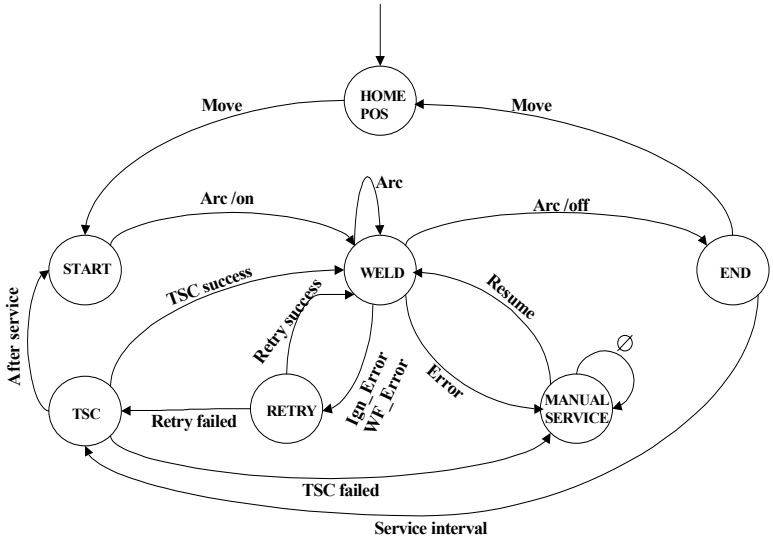


Figure 19 The seven states of the robot simulator

It should be noted that the transition “Arc” is a generalization for both the ArcC and the ArcL commands.

The robot starts and ends up in the HOME POS state via the START, WELD and END states during a normal weldpart. However, depending on the selected level of simulated error frequency, welding errors as well as other hardware failures may occur. These errors are spread based on the internal probability of the errors appearing. For instance,

an ignition error is far more common than a collision, a wirefeed error occurs more often than an empty gas tube, and so on.

If a welding error occurs, the robot tries to re-ignite twice. The chance of success depends on what type of error it is, and the chance of success is also decreased with every retry. If re-ignition fails, the robot tries to clean the weldgun tip in the TSC[1]. The chance of success here is also depending on the type of error.

If another type of error occurs, such as an empty wire bobbin or gas tube, the robot enters MANUAL SERVICE directly, since an attempt to re-ignite is a waste of time.

The tuning phase needs no detailed explanation of its implementation. It is to be thought of as an application run on the teach pendant unit. It is hence merely an interface between the user and the robot, and is best described with a schematic:

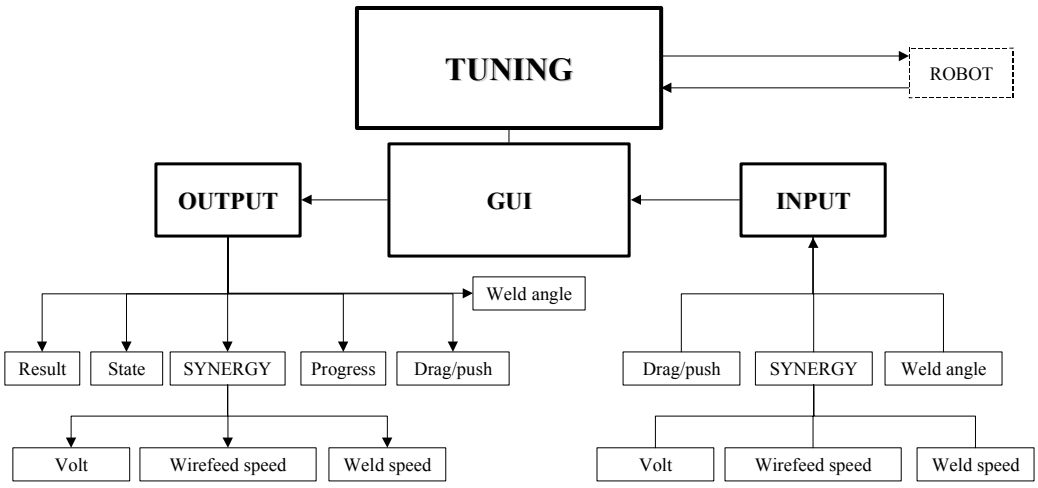


Figure 20 The tuning module

The input is sent to the robot, meaning the visual output is not updated until the next interrupt occurs, when the robot sends the information back to the tuning module. This is not an optimal solution for the prototype, since the delay might be experienced as if the input was not registered, but the principle of having communication between the teach pendant and the robot was preferred to instant output just to get a better sense of reality.

[1] Tool Service Center, an automatic cleaning and recalibration tool

The final part of the simulation phase is the error-handler.

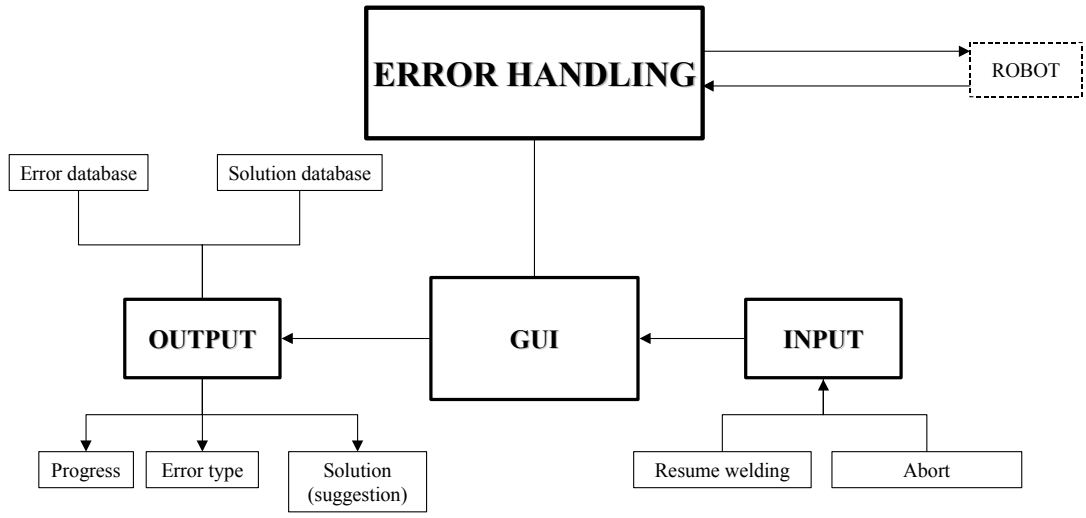


Figure 21 Schematic of the error-handling module

The error-handler is inactive until the robot enters the state MANUAL SERVICE. When this happens, the error-handler is sent an error code. The error code indexes a small error database to present both a visual and textual description of the problem, as well as suggestions for remedy. The user can choose to resume the welding from the point it was halted, or simply abort the welding process. It should be noted that it would not be possible to implement something like this in a real system today, since the hardware (the robot) does not support monitoring of all possible errors that can occur. For instance, it is not possible to point out exactly that the gas tube is empty if ignition fails, as in the case with the prototype.

4.5 Pros and cons

The prototype is developed in Visual Basic. It is very simple, with slightly over-dimensioned components. Furthermore, it probably lacks several desirable features. However, we still think it serves the purpose as a concrete representation of our basic idea of how arc welding can be made easier.

This section discusses advantages and disadvantages. It is important to keep in mind that the created application is nothing but a *prototype*, a suggestion for a possible solution. This implies that not every intention or idea actually has been implemented. A feature that is supposed to work in one way, but does not today, will not be mentioned as a disadvantage.

4.5.1 Advantages

There are several improvements to the prototype.

- Concerning ease of use, it has a straightforward, intuitive user interface with big and understandable components that combine text and images.
- The navigation is simple, just back and forth, which is made possible thanks to the "wizard like" step-by-step setup.
- There is topic related help available at all times
- Undo and cancel options at every possible point of changing the data.
- Programming arc welding robots is an advanced thing to do. There are lots and lots of parameters that need to be set up, and set right, to get an acceptable result. However, there are also a lot of parameters and coding possibilities that are available, but do not *need* to be set up. For example, the small company with its low quantities probably needs merely the basic features of the arc welding system. The main idea here is to show not too much detail or information at once. *The prototype therefore hides unneeded, advanced features and simplifies and automates the use of necessary ones. At the same time, advanced users are allowed to manually edit the resulting RAPID code.*
- To relieve the user from as much low-level editing as possible, the prototype uses a database containing welding information to generate welding parameters depending on the users welding process setup. This provides the user with a default setup, hopefully relieving him of editing every weldline separately.
- Another suggestion for simplified use is the real time tuning phase. The prototype provides quick access to tune the most common parameters, such as voltage, wirefeed speed, welding speed, work angles, etc.

