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RELIABILITY, SAFETY AND MAINTENANCE OF INDUSTRIAL ROBOTS A REVIEW

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Abstract— This paper presents a review of published literature on robot reliability, safety and maintenance. The literature is studied in three categories like robot safety, robot reliability and miscellaneous. Q robot has to be safe and reliable. An unreliable robot may become the cause of unsafe, inconvenience, high maintenance cost, over the years various assensment methods have been developed like fault tree analysis, failure mode, effect analysis, and markovian analysis.

Keywords— Industrial robots, reliability, safety, maintenance

I. INTRODUCTION

Industrial robots are important components in manufacturing systems, and have been applied in a wide variety of applications, such as welding, material handling, assembly and painting. Robots are invaluable in manufacturing environments due to their high reliability, precision, repeatability and predictability. Once the robots have been programmed correctly to perform certain manufacturing operations, these processes can be achieved with high speed and precision. In particular, the application of robots in standard manufacturing tasks, such as materials handling, spot welding, and spray painting, can achieve high productivity and efficiency. The World Robotics Report show that a record high of 384,100 units were shipped globally in 2018 year – an increase of 1% compared to the previous year. It is show t the annual sales volume of industrial robots increased by the sixth times in a row in year 2013-2018.

Reliability improvement is always a prime concern in the life cycle management of manufacturing facilities. For this purpose, various activities are conducted in terms of reliability design and maintenance. In addition, it is well recognized that planning proper operating conditions is effective for reliability improvement of the facilities. Improper operating conditions lead to **so called forced** deterioration of components and shortens the life of the facility. Reliability in the use of robotics outside factories or processing plants has become a matter of great concern. Domestic robots and those intended to assist nurses and surgeons in hospitals are example of reliability and safety critical cases. Need of co-operation between humans and industrial robots is increase, especially in production applications. Human safety is the most important concerns; prevent any fenceless cooperation between industrial robots and humans.

OBJECTIVES OF INDUSTRIAL ROBOTS

1. To remove human operators from potentially hazardous work environments.
2. To reduce labor cost
3. To increase output rate
4. To perform dangerous tasks
5. To improve product quality
6. To increase manufacturing flexibility
7. To reduce material waste
8. Compliance with government regulation

II. LITERATURE SURVEY

Adrian Kampa 2018 - **The Review of Reliability Factors Related to Industrial Robots**

Problem of industrial robot reliability is closely related to machine reli-ability and is known as and described in the literature, it is also more connected and complex with specific robot related problems and safety requirements (near failure situations, human errors, software failures, calibration, singularity, etc.). Compared to generation of the first robot, the modern robots are more functional ,advanced, and reliable. Robot's producers declare robot working time without failures, but there are publications about the real robot reliability and about occurring failures. Surveys seen that not every robot user has collects data about robot failures and monitoring . The practice seen, that the un-reliable components are in the robot's equipment, including sensors, wiring, grippers, tools, which are often custom made for different purposes. The life of a industrial robot is about 11to15 years, because the key mechanical components (e.g. drives, gears, bearings) are wearing out. The key factor is the periodical maintenance following the manufacturer's recommendations. The refurbishment of the robot it can work further possible, but there are also better and new robots from modern generation.

G. LATIF-SHABGAHI 2009 - **RELIABILITY ANALYSIS OF ROBOTS BY FAULT TREES:** A **NOVEL METHODOLOGY**

Fault tree analysis is a systematic method for reliability estimation of complex systems and their design verification. Robots are example of such complex systems that are used, usually, in hazardous environments increasing their potential for failures The construction of fault tree is an important step in reliability estimation of systems. This paper introduces a **novel methodology** for construction of a robot system fault tree. The starting model is the Simulink-model of the robot system. The main advantage of Simulink representation of a system topology is its wide application in the modeling and simulation of engineering systems. Reliability in the use of robotics outside factories or processing plants has become a matter of great concern. Domestic robots and those intended to assist nurses and surgeons in hospitals are example of reliability and safety critical cases. Fault tree is one of the systematic methods to examine the safety and reliability of robotic systems. A new methodology for automatically construction of fault trees has been proposed in this paper. System block diagram is modeled in MATLAB-Simulink and then an *"Extended model"*, that contains functional (or failure) and behavioral information of the system, is built manually by the user.

