Welding Robots

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Technology, System Issues and Applications

With 88 Figures

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Dedicated to the memory of my father Joaquim
and to Dina, Rita, Beatriz and Olímpia.
J. Norberto Pires

Dedicated to my wife Marília and my sons André and Joana
Altino Loureiro

Dedicated with love to Ziona,
Rebecka, Natalie and Daniela.
Gunnar Bolmsjö

Foreword

Industrial robots are essential components of today's factory and even more of the factory of the future. The demand for the use of robots stems from the potential for flexible, intelligent machines that can perform tasks in a repetitive manner at acceptable cost and quality levels. The most active industry in the application of robots is the automobile industry and there is great interest in applying robots to weld and assembly operations, and material handling.

For the sake of competitiveness in modern industries, manual welding must be limited to shorter periods of time because of the required setup time, operator discomfort, safety considerations and cost. Thus, robotic welding is critical to welding automation in many industries. It is estimated as much as 25% of all industrial robots are being used for welding tasks.

Robotic welding is being initiated to satisfy a perceived need for high-quality welds in shorter cycle times. The first generation of robotic welding system was a two-pass weld system, where the first pass is dedicated to learning the seam geometry followed by the actual tracking and welding in the second pass. The second generation of welding systems, on the other hand, track the seam in real-time, performing simultaneously the learning and the seam tracking phases. The third generation of welding systems not only operates in real-time but also learns the rapid changing in seam geometries while operating within unstructured environments. Flexibility was achieved with this third generation of welding systems but at the expenses of a considerable amount of programming work of high skilled people in system's integration directed to specific applications. However, availability and agility are additional key issues in modern manufacturing industries, demanding new welding systems incorporating these features as well, revealing in this way the flexibility of the system to the normal operator without the need of extra skills from him.

This book covers up-to-date and relevant work in the area of third generation of robotic welding systems with availability and agility features. The principal welding processes are reviewed from the point of view of their automation. A distributed system's approach is followed for the integration of the different components and software of the welding cell and its integration within the global production system. Particular emphasis is given to the availability and agility to the end user. Application examples demonstrating step-by-step the system's integration design clarify the relevant aspects to the interested reader.

The authors have made a strong-minded effort to set their work in the context of international robotic arc welding research. The mix of specific research issues and the review of broader research approaches make this a particularly welcome contribution.

This book is directed towards readers who are interested in developing robotic welding applications, and in particular to perform system integration. Although this work is presented in the context of arc welding, the issues related to system integration are general in nature and apply to other robotic applications as well. This book constitutes a valuable source of the kind of information on robotic welding that result of years of experience, making it suitable as well for the decision maker, the application engineer, the researcher, the technician, and the student.

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Preface

Modern manufacturing faces two main challenges: more quality at lower prices and the need to improve productivity. Those are the requirements to keep manufacturing plants in developed countries, facing competition from the low-salary regions of the world. Other very important characteristics of the manufacturing systems are flexibility and agility of the manufacturing process, since companies need to respond to a very dynamic market with products exhibiting very short life-cycles due to fashion tendencies and worldwide competition. Consequently, manufacturing companies need to respond to market requirements efficiently, keeping their products competitive. This requires a very efficient and controlled manufacturing process, where focus is on automation, computers and software. The final objective is to achieve semi-autonomous systems, *i.e.*, highly automated systems that work requiring only minor operator intervention.

Robotic welding is one of the most successful applications of industrial robot manipulators. In fact, a huge number of products require welding operations in their assembly processes. Despite all the interest, industrial robotic welding evolved only slightly and is far from being a solved technological process, at least in a general way. The welding process is complex, difficult to parameterize and to monitor and control effectively. In fact, most of the welding techniques are not fully understood, namely the effects on the welding joints, and are used based on empirical models obtained by experience under specific conditions. The effects of the welding process on the welded surfaces are currently not fully known. Welding can in most cases impose extremely high temperatures concentrated in small zones. Physically, that makes the material experience extremely high and localized thermal expansion and contraction cycles, which introduce changes in the materials that may affect its mechanical behavior along with plastic deformation. Those changes must be well understood in order to minimize the effects.