The intention and hope is that these advantages together make it possible for a wider range of people to program arc welding robots, since a user does not have to know everything about programming in RAPID, nor everything about the process phase.

4.5.2 Disadvantages

There are also a number of drawbacks with the suggested prototype, even when unimplemented features are not considered.

- First of all, since it was created using the "imagination-is-the-limit"-principle, the prototype does not follow any standardized design or layout patterns.
- This version requires quite some screen space, high resolution and many colors to provide an intuitive interface. Integration with and adaption to an existing low-resolution system might decrease the usability in several ways. Designing the GUI (images, layout, colors, etc) in a final application could hence be a difficult task if there are strict limitations to screen size, resolution and color depth.
- A possible problem of more general type is that the prototype offers a new way of programming. This may not appeal to experienced users as desired, and was mentioned earlier as the classical problem of "adaption resistance" among programmers[1].
- Finally, not everything in the prototype would even be possible to implement on a real system today. This depends mainly on limitations in the hardware. An example is the error handling phase in the prototype. It presents a desired way of handling errors and displaying the exact problem and its remedy to the user, but the hardware today does not support this kind of sophisticated monitoring of individual components.

[1] See [3.2.2 Known Visual Programming difficulties]

4.6 User evaluation

The user evaluation was performed on three people. These test persons have very good knowledge about robot programming and especially on how to program an arc welding robot. This implies that the results from the evaluation give at least an indication of how people with relevant knowledge understand the concept of the prototype.

The users were brought in one at a time. Each one of them was given a short, formal introduction, providing them only with the background and purpose of the test. In other words, no details or instructions on how to use the prototype were mentioned, so the user was free to investigate and explore it in any way desired.

The evaluation method that was used is called "cooperative evaluation[1]". The cooperative evaluation method means that the users think aloud and tell the evaluator about their thoughts about what is going on, why something happened, etc. The users also tell the evaluator how the system is understood and what can be seen on the screen and so on. The users and the evaluator can ask questions too each other during the whole process. With this method, the users feel more comfortable with themselves and have the courage to criticize the system. Observation data during every evaluation moment is written down in a protocol.

There was a surprisingly positive attitude among the testers. They were of varying age and experience levels, but they all seemed to be inspired and encouraged by the concept with a graphical tool for online programming. On a detailed level, there were of course a lot of remarks on what the prototype lacks and what could be done in a better way. However, the remarks were of very differing natures. There seems to be as many opinions on what is useful, necessary, good, bad or stupid as there are individuals. The remarks reflected this and were sometimes contradictory. In spite of all that, the overall impression was that the idea behind the prototype is to take at least one step in the right direction.

The evaluation results can be viewed in the next section, and a summary of the users' comments during the evaluation can be viewed in [Appendix F].

[1] Also known as the walk-through method

4.6.1 Evaluation results

The results are presented as a step-by-step presentation of the prototype with the evaluation expectations and results to each step. Each step is illustrated with a screenshot of the actual prototype.

4.6.6.1 Evaluation part 1

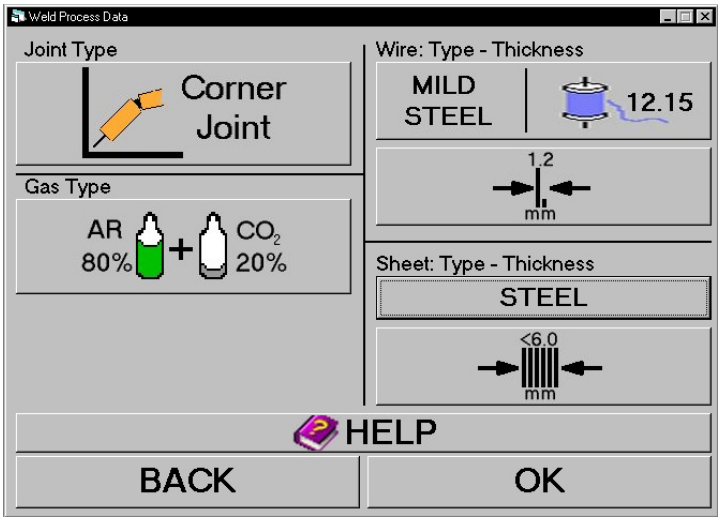


Figure 22 Evaluation part 1 (Weld Process Data)

Expectation
The idea with this step is that the user selects a parameter from each one of the available types (joint type, gas type, wire type, wire thickness, sheet type and sheet thickness). The concept of the pictures is to simplify and help the user to see what to do and what happens when a button is pressed. The text over the buttons should guide the user right if they do not understand the picture alone. A comment to this step is that it is not necessary for the user to do the selections in a special order.

Result
1. A problem that arose was that the users thought the wire type button was actually two separate ones, depending on the vertical line in the middle of the button.

2. Another problem in this step was hesitation on what to do and how to interact with the program.

3. Confusion whether the selections need to be done in a certain order or not.

Action
It is a small problem and can be solved easily with education of the users.

4.6.6.2 Evaluation part 2

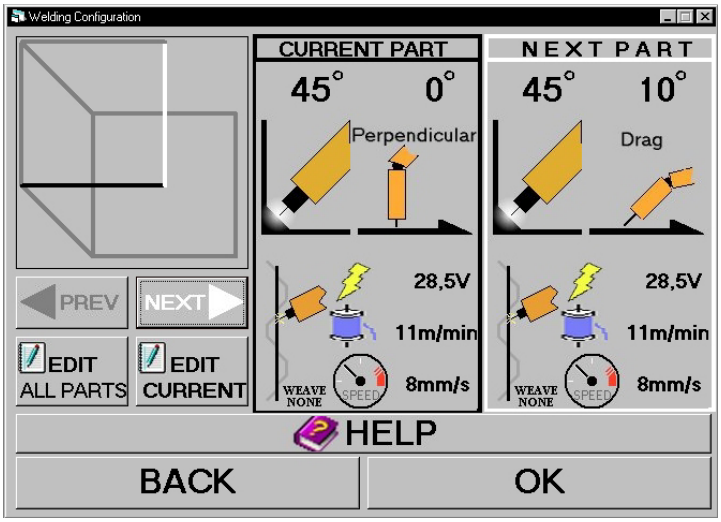


Figure 23 Evaluation part 2 (Welding Configuration)

Expectation
The idea behind the "welding configuration" phase is that the user gets an overview of the most important generated welding parameters without taking the risk of accidentally changing them. To show only the most important parameters is in line with removing unnecessary distracting information from the user. The user now sees two weldlines at a time, the current and the next (following) line. These two lines are marked with black and white colors respectively in the upper left corner image. These colors are supposed to visually connect the lines to the black and white frames containing the weld parameter data in the "current part" and "next part" views.

Result
1. The first reaction was silence and confusion. The users repeatedly tried to click non-buttons and were expressively not sure how to interact with the program. However, this initial confusion did not last for long, since all testers managed to edit and cycle through the different weldlines after no or very little guidance.

2. Someone wondered were the voltage, wirefeed speed and welding speed values came from, since he had not set them himself.

3. Another comment was that the word "current" was unfortunate in this context.

4. All of the testers had problems with the connection between the black and white lines and their respective parameter frames, but after a short explanation there were exclusively positive reactions.

Action

More conspicuous colors were suggested though, as opposed to our attempt to please colorblind users. After getting familiar with the configuration layout, the users' comments were very encouraging.

4.6.6.3 Evaluation part 3

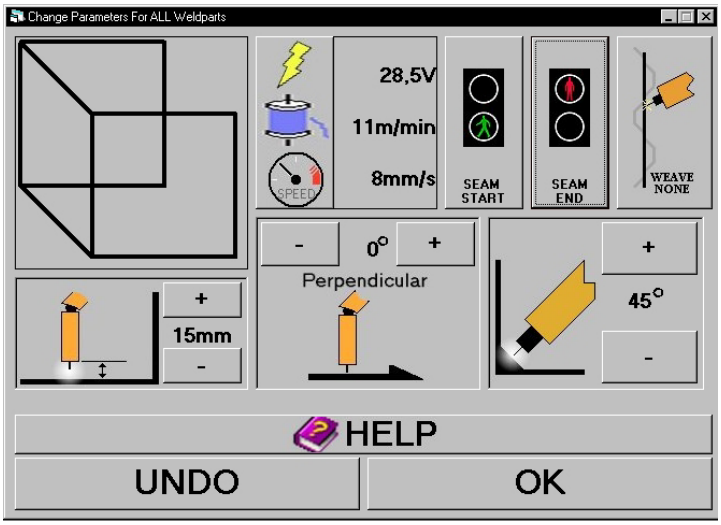


Figure 24 Evaluation part 3 (Change Parameters)

Expectation

In this part of the welding setup the user has the possibility to change the parameters that have been generated in an earlier step of the program. The user can change the values for all of these parameters, as well as change the values for some default parameters not highlighted earlier at all in the program. The thought is that the combination of text and images on every button helps the user to change the right parameters.

