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Guest editorial

We were delighted to be invited by the editors of *Reliability Engineering and System Safety* to organise a special issue on the Safety of Robotic Systems. Robotic systems have now reached a level of sophistication far beyond single-task repetitive machines. The development of systems which are multi-purpose involving some degree of autonomy are now being developed in several areas of application, among those the nuclear, aeronautic and medical areas.

The objectives for selecting and arranging the contributions were:

1. to describe the present state-of-the-art through papers on system development, specific equipment development and views on their use;
2. to describe how reliability methods can be targeted to robotic systems, both in design and operation;
3. to highlight important ongoing research activities.

The purpose for the selection is twofold: (1) giving readers less familiar with the area of robotic systems an idea on the progress and perspectives and (2) giving the reliability society an update on the progress in development of methods appropriate for robotic systems and their application.

It is not our intention to discuss the contents of the papers, but a short introductory summary might illustrate how we view the papers and their contribution in meeting the objectives of the special issue.

The issue begins with a paper by Paredis & Khosla, which gives a good overview of the problems and state of the art in the area. For robot manipulators, a key failure is that of one of the joints of the arm. In the work by Paredis & Khosla, a new algorithm is introduced which allows the trajectory of the robot to be globally planned in such a way as to guarantee tolerance of such a failure, under certain assumptions.

The issue of recovery from hardware faults is also discussed in the paper by Hooper *et al.*, which discusses a four-level mechanical architecture for robot fault tolerance. Both algorithms and hardware are described in the paper.

The next three papers in the issue all discuss, to varying degrees, the use of fault trees in analysing robot reliability. The paper by Khodabandeloo introduces and discusses the merits of fault and event trees in robot manipulator analysis. The use of these techniques in a wide variety of applications is discussed.

The papers by Lauridsen *et al.* and Walker & Cavallaro address the issue of reliability analysis of robots for nuclear environments. The work of Lauridsen *et al.* discusses various analyses, including fault tree analysis, performed for different robot designs. The robots considered are for deployment in radiation environments in Europe.

The work in Walker & Cavallaro discusses the fault tree analysis of a robot design to be deployed in radioactively contaminated waste tanks in the USA. In the paper, it is shown how the use of fault trees allowed the identification of uncovered failure modes in an initial design for the robot.

In the next paper in the issue, Sharp & Decreton continue the discussion of robots for radioactive environments. The effects of radiation on typical robot components is described, and examples of systems to which radiation tolerant design rules have been applied is presented.

Safety issues are of prime importance in robot applications that are currently driving work in robot reliability. In the paper by Gaskill & Went, the issue of safety directives and standards in the European Community is discussed. Recent standards pertaining to programmable electronic systems are described, and their potential impact on robotics noted.

One important issue that arises when considering robot reliability is that of how to characterize and compare robots from a reliability and fault tolerance perspective. The paper by Hamilton *et al.* introduces several performance measures, designed to rate robot systems for fault tolerance and performance. The measures are supported by a series of examples.

In most safety-critical robot applications today, the robots are controlled via teleoperation, that is, there is a human operator in the control loop. The paper by Dassonville *et al.* investigates some safety-related reliability issues raised by the human-machine interface. In particular, the issue of trust between human and machine is analyzed, and some experimental results presented.

The final two papers present new sensing algorithms for collision avoidance and robot safety. The paper by Graham & Zurada uses a neural network methodology to integrate sensory input followed by a collision detection decision that then affects the control algorithm.

In Wikman & Newman, the concept of reflex control is developed within an integrated control system for autonomous robot operation. The reflex control algorithms are able to operate in real-time and either prevent the execution of a dangerous command or trigger a response where the robot moves away from an object in order to possibly share a workspace with another robot or human.

The short summaries show the wide range of applications of reliability supported assessments of robotic systems both in design and operation. We have identified some important issues, which we believe will be on the agenda in the future:

1. integration of reliability aspects into the system design in such a way that failure identification and even some failure corrections can be carried out while operating
2. integration of reliability aspects to achieve the state that the increased level of intelligence does not compromise safety
3. verification of the level of safety of the robotic systems and comparisons with the safety of the same task carried out by a human.

We hope this issue of *Reliability Engineering and System Safety* describes the level of activity in this rather new and rapidly developing area. The papers clearly show the usefulness of the reliability assessment also in this area, and demonstrate the need for further developments to the requirements of robotic systems in particular, as the level of sophistication increases and with the extended demand from users.

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