The majority of industrial welding applications benefit from the introduction of robot manipulators, since most of the deficiencies attributed to the human factor is removed with advantages when robots are introduced. This should lead to cheaper products since productivity and quality can be increased, and production costs and manpower can be decreased. Nevertheless, when a robot is added to a welding setup the problems increase in number and in complexity. Robots are still difficult to use and program by regular operators, have limited remote facilities and programming environments, and are controlled using closed systems and limited software interfaces.

The present book gives a detailed overview of Robotic Welding at the beginning of the twenty-first century. The evolution of robotic welding is presented, showing to the reader what were the biggest steps and developments observed in the last few years. This is presented with the objective of establishing the current state-of-the-art in terms of technologies, welding systems, software and sensors. The remaining issues, *i.e.*, the issues that remain open are stated clearly, as a way to motivate the readers to follow the rest of the book which will make contributions to clarify most of them and help to solve a few.

To do that, a good chapter on "Welding Technology" is presented, describing the most important welding techniques and their potential and requirements for automation using robot manipulators. This chapter includes recent results on robotic welding processes, which can constitute a good source of information and practical examples for readers.

A good revision with current research results on "Sensors for Welding Robots" used on robotic welding is also presented. This includes sensors for seam tracking, quality control and supervision. This chapter includes all system requirements necessary to use those sensors and sensing techniques with actual robot control systems. Hardware and software interfaces are also covered in detail.

A good revision on available welding systems, including hardware and software, clarifying their advantages, and drawbacks is also necessary to give to the reader a clear picture of the area. The book includes a chapter on "Welding Robots: System Issues", which covers recent state-of-the-art of industrial robotic welding systems currently available in industry and university laboratories.

Finally, a few industrial applications using the presented techniques and systems is presented. The present book includes a chapter on "Robotic Welding: Application Examples", where a few selected applications are described in detail including aspects related to software, hardware, system integration and industrial exploitation. This chapter uses actual robots, but it is presented in a general way so that the interested reader can easily explore his interests.

Conclusions stating what was presented and what are the next challenges, guiding the reader to what are the next required developments, is presented at the end of the book. A good collection of references is also presented, to enable the reader to explore further from the literature.

J. Norberto Pires, Coimbra, 2005

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Introduction and Overview

1.1 Introduction

Actual market conditions are only compatible with small/medium batch manufacturing, due to strong competition and dynamical behavior of the market. In those conditions, robotic production setups exhibit the best "cost per unit" performance if compared with manual work and with hard automated setups (Figure 1.1) [1]. Consequently, near future requires powerful and more flexible machines in order to handle requests from small businesses, which need more remote interfaces, powerful programming languages, force control, powerful Advanced Programming Interfaces (APIs) for high level programming, *etc.* That means exposing to the user the flexibility stored inside the manufacturing robotic machines, as a result of several decades of engineering, which is currently barely used.

What makes robotics so interesting is that it is a science of ingenious devices, constructed with precision, powered by a permanent power source, and flexible from the programming point of view. That does not mean necessarily open source, but instead the availability of powerful APIs, and *de facto* standards both for hardware and software, enabling access to system potentialities without limitations. This is particularly necessary on research environments, where a good access to resources is needed in a way to implement and test new ideas. If that is available, then a system integrator (or even a researcher) will not require open source software, at least for the traditional fields of robotics (industrial robot manipulators and mobile robots). In fact, that could also be very difficult to achieve since those fields of robotics have decades of engineering efforts, achieving very good results and reliable machines, which are not easy to match. That open source issue is nevertheless very important for the emerging robotics research (like humanoid robotics, space robotics, robots for medical use, *etc.*) as a way to spread and accelerate development (Figure 1.2).