Result

1. Some of the users had difficulties understanding how to change the values for voltage, wire feed speed and weld speed. Attempts were made to click the text beside the real button.

2. The users never reflected over the images when trying to change values for the seam start and seam end data, they only read the text on the button.

3. Another problem the users had in this step was with the meaning of the image where they can change the push/perpendicular/drag angle of the weld. They did not have a clue what value they changed when the minus or plus sign was pressed.

4. Another question the users had in this step was how value(s) were changed when editing all parts simultaneously.

4.6.6.4 Evaluation part 4

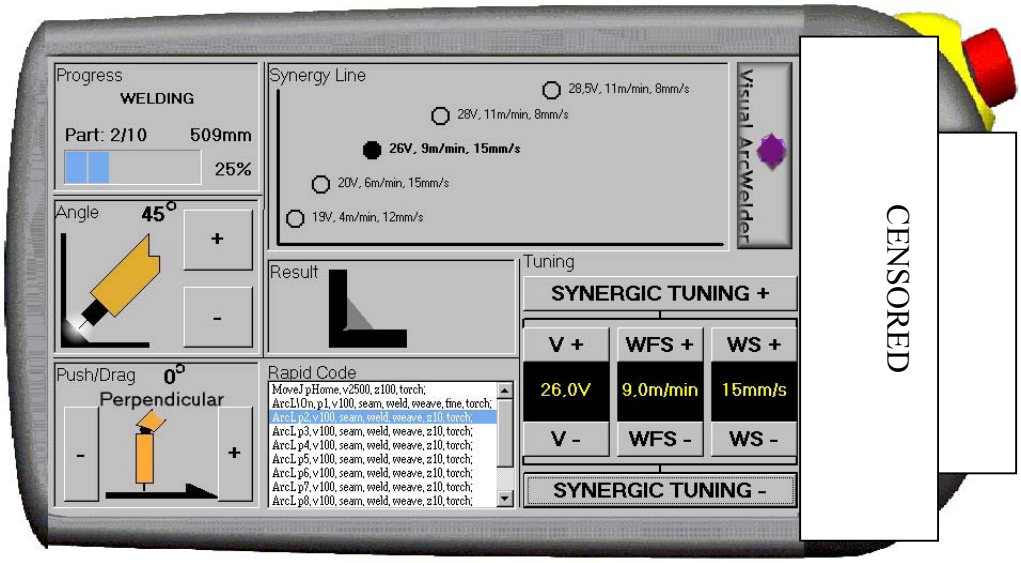


Figure 25 Evaluation part 4 (Real Time Tuning during program execution)

Expectation
The idea is to gather the most common (or commonly wished for) real time tuning options in one single window. Intuitive interaction and clear visual feedback for every interaction were also kept in mind during design.

Result
1. The first thing that was commented was simply the great idea of having all tuning options in one place, accessible during the whole welding process. In connection to this the testers mentioned how difficult it is to switch to tuning and actually have time to do any tuning with the current system.

2. Another appreciated aspect was the possibility to tune angles in real time. None of the testers had any visual interaction or comprehension problems at all, however it was stated that the synergic tuning feedback via a plotted curve might be too advanced for the common operator. Positive remarks were given to the result calculation. The actual response to the tuning phase was rather close to the expected response.

5 Future work

Proposals for future work:

- **The visual interface**: should be designed by expert designers/graphic artists to reach the best results. Component design is more difficult and important than often given credit for. Better dynamics in the visual feedback is also desirable.

- **The path programming phase**: the latest technique should be used to get the weld points into the system. A gyro pen, which unfortunately merely is a future technique at the moment, or some similar technique is optimal, and was also referred to in the current prototype. Visualization of these weldpoints is also interesting since it, if combined with the possibility to configure weld data by selecting/deselecting them by touch, gives the user an even more intuitive and powerful tool.

- **The tuning phase**: better synergy tuning opportunities and possibility to tune the weave data as well as to adjust the weld gun diagonal offset to the weld point for improved results.

- **The error handling phase**: an error handling system that monitors and indicates different weld, collision and process errors to the user, and in similarity to the prototype introduces some kind of solution proposal for the error. A proposal for such a system to visualize and remedy the arisen error is to use some kind of wizard similar to that in a photocopier.

- **Measurement standards**: functionality not implemented in today's prototype is inches as complement to millimetres, amperes as complement to meters per minute, etc.

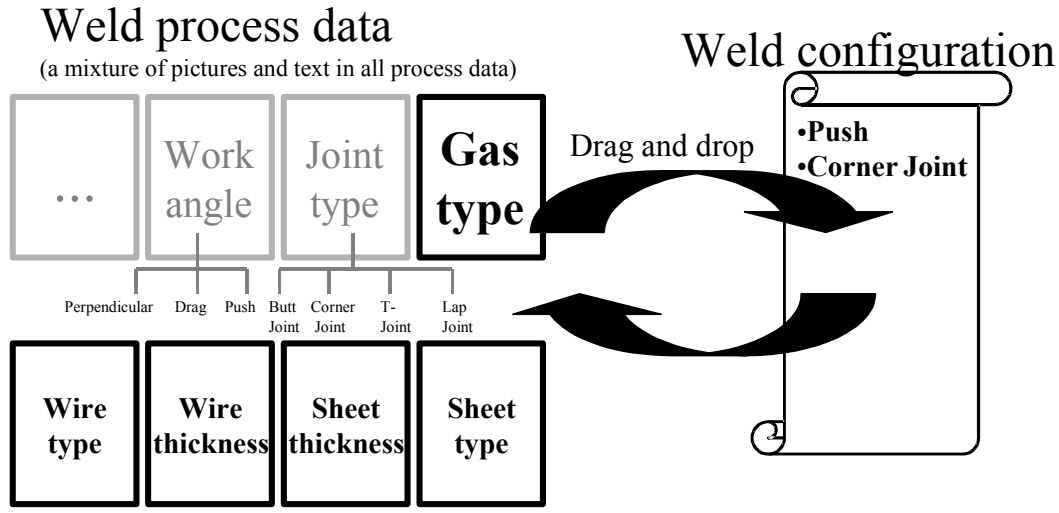
- **Help functions**: Extended, more detailed, case-based help functionality at all times.

- **More automation**: an improvement to make the prototype more usable and powerful, and to decrease the amount of thinking for the user, is to extend the database support for different joint-, gas-, wire- and sheet types.

- **The RAPID code**: integration with the common RAPID editor for manual code editing and consequently also a RAPID code generator, as glanced at in the prototype, are needed to manually fine-tune the welding program.

- **A suggestion for a future thesis**: investigate if there are any possibilities to use a combination of different techniques to simplify robotic arc welding. Such a combination is gesture based visual programming, which should be interesting in a few years when the technique is sufficient.

- **A new idea**: during the progress of this thesis, new ideas have emerged that are not possible to test within the time limits of this project. Such a way or future idea of an application for the weld configuration is something similar to the figure down below. It is only to be seen as a first draft of how the application can be done in a different way and not a complete design on how to do it.



How to create a weld configuration

Create a new weld configuration

•Drag and drop weld process data into the weld configuration folder
•When the weld process data folder is black - enabled
•When the weld process data folder is grey - disabled

Change the weld configuration

•Change weld parts by dragging it back from the weld configuration folder and drop it into the weld process data folder
•Select a new part, drag and drop it into the weld configuration folder

The weld configuration is finished when all weld process data folders are disabled

6 Conclusions

The purpose with this thesis was not to create as much functional program code as possible, nor to build a fully functional application. Instead it was of importance to show whether it is possible or not to build an intuitive, simple and straightforward application using visual programming for the robot arc welding industry, and to make this process easier on the user.

With this in mind, a prototype was created using Visual Basic, since it is a language that allows for simplicity and speed to create very much in very little time. Another thought behind the choice of Visual Basic was that it is easy to make changes, and easy to remove or add functionality if needed. These qualities allowed for a rather functional prototype, which was of importance, since we were able to introduce most of our ideas and get lots of creative feedback at the user evaluation.

