Robot Reliability and Safety

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This book is affectionately dedicated
to my son Mark

Preface

Robots are increasingly being used in industry to perform various types of tasks. Some of the tasks performed by robots in industry are spot welding, materials handling, arc welding, and routing. The population of robots is growing at a significant rate in various parts of the world; for example, in 1984, a report published by the British Robot Association indicated a robot population distribution between Japan (64,600), Western Europe (20,500), and the United States (13,000). This shows a significant number of robots in use. Data available for West Germany and the United Kingdom indicate that in 1977 there were 541 and 80 robots in use, respectively, and in 1984 these numbers went up to 6600 and 2623, respectively. Just as for other engineering products, the reliability and safety of robots are important.

A robot has to be safe and reliable. An unreliable robot may become the cause of unsafe conditions, high maintenance costs, inconvenience, etc. Robots make use of electrical, mechanical, pneumatic, electronic, and hydraulic parts. This makes their reliability problem a challenging task because of the many different sources of failures. According to some published literature, the best mean time between failures (MTBF) achieved by robots is only 2500 hours. This means there is definite room for further improvement in robot reliability. With respect to safety, there have been five fatal accidents involving robots since 1978. A Swedish report stated that in Sweden there were 36 accidents involving robots that caused human injury during the period 1979 to 1983. Furthermore, Japanese findings indicate that 8% of persons working with robots have been injured, and as many as 36% of them have experienced an accident of some sort. Because of such situations, the robot safety issue has become of the utmost importance. Hence, one may say that robot reliability and safety are the most challenging problems to be dealt with, and this book focuses on both of these important areas.

The main objective of this book is to be wide in scope, in particular with respect to reliability. However, some areas of reliability, such as software reliability and fault tolerance, are not covered in depth due to several factors: space limitation, the size of computer software and hardware in robots in relation to general computer systems, etc. Some general concepts presented in

Chapter 2 can be applied in the case of fault tolerance. For example, triple-modular redundancy (TMR) is probably the most discussed term in computer redundancy reliability, and is basically a special case of the k -out-of- n system with a voter. The k -out-of- n system is described in Chapter 2. In any case, for further studies of computer software and hardware reliability and other areas, the relevant references are cited at appropriate places in the text.

This book is the result of filtering through almost all of the published literature on robot reliability and safety, as is evident from the listed references in the book. The book is intended for readers such as practicing engineers and senior undergraduate and graduate students with no previous knowledge of the subject. In general, emphasis is on the structure of concepts rather than on mathematical rigor and minute detail. The sources of most of the material presented are given in the references, if the reader wishes to delve deeper into a specific area. The book contains over 750 references and approximately 40 solved examples. The references will provide the reader with further information on relevant topics.

Twelve chapters and an appendix constitute *Robot Reliability and Safety*. The purpose of Chapters 1 to 3 is to provide the necessary background to help in understanding the remaining chapters of the book. Chapter 1 briefly discusses robots and robot reliability and safety histories, basic terms and definitions, and the scope of the book. Introductory aspects of general reliability and safety are presented in Chapter 2. Chapter 3 consists of basic robotics; this allows the reader to familiarize himself/herself with the subject of robotics, or if he/she already possesses such a background on the said topic, to refresh his/her memory. The topic of robot accidents is discussed in detail in Chapter 4. This chapter covers subjects such as real-life examples of robot accidents in Japan, Western Europe, and the United States; causes and characteristics of robot accidents, effects of robot accidents, and robot accident analysis and prevention. Chapter 5 discusses various fundamental aspects of robot safety: Some of these are robot safety problems; the use of robots to promote safety; weak points in planning, design, and operations causing safety problems; the manufacturer's and user's role in robot safety; and robot safeguard methods. Several topics related to robot safety are discussed in Chapter 6: These include robot safety education, safety considerations in robot testing and start-up, commissioning and acceptance, safety considerations in robot welding operations, robot safety in the automobile industry, robot safety standards, and robot safety research.

Chapter 7 covers human factors in robotics. Human factors play an important role regarding robot reliability and safety. Topics such as robots versus humans, human factors' issues during the factory integration of robot systems, benefits and drawbacks of robotization from the standpoint of human factors, guidelines for safeguarding the operator and the teacher, human error data in robotics, and the mathematical modeling of robots with respect to human error are described. A mathematical model presented in this chapter is applicable when the robot system failure times due to humans or nonhumans are

exponentially distributed. If different human error rates occur during robot teaching, operation, and design, one should take an average of these three rates and then use the resulting figure in the derived model equations. However, if distinct probabilities are required for each of these three distinct modes, then the new equations can be developed in a similar manner.

The subject of robot reliability is discussed in depth in Chapter 8. Many reliability-related topics are covered in this chapter: robot-related failure terms, general categories of robot failures and their protection, selected references related to robot reliability, types of robot halts and warm restarts, hazard detector's fail-safe design, guidelines for developing a robot reliability standard, robot reliability measures, and a reliability analysis of electric and hydraulic robots with the aid of block diagram and fault tree methods. Chapter 9 discusses the important subject of robot maintenance; this subject is related to robot reliability, because poor maintenance leads to poor reliability. Failure data and analysis are discussed in Chapter 10, and are vital for robot-reliability analyses. This chapter covers many topics, some of which are reliability-related data sources, failure data for selected items and tasks, and the hazard plotting method. Economics generally plays an important role in robot reliability and safety analyses; therefore, Chapter 11 is totally devoted to this theme and discusses various aspects of robot economics. The topics covered are concerned with factors for installing robots, robot installation costs, robot economic techniques and methods for making robot financial decisions, robot life-cycle costing, and robot associated-cost estimation models. Robot testing is very important in the reliability evaluation of robots under development; thus, Chapter 12 discusses robot testing and the pertinent information related to robots. Some of the topics covered in this chapter are robot performance testing, robot reliability testing, robot specifications, and general information on robots. The appendix lists over 460 references on robot reliability and safety and related areas.

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