Industrial Robotic Welding is by far the most popular application of robotics worldwide [6]. In fact, there is a huge number of products that require welding operations in their assembly processes. The car industry is probably the most important example, with the spot and MIG/MAG welding operations in the car body workshops of the assembly lines. Nevertheless, there are an increasing number of smaller businesses, client oriented, manufacturing small series or unique products designed for each client. These users require a good and highly automated welding process in a way to respond to client needs in time and with high quality. It is for these companies that the concepts of *Agile Production* [7],[8] apply the most, obviously supported by flexible manufacturing setups. Despite all this interest, industrial robotic welding evolved slightly and is far from being a solved technological process, at least in a general way. The welding process is complex, difficult to parameterize and to effectively monitor and control [1]-[7]. In fact, most of the welding techniques are not fully understood, namely the effects on the welding joints, and are used based on empirical models obtained by experience under specific conditions. The effects of the welding process on the welded surfaces are currently not fully known. Welding can in most cases (*i.e.* MIG/MAG welding) impose extremely high temperatures concentrated in small zones. Physically, that makes the material experience extremely high and localized thermal expansion and contraction cycles, which introduce changes in the materials that may affect its mechanical behavior along with plastic deformation [9]-[11]. Those changes must be well known in order to minimize the effects.

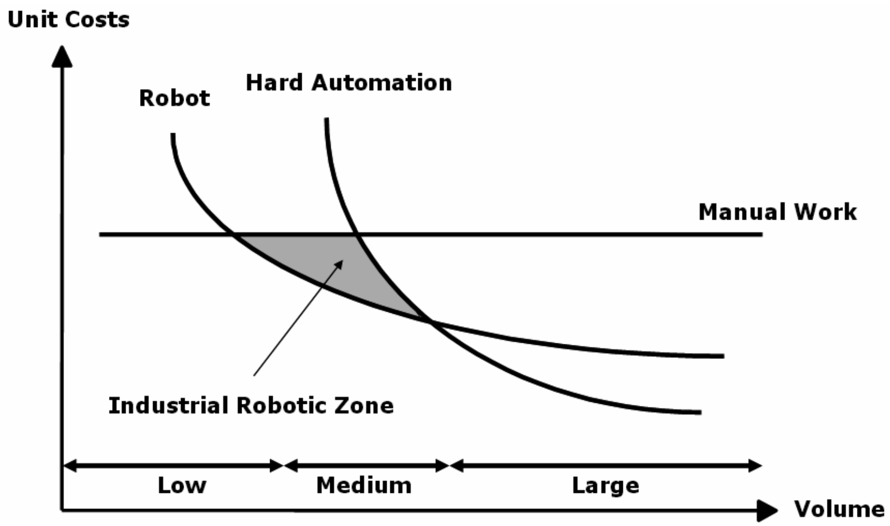

Figure 1.1. Industrial robot zone

Using robots with welding tasks is not straightforward and has been a subject of various R&D efforts [12]-[16]. And that is so because the modern world produces a huge variety of products that use welding to assemble some of their parts. If the percentage of welding connections incorporated in the product is big enough, then some kind of automation should be used to perform the welding task. This should lead to cheaper products since productivity and quality can be increased, and production costs and manpower can be decreased [17]. Nevertheless, when a robot is added to a welding setup the problems increase in number and in complexity. Robots are still difficult to use and program by regular operators, have limited remote facilities and programming environments, and are controlled using closed systems and limited software interfaces [18]-[22].