There are several improvements to the prototype concerning ease of use. Unneeded, advanced features are hidden, and the use of necessary ones is simplified and automated. It has a straightforward, intuitive user interface, and the navigation is simple. The results from the user evaluation also contributed to these conclusions. With that, the prototype gives a straight answer that it is very much possible to build an application using visual programming techniques.

Altogether, it is shown that by using simple means and already available technique, existing applications can be greatly simplified.

Since the prototype does not follow any ABB standards, there are several technical problems to solve before the ideas can be used to their full extent. Integration with and adaption to an existing low-resolution system would for example be a difficult task if there were strict limitations to screen size and color depth. Consequently, the prototype itself cannot be applied on the teach pendant unit in its current performance. Although it is important to look at the prototype merely as a tool for presenting a concept and an idea in this matter, there is an example of what it might look like if it actually could be applied on the teach pendant unit in [Appendix C].

Another purpose with this thesis was to present a summary of the state-of-the-art within visually aided software applications available on the robot programming market up to date.

The extensive state-of-the-art search shows that visual online programming tools for arc welding robots are rare. The only such tool that was found was the KIE, or the KUKA Icon Editor[1]. In addition, the tools that were found almost exclusively concentrated on building a program using a flowchart approach. Instead of repeating these ideas and focusing on replacing RAPID code instructions with a visual symbol on a [1:1] or even [n:1] relationship basis, we took the abstraction one step further, and completely removed the obvious connection to RAPID instructions.

The people who participated in the user evaluation were of varying age and experience levels, but they were all inspired and encouraged by the concept with a graphical tool for

[1] [2.4.4.2 KIE – KUKA Icon Editor]

online programming. To reflect a few of the participants' thoughts, the combination of images and words throughout the application should be a big help for the beginner. There were also some remarks on what is missing or could be done in a better way. For instance, possibility to modify and adjust the interface and degree of difficulty and details depending on the user's skills was wished for. However, the overall impression was that the idea behind the prototype is very good and that it is a step in the right direction for online programming.

The intention and hope is that the results lay a ground for further research to make it possible for a wider range of people to program arc welding robots.

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Appendix A

As part of the background research, an interview as well as an end user survey was performed in an attempt to clarify how visual aids would help during the programming phase. Unfortunately, this survey turned out to get very little response, and is not sufficient to draw any general conclusions from. However, the few users that answered the survey tend to have answered the same four or five questions, so a summary gives at least a hint of a bigger picture.

Summary of the end user survey and interview

Background information		
Participants	**Age**	**Robot programming experience**
5	18 to 35	6 months to 6 years

What would you think about replacing *occasional* commands or instructions with intuitive symbols?				
Very good	**Good**	**Ok but unnecessary**	**It would be worse**	**Don't know**
20%	80%	0%	0%	0%

What would you think about having a completely visual system that guides you through the entire welding setup via a point-and-click interface, i.e. everything including setting up weld points, tuning the weld parameters and handle errors?				
Very good	**Good**	**Ok but unnecessary**	**It would be worse**	**Don't know**
60%	40%	0%	0%	0%

A few of the comments regarding why this would be good or very good were

… "RAPID is too complicated"
… "symbols are easier to memorize and keep track of than instructions"
… "would probably be faster"
… "the present menu system is complicated"
… "the abbreviations are difficult to understand"
… "would be easier to optimize the joints"
… "it would be easier to get an overall picture of what is going on"
… "visual feedback and images would definitely be a bonus"

Other more general comments were

… "it would only be better if the system offered a default setup"
… "the error handling needs better feedback"
… "suggestions on how to solve certain problems would be nice"

Appendix B

Requirement specification

Requirements

Minimize programming time
- **Hiding and clustering:** What you see is what you program WYSIWYP
- **Minimize visual distractions:** Show only the necessary input/output

General welding options
- MAG welding for mild steel only
- Support only one weld type (possibility to add more types in the future)

Interface
- **Intuitive:** Logical steps through the weld process
- **Text and pictures:** Combination of text and pictures output

Visual tuning in real time
- **Tuning:** linked and individual tuning of (weld_speed, weld_voltage, weld_wirefeed)
- **Angle:** Change the angle of the weld gun

Visual feedback during welding
- **Position:** Display the current weld position
- **Synergy (weld line):** Display synergy line, relation between (weld_speed, weld_voltage, weld_wirefeed)
- **Result:** Predicted weld result

Visual feedback during error handling
- **Position:** Display the current weld position
- **Probable error location and suggested problem solution:** Wizard and choice of action

Restrictions

- **Application specified for arc welding only:** Not a generic application
- **Functionality:** As simple as possible
- **Size of the display:** as big as the new graphical teach pendant

Assumptions

- Unlimited input devices available
- The robot is calibrated
- Hardware support for error handling
- Software support for different joint types (information taken from SECRC)
- All the latest technologies available

Appendix C

Examples of how the prototype could be applied on the teach pendant unit.