Jinhui Wu, Dequan Zhang 2019- **A MOMENT APPROACH TO POSITIONING ACCURACY RELIABILITY ANALYSIS FOR INDUSTRIAL ROBOTS**

First, the kinematic models of industrial robots are established based on the Denavit–Hartenberg method, in which the link lengths and joint rotation angles are treated as uncertain variables. Second, the Sobol' method is used to analyze the sensitivity of uncertain variables for the positioning accuracy of industrial robots, by which the sensitive variables are determined to perform the reliability analysis. Finally, in view of the sensitive variables, the first-four order moments and probability density function of the manipulator's positioning point are assessed by the point estimation method (PEM) in three examples. The Monte Carlo simulation method, the maximum entropy problem with fractional order moments (maximum entropy problem with fractional order moments method (ME-FM) method), and the experimental method are also performed as comparative methods. All the results demonstrate that the proposed PEM has a higher accuracy and efficiency to assess the positioning accuracy reliability of industrial robots. Reliability analysis of industrial robots not only provides the perfect direction of the position errors compensation for industrial robots control, but also introduces a for determining the structural dimensions tolerances and joint rotation errors in the design of industrial robots. For positioning accuracy reliability analysis of multiple Joint and kinematic trajectory, further investigations are needed.

Yamada 2002- **RELIABILITY IMPROVEMENT OF INDUSTRIAL ROBOTS BY OPTIMIZING OPERATION PLANS BASED ON DETERIORATION EVALUATION** proposes a novel method for improving reliability of manufacturing facilities by optimizing operating conditions so as to reduce deterioration of critical components and to extend the life of facilities components. The deterioration of the components are evaluated from the stress acting on them during operations by means of a life cycle simulation. The method is applied to an industrial robot whose operating conditions are defined in terms of layout of the robot and a motion pattern. In the optimization process, the operating conditions of the robots are modified so as to reduce gear wear in the critical joint which has the least life. The optimization is performed by means of a hybrid GA which consists of genetic algorithm and simulated annealing. The effectiveness of the method is verified by applying it to the assembly robot.

B.S. Dhillon 2000 **– Robert system reliability and safety in Canada: a survey of robot users**

This author literature survey of robot in Canadian users concerning robot reliability and safety. Data on 26 questions were analyzed and the resulting findings are presented in the form of tables, histograms, pie charts, etc. Provides conclusions including the fact that approximately 75 per cent of companies are using robots for commercial purposes; in particular the automotive sector. most general types of robots used in industry are intelligent robots; . The purposes of introducing robots in the facilities are to reduce labor cost, to increase output rate, to improve product quality, to improve manufacturing flexibility, and to perform dangerous tasks; . The most specific tasks frequently performed by the robots in the industry are welding, material handling, and laser/water jet cutting. Generally most of the companies have policies for the specifications of robot reliability/maintainability/safety.

Most of the companies provide robot safety education or training to their workers. . The general parameters for reliability measurement are MTBF (mean time between failures), MTTR (mean time to repair), and life cycle cost. . Mostly, professional standards are used by the companies to ensure robot reliability, maintainability and safety. Major sources of failure in robotic systems from the users' point of view are software failure, human error and circuit board troubles.Most extensive techniques used to assess the reliability of the robot components are FMEA (failure mode and effect analysis), and FTA (**fault tree analysis**). The robot manufacturers provide frequently ineffective maintenance manuals; and robot-related problems are generally less than 50 per year. Most of the companies have preventive maintenance programs for their robots.Most popular safeguard methods used in the Canadian industry for robot safety are: physical barriers, flashing lights, and warning signs.

B . S . Dhillon and A . R . M . Fashandi 1997- **Safety and reliability assessment techniques in robotics**

In performing the reliability analysis of a robot system, first of all an important task is to identify the most suitable available analytical methods . After considering the factors such as cost , simplicity , and ef fectiveness , the most appropriate of the analytical methods are as follows :

- Failure Mode and Ef fects Analysis (FMEA) ,
- Fault Tree Analysis (FTA) ,
- Block diagram ,
- Combinational models (i . e ., combined Fault Trees and block diagram) ,
- Markov and Non-Markovian Models , and
- Simulation Technique (Monte-Carlo)

P. K. Bhatti 1988 **- Reliability Analysis of Robot Manipulators**

The major sources of kinematic errors in robot manipulators are discussed. The random nature of the errors makes it imperative to use a probabilistic approach in the kinematic model. The kinematic parameters are assumed to be random variables following Gaussian distribution. The concept of reliability is applied to robot kinematics and the term “manipulator reliability" is introduced. Two techniques are presented to compute the manipulator reliability. In the analytical approach the joint probability density function of the position and/or orientation parameters is identified from the known geometric properties of the manipulator and the reliability is computed by integrating this function. In the numerical approach, a Monte Carlo simulation procedure is used for computing the manipulator reliability. The reliability analysis procedures are illustrated with a two-link planar manipulator and a six degree-of-freedom (Stanford) manipulator. The reliability of the two-link planar manipulator is computed using both analytical and numerical techniques and the results obtained with the two techniques are compared.