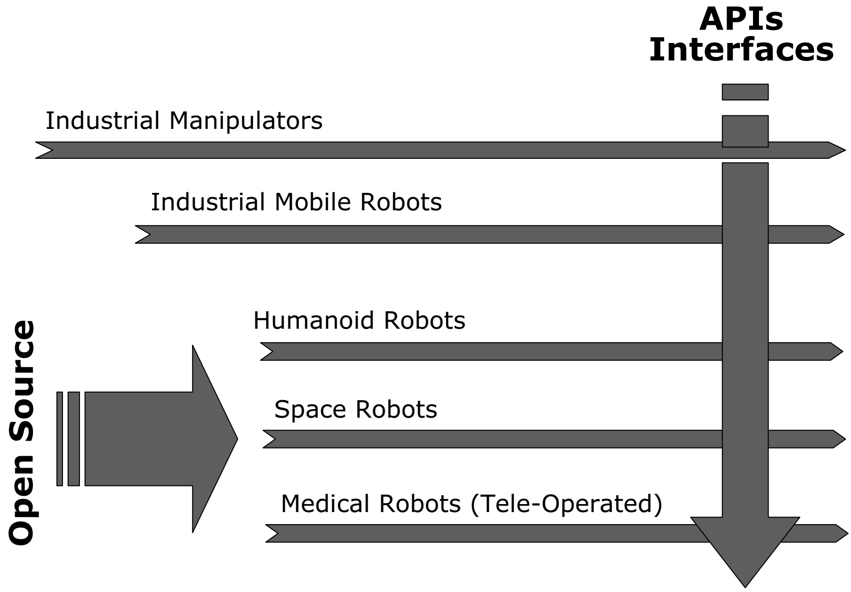

Figure 1.2. Traditional and modern fields in robotics research: where is open source needed?

In this book, most of these problems are addressed in detail along with a comprehensive presentation and discussion of a laboratory system built with the main objective of being a test bed for welding experiments. Our experience with the system shows that it has potentialities for industrial utilization, and in fact that idea is explored in the book, using industrial partner test-cases. For that purpose mainly industrial equipment was selected in designing the system, as a way to facilitate its industrial exploitation. The book also addresses aspects of system programming and welding parameterization, which constitute one of the main contributions of the book.

1.1.1 Why Robotic Welding and a CAD Programming Interface?

Automation of the welding process is a very challenging area of research in the fields of robotics, sensor technology, control systems and artificial intelligence. This book discusses the automation of the welding process taking as an example the arc welding process. Although there's a huge number of welding processes, usually suited for a particular type of application, arc welding is used in nearly all applications in the metal manufacturing industry. The two most common types of arc welding processes are the gas shielded tungsten arc welding (GTAW) and the gas shielded metal arc welding (GMAW) processes.

The gas shielded tungsten arc welding process (GTAW), also known as tungsten inert gas (TIG), is a welding process where the arc is created between a non-consumable electrode and the work metal. The process is shielded from contamination by the atmosphere using an inert gas, usually argon or a mixture of gases. The intense heat, generated by the electric arc produced by an electric current in the 50 to 700 A range, melts the work metal and allows the joining as the metal solidifies. Since the electrode is non-consumable the welding can be performed without the addition of filler metal, but in some cases a filler metal is used depending on the requirements established for the particular join.

The gas shielded metal arc (GMAW), also known as MIG (Inert Gas Metal) / MAG (Active Gas Metal) welding process, uses the heat of the electric arc to melt the consumable electrode wire and the metallic components to be welded. Figure 1.3 illustrates the welding principle. The fusion is carried out under the protection of an inert gas (argon or helium), or mixture of an inert gas with much cheaper gases like oxygen or carbon dioxide (CO_2), in order to prevent the pernicious contamination with some gases of the atmosphere (oxygen, nitrogen and hydrogen). Applying a high current to the electrode causes its tip to melt transferring in this way metal to the work-piece. The electrode is fed automatically to the arc using a coil that unfolds at a controlled speed. The rate at which the electrode is fed is known as *wire feed rate*, and is one parameter of fundamental importance for controlling this welding process. Depending on the magnitude of the electrode current and voltage, along with the type of gas and size of the electrode, four different types of metal transfer modes can be obtained: spray, short-circuiting, globular and pulsed transfer.

A complete description of these and other current welding processes will be presented in Chapter 2. Nevertheless, the brief description above makes it easy to conclude that a good quality weld relies on the welder's experience and skill. The experienced and skilled manual welder is able to select the welding process parameters based on similar cases previously encountered. In particular, he is able to:

1. Select the type of shielding gas, the type and diameter of wire to use, and the initial current and voltage settings more suitable for the case in hand.
2. Adjust continuously the process variables by looking to the molten pool or by listening to the sound produced by the arc.
3. Maintain the torch in the correct position with precision and stability, which is fundamental for a good and constant weld.