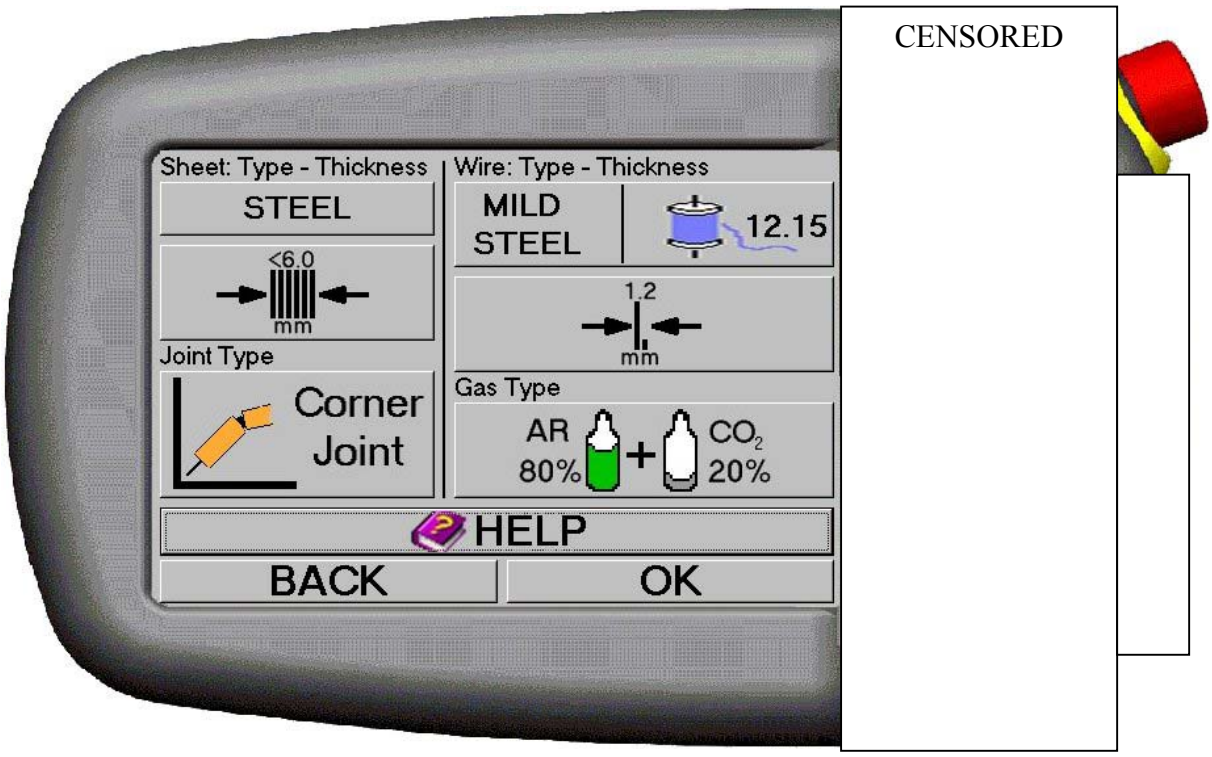


Figure 26 Process data configuration on the TPU

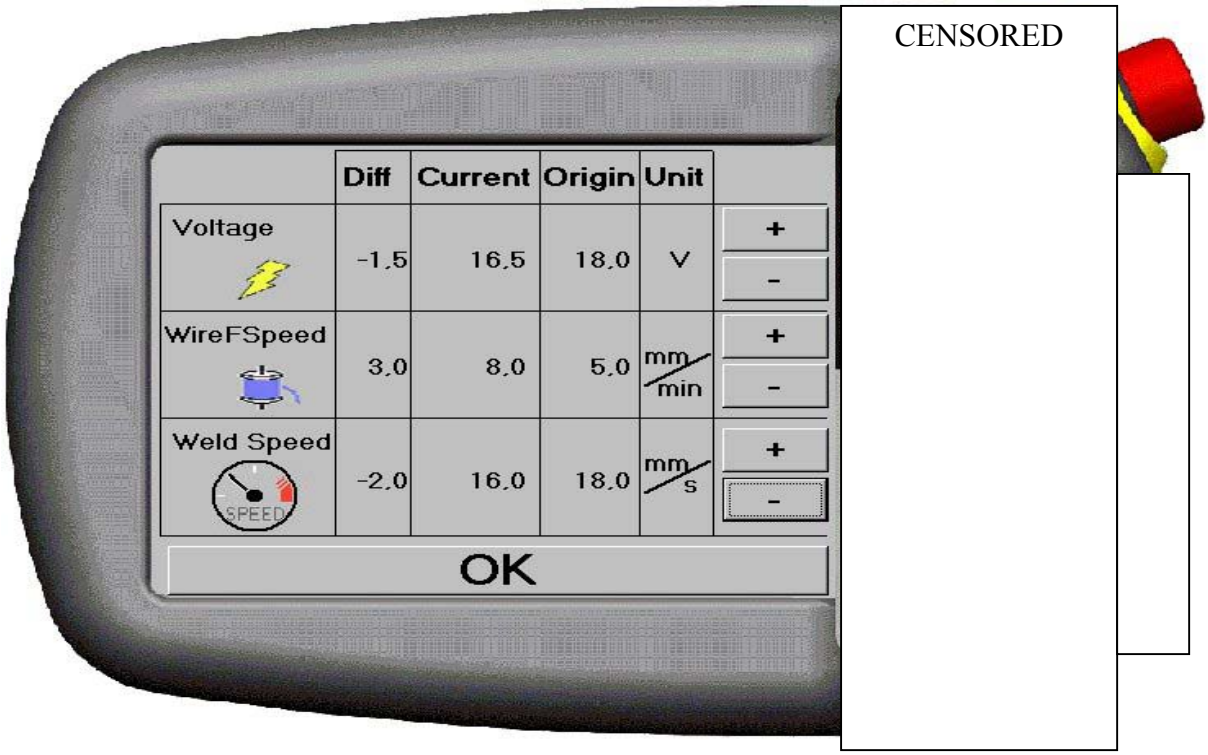


Figure 27 Weld data parameter setup on the TPU

Appendix D

The prototype real time tuning module.

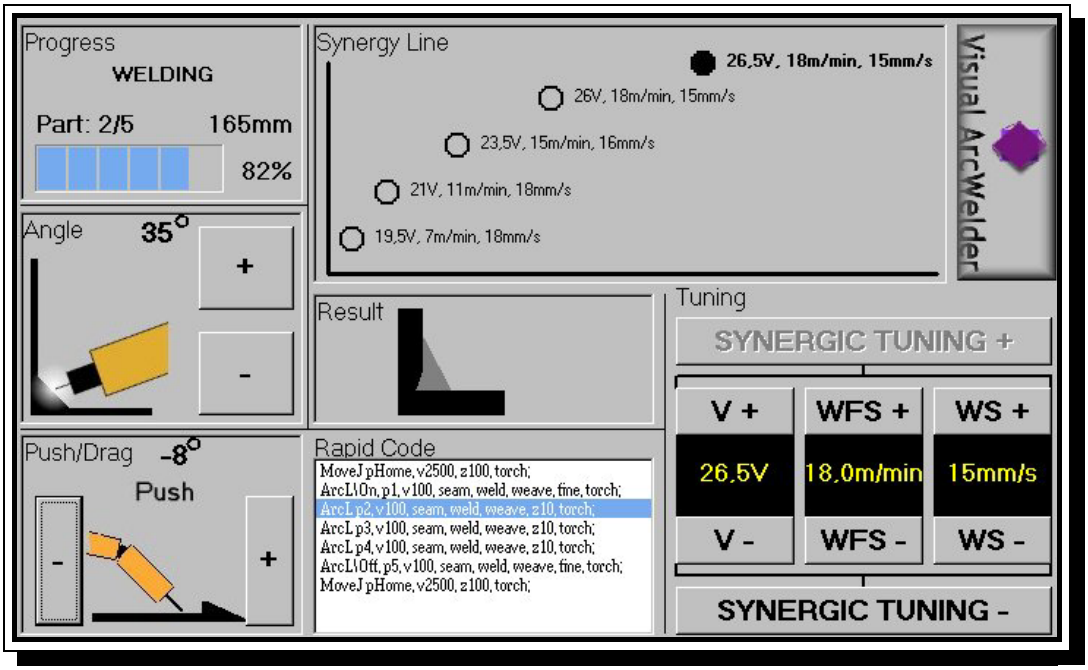


Figure 28 Real time tuning in the prototype

Appendix E

Command	Description
Draw <x>,<y>,<z>	Linear Movement
drive <joint>,<angle>,<speed>	Rotational Movement
move <point>	Move directly to a recorded location (see *here*)
Appro <point>,<dist>	Approach <point> leaving "dist" mm still to move
depart <dist>	Depart from current position by "dist" mm. Tool z-axis
openi / closei	Open/Close Gripper
above/below	Set elbow position for following movements
lefty/righty	Change robot configuration to left- or right-handed
uwrist/dwrist	Similar to above/below but applies to wrist JT5
Ready	Return to zero state; the point at which all potentiometer values are zero.
Where	Find current position (world mm) of end-effector (XYZ) with respect to point of rotation in Joint (JT) 1. It also supplies the angle of wrist joint rotation (OAT). This also returns the current degree of rotation of each joint relative to each zero state
Here <point>	Define a location in world coordinates of the end-effector to allow the robot to easily return to a known point
Tool	By applying this function, the end-effector moves in tool coordinates, such that the z-axis is now aligned along the length of the gripper as opposed to the world z-axis (perpendicular to the ground)

Table 2 Common VAL commands

Description	Inform 2	KAREL	RobotScript
Joint Motion	`MOVJ`	`$MOTYPE = JOINT` `MOVE TO`	`MoveJointTo`
Linear Motion	`MOVL`	`$MOTYPE = LINEAR` `MOVE TO`	`MoveLinearTo`
Turn on output	`DOUT OT= (12) ON`	`DOUT[12] = ON`	`SetDigitalOutput 12, 1`
Addition	`ADD 112 113`	`X = 112+113`	`X = 112+113`

Table 3 Comparison of Robot Language Syntax

Appendix F

The user evaluation was performed on three persons with knowledge about arc welding robots and how to program them. Here is a compilation of the most common actions, reactions and comments these test users had, gathered under a few larger subcategories.

Layout (text, pictures and colors)

- The text was often read before, or even instead of, looking at an image
- There were overviewing difficulties with the "welding configuration" part of the setup
- Difficulties to connect the black (current) and white (next) part with the correct part data
- The word "current" is an unfortunate choice since it has ambivalent meanings in this case
- The combination of images and words is a good help for the new user
- Some buttons are hard to discover. The users frequently tried to press non-buttons
- Insecurity about whether actions must be performed in a certain order

Intuition

- Easy to understand the images and the actions behind them in the "process data setup", even if you don't know anything from the beginning
- Many of the older robot operators who are used to S3 do have the welding knowledge, but know nothing about computers. To them it would be a great relief to use such a simple, intuitive point-and-click system

User friendliness

- Good solution with the most useful functions collected in one place during program execution – gets very easy to use
- Database support for the welding parameters is good. Also a good thing to disable not recommended process parameter combinations

Contents

- Possibility to switch between different tuning functions and feedback during execution would be better
- Weave data parameters need to be editable
- Possibility to set the A-measurement for the selected joint type is preferable
- Weave data parameters should be tunable
- Pulse data parameters should be tunable
- It would be nice to be able to change the wire stickout during program execution
- The idea of synergic tuning is very useful, but needs improvement
- Synergic tuning can be very confusing for the beginner and/or for people not familiar with the synergy line
- Help functionality could be useful the first weeks, but with possibility to disconnect it if you do not want to use it or need it
- It would be very helpful and useful if the predicted result can be shown in real-time
- Very good to have the option to edit the generated RAPID code manually

General remarks

- It is a very good idea and takes the programming phase in the right direction
- If it works satisfactory it is an opportunity to entice new customers to ABB robots
- General tester enthusiasm
- Some divergency about what functionality is important to have in a final product

Appendix G

Rubrik: Visuell programmering
Inriktning: Robotteknik
Område: Användargränssnitt
Ämne: Datalogi
Nivå: D

Företag: ABB Automation Technology Products AB Robotics, Västerås
Startdatum: 010813
Prel. slutdatum: 020113
Handledare företag: Ralph Sjöberg, ralph.sjoberg@se.abb.com
Handledare skola: Rikard Lindell (IDt), rikard.lindell@mdh.se
Examinator skola: Peter Funk (IDt), peter.funk@mdh.se
Student: Mikael Johnsson
Student: Andreas Örmo

Beskrivning:
ABB Automation Technology Products AB Robotics utvecklar, tillverkar och säljer industrirobotar. En industrirobot är ett komplicerat datorstyrt system, med många ingående delsystem. Våra användare ställer stora krav på att industriroboten kan hanteras enkelt och effektivt.

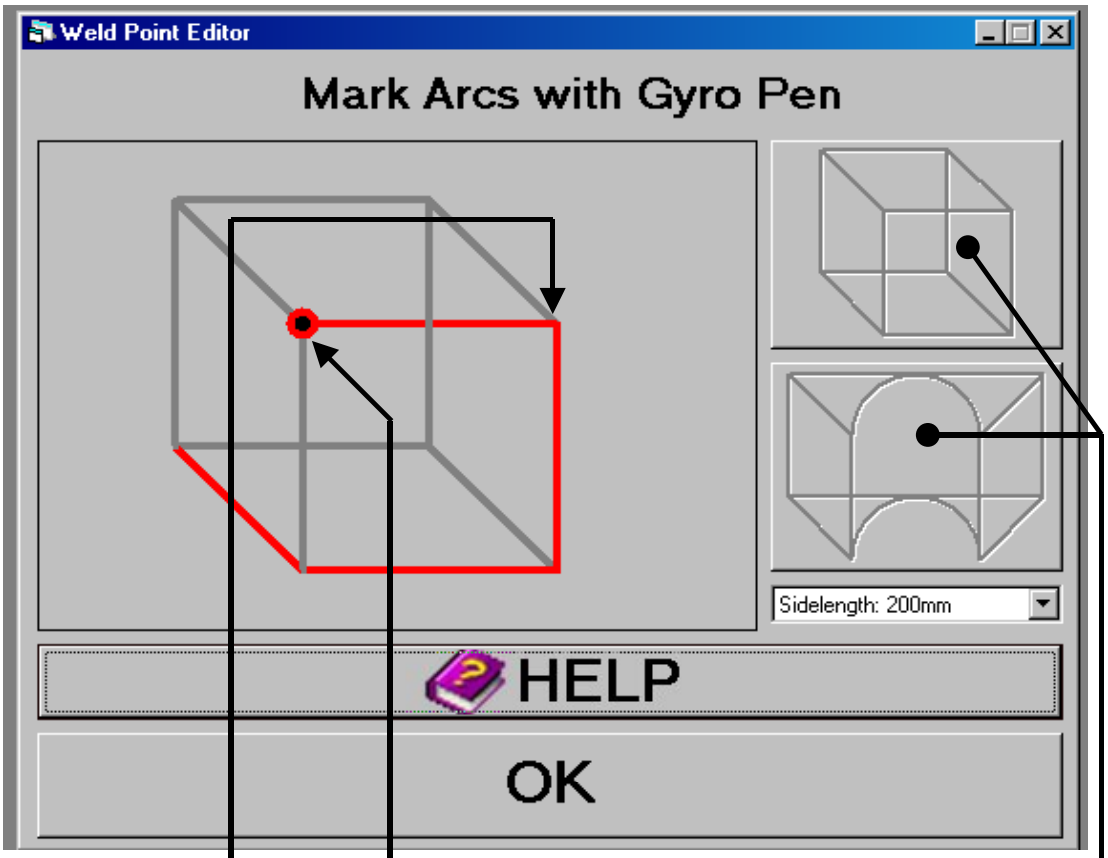
Med avsikt att förenkla och effektivisera framtidens handhavande av robotar skall vi undersöka möjligheterna att utnyttja en grafisk beskrivning av programinformationen och process-informationen. Det finns ett tidigare examensarbete som skall ligga till grund för det fortsatta arbetet.

Uppgiften består i att:
- undersöka ”State of the Art” inom visuell programmering
- utreda vilka krav som ställs på ett visuellt programmeringssystem i en processrobot-tillämpning (ex. bågsvetsning)
- specificera och konstruera ett prototypsystem med inriktning på handhavandet
- utvärdera systemet map. användbarhet (enkelhet och effektivitet) och realiserbarhet

Arbetet utföres lämpligen av en eller flera studenter som i projektform tillsammans med oss arbeta fram en kravspecifikation och implementerar en prototyp. Arbetet bör genomföras i ABB Robotics lokaler eftersom all utrustning och programvara som behövs finns där.

Appendix H

This section serves as a user manual to the prototype. The steps are explained in natural order.

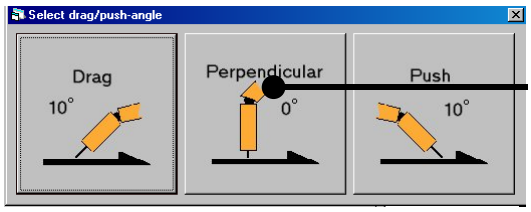


Start off by selecting one of the shapes/pictures

To select a weld line:

1 Click in a corner (you get a red circle in the corner) to select a starting point for the weld.

2 Click in a second corner to set a finishing point to the weld (the selected line turns red).



3 In the select drag/push-angle menu that pops up, click on a picture to select a desired standard weld angle.

4 To select more weld lines repeat step 1-3.

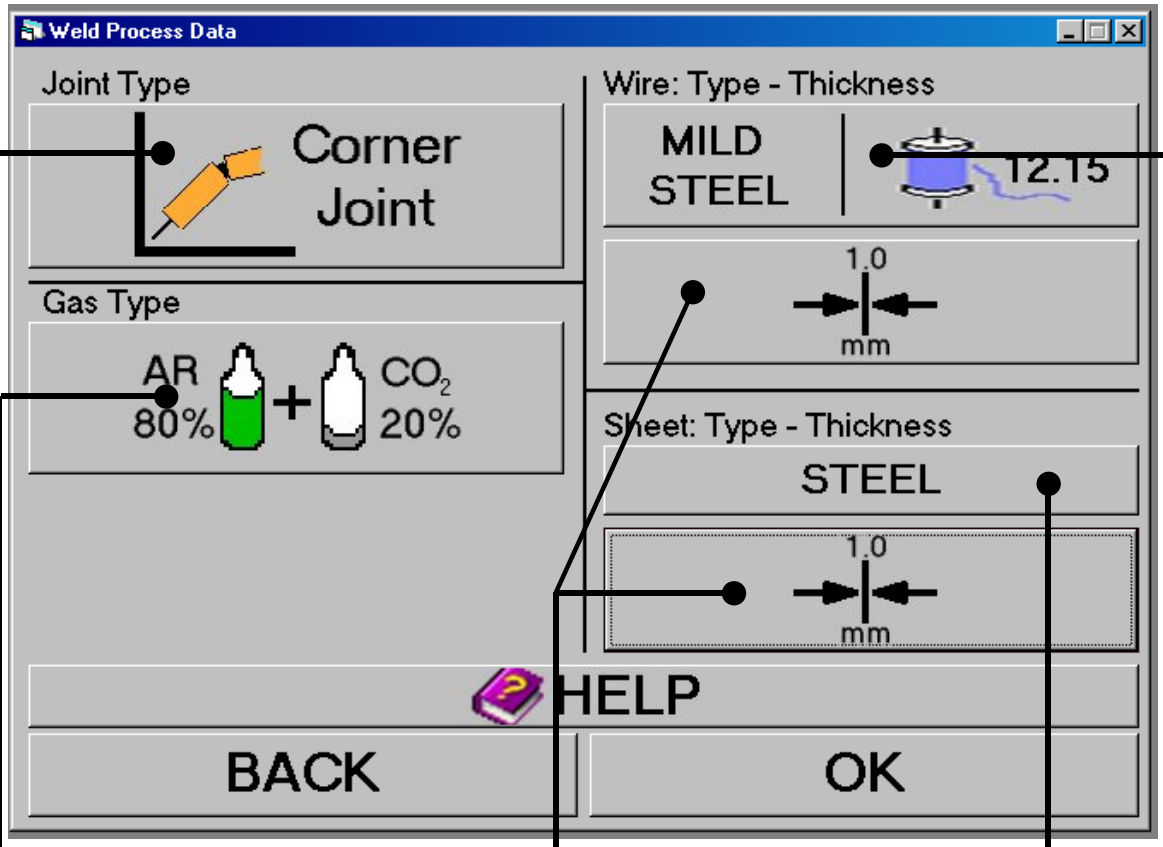
To deselect a weld line:

1 Click in any corner (you get a circle in the corner) connected to the weld line you want to unmark.

2 Click in the second corner of the weld line to unmark the line (line turns grey again).

When done:

Click "OK" to continue your welding configuration.



Change gas type:

1 Click on the gas type picture

2 In the gas type popup-menu, click on a gas type picture to change it and go back.

3 Click "CANCEL" to cancel action and return to the previous value.

Change joint type:

1 Click on the joint type picture.

2 In the joint type menu that pops up, click on a joint type picture to change it and go back.

3 Click "CANCEL" to cancel action and return to the previous value.

When done:

Click "BACK" to return to the "Weld Point Editor".
Click "OK" to continue the welding configuration.

Change sheet type:

1 Click on the sheet type picture

2 In the sheet type menu that pops up, click on a sheet type picture to change it and go back.

3 Click "CANCEL" to cancel action and return to the previous value.

Change wire type:

1 Click on the wire type picture

2 In the wire type menu that pops up, click on a wire type picture to change it and go back.

3 Click "CANCEL" to cancel action and return to the previous value.

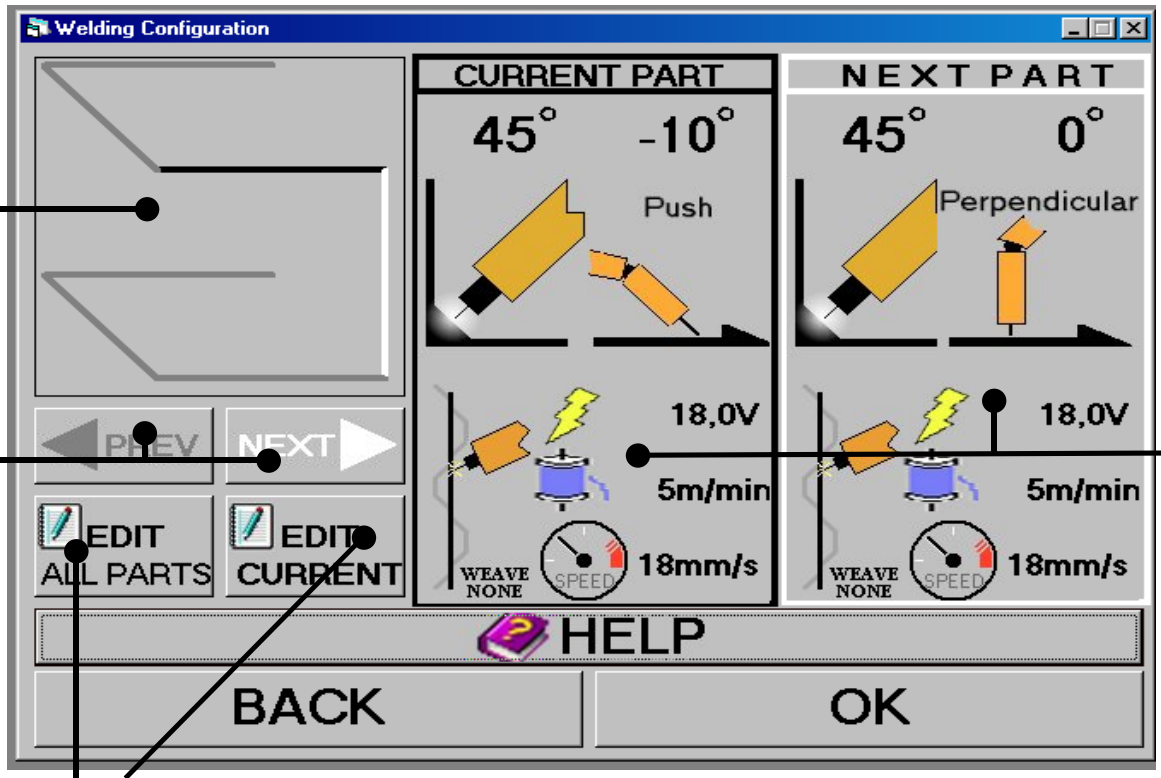
Change thicknesses:

1 Click on the desired thickness picture

2 In the thickness popup-menu, click on a thickness picture to change it and go back.

3 Click "CANCEL" to cancel action and return to the previous value.

The picture in the upper left corner shows the selected weld lines. The black line is the current weld line, the white one is the line following the current weld line. All remaining weld lines are grey.



Welding configuration data is shown for the current and the next weld lines.

EDIT CURRENT:

By clicking on the "EDIT CURRENT" button, you will enter the manual weldpart editor. Changes to the parameters will only apply to the CURRENTLY SELECTED WELD LINE, which is marked as a black arc in the top left corner.

EDIT ALL PARTS:

By clicking on the "EDIT ALL WELDPARTS" button, you will enter the manual weldpart editor. Changes to the parameters will apply to ALL WELD LINES, which is indicated by all arcs being black in the top left corner. This should be done before editing the individual parts.

PREV/NEXT:

By clicking on the "NEXT" or "PREV" buttons you can step through all of the weld lines one at a time and see the weld configuration for them in the "CURRENT PART" and "NEXT PART" displays.

When done:

Click "BACK" to return to "Weld Process Data".
Click "OK" to finish the welding configuration.

Weld Data:

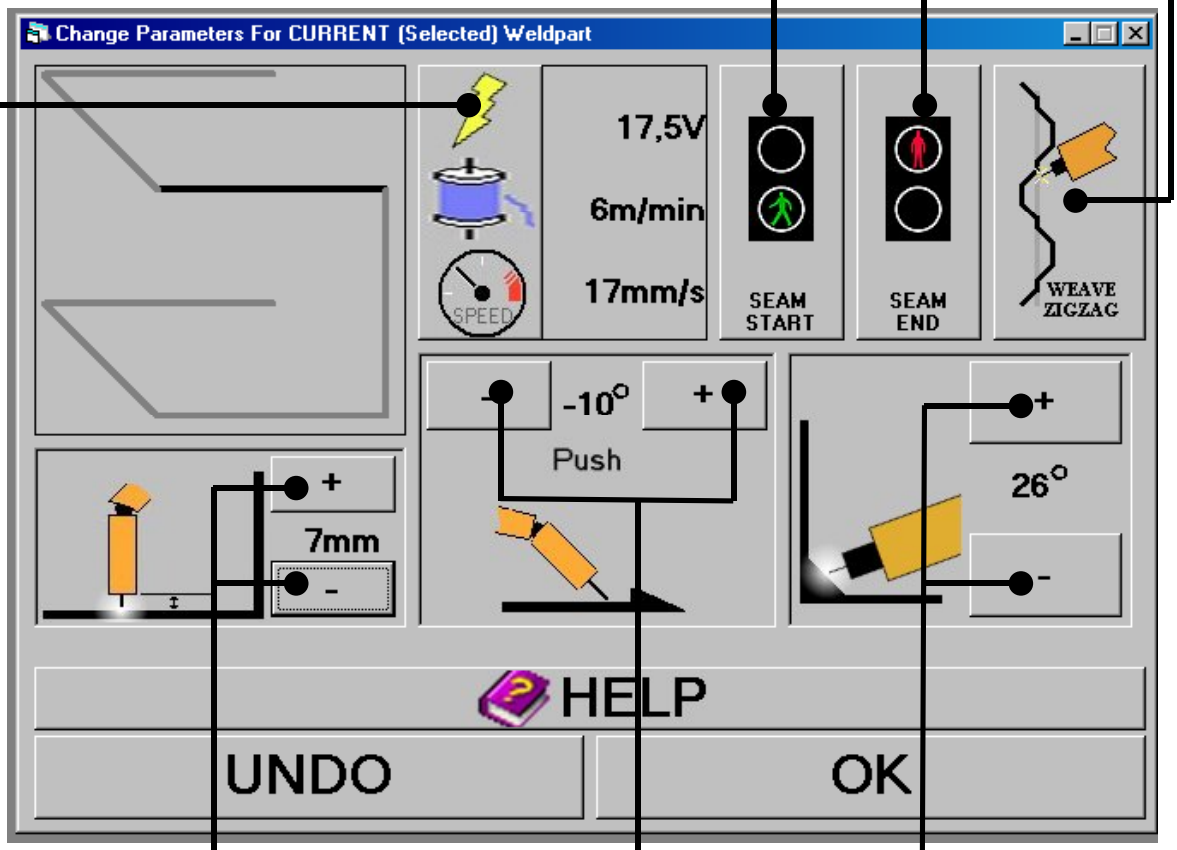
Click the button to change the values for voltage, wirefeed speed and welding speed. Use the minus and plus signs in the popup window that appears to change the desired values.

Weave Shape:

Click the weave button to change the weave shape. Select a weave shape in the popup window to change it and go back.

Seam Start/Seam End:

Click the ”SEAM START” button to change the values for ignition voltage (ign_voltage) and ignition wirefeed (ign_wirefeed). Click the ”SEAM END” button to change the value for burn back time (bback_time). In both cases, use the minus and plus signs in the popup window to change the values.



Torch distance, push/drag angle, work angle:

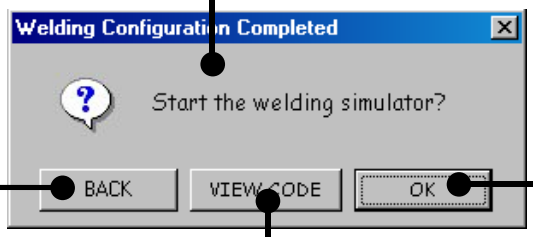
To change the values for torch distance, push/drag angle or work angle, just use the minus and plus signs next to the appropriate picture.

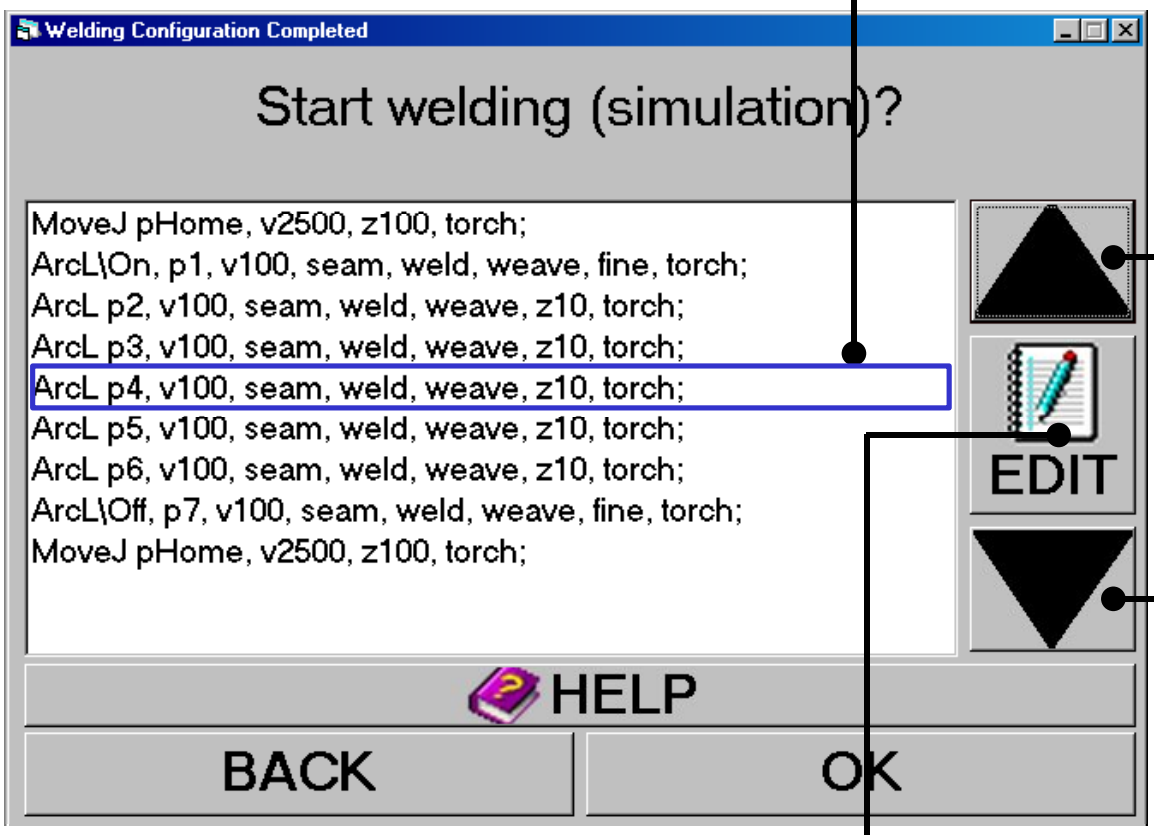
When done:

Click "UNDO" to RESET all changes and return to "Welding Configuration".
Click "OK" to APPLY all changes and return to "Welding Configuration".

Welding Configuration Completed:

Click ”BACK” to go back to the ”Welding configuration”.
Click ”VIEW CODE” to see the generated RAPID code.
Click ”OK” to proceed to the simulation phase.





EDIT:

Click "EDIT" to change the RAPID code for the selected row.

UP/DOWN ARROWS:

Use these buttons to select the next upward/downward RAPID code row.

When done:

Click "OK" to start simulating a welding session.
Click "BACK" to return to "Welding Configuration".

PROGRESS:

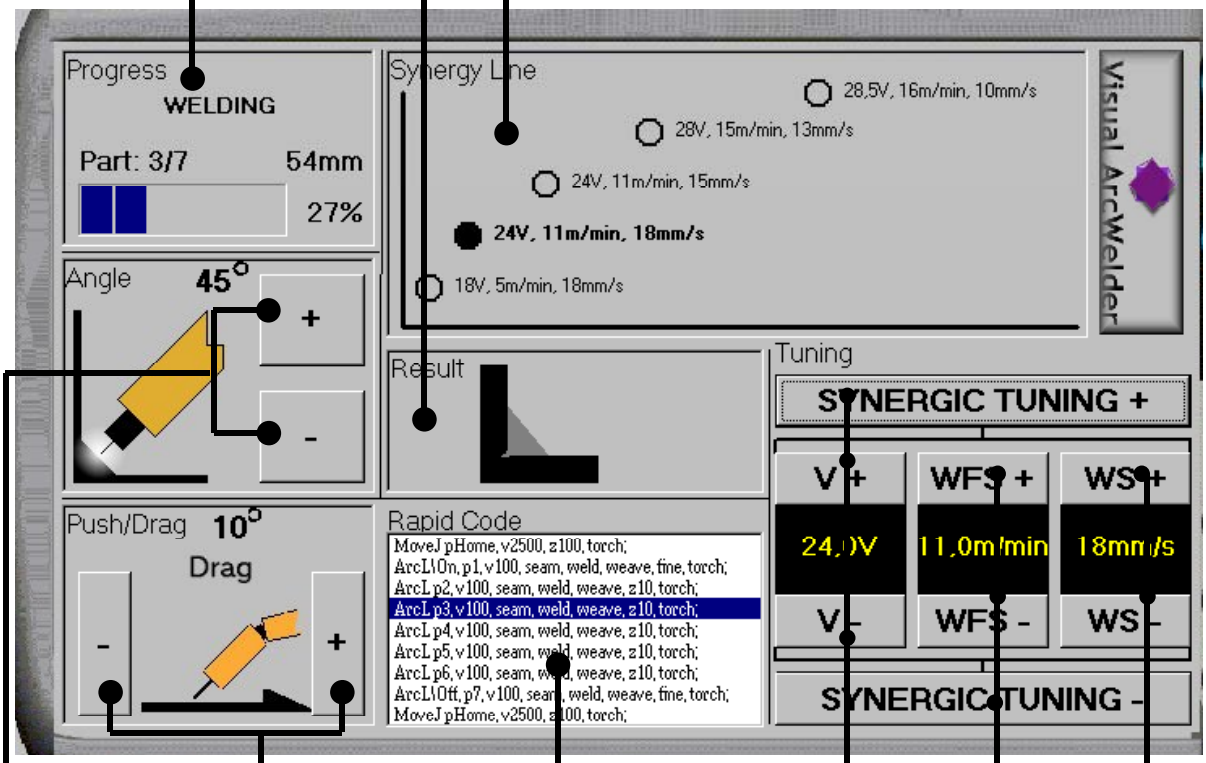
Shows the progress for the current weld part as well as the total progress.

RESULT:

Shows the anticipated weld result for the current parameter setup.

SYNERGY LINE:

Shows the current weld data parameters plotted as a curve.



PUSH/DRAG:

Tune the push/drag angle by pressing the minus- or plus buttons.

ANGLE:

Tune the work angle by pressing the minus- or plus buttons.

RAPID CODE:

Shows the RAPID code lines for the whole program. The codeline being executed is marked.

TUNING:

Tune the Volt, Wire Feed Speed or Wire Speed by pressing the minus- or plus buttons. Tune along the synergy line by pressing the ”SYNERGIC TUNING” plus- or minus buttons.