Grzegorz Gołda, Adrian Kampa and Damian Krenczyk 2019**-The Methodology of Modeling and Simulation of Human Resources and Industrial Robots in FlexSim**

The advanced computer simulation software like FlexSim enables to build the sophisticated models of the production systems with machines, operators, and robots with stochastic (short-time and long-time) reliability parameters, which allows better representation and understanding of a real production process. As it was predicted, the experiments confirm the advantage of the application of robotic manufacturing line compared to manually operated line. However, this is one of the best examples of robotic improvement in manufacturing, and in other cases of machine tending, the difference between human operator and robot is not so clear to see.

Hamed Fazlollahtabar 2019- **Triple state reliability measurement for a complex autonomous robot system based on extended triangular distribution**

Manufacturing systems including autonomous robots make the problem more challenging. By increasing the number of components in the autonomous manufacturing system and with respect to their intermittent interactions, a complex system is evolved. The reliability of such a system is significant due to high repair costs and failure downtime duration. In this framework, an extension of the triangular probability distribution is proposed. In addition, an analysis on the failure rate using the maximum likelihood estimation is reported.

Grzegorz Gołda, Adrian Kampa, Iwona Paprocka 2018 - ANALYSIS OF HUMAN OPERATORS AND INDUSTRIAL ROBOTS PERFORMANCE AND RELIABILITY

The robot achieves much greater performance then human operator and is more reliable especially in the long time and therefore robotic workstation achieves significantly higher productivity. Due to the high costs associated with the robotization of manufacturing processes, financial analysis of investments plays important role. Presented simplified financial analysis show that robot implementation profitability is depended on varying labor cost in different countries.

Chiara Talignani Landi 2018- Relieving operators' workload: Towards affective robotics in industrial scenarios robotics that can be applied to industrial applications. Considering a human-robot interaction task, we propose to analyse the mental workload of the operator, and subsequently adapt the behavior of the robotic system, introducing assistive technologies. These technologies would prevent the performances deterioration caused by the human stress, helping him/her only when needed and decreasing the user's mental workload. Experimental validation of the proposed architecture is performed on a group of 15 users that teleoperate an industrial robot for performing a pick and place task. The proposed system has been experimentally validated on a group of 15 users that teleoperate a FANUC industrial robot for performing a pick and place task. The experiments showed that, when the interaction task overloads the user's sustainable mental workload, the assistive sys- tem based on the virtual fixtures can help the majority of the users to reduce the stress and to become familiar with the haptic device.

SAFETY

Nicola Pedrocchi 2012- **Safe Human-Robot Cooperation in an Industrial Environment**

Robots and the enabling technologies allowing acquisition data from sensor fusion and environmental data analysing. The introduction of collaborative workspaces, where humans and robots can simultaneously work, sharing the work cell without physical fences, have deeply modified the way we think about the integration of robots on shop-floors. Nevertheless, safety options provided by basic supplies of IRs are still quite limited or unavailable.

Joshep R-1994 **A Survey of NASA and Military Standards on Fault Tolerance and Reliability Applied to Robotics**

The application of these standards to the design of robots will be extremely important in many applications, particularly in hazardous environments. Industrial groups, such as RIA, have proposed standards or safety and are currently developing standards for reliability.

J.F. Engelberger 1974- **Three Million Hours of Robot Field Experience**

In this still embryonic field of industrial robotics, one class of machine, the Ultimate, has accumulated over three million hours of work experience. It is the purpose of this paper to use the record of this experience to encourage manufacturers in search of increased productivity. Robot reliability is a very complex issue. There are many interlocking variables in predicting and achieving various levels of reliability; there is even more diffuse variability in needs of different jobs; and, all these factors are capped by a bewildering range of environmental restraints. There are two concepts to be considered in a discussion of reliability: one is "Mean Time Between Failure", MTBF, and the other is "downtime"

S.K. Ong 2020- **Augmented reality-assisted robot programming system for industrial Applications**

Robots are important in high-mix low-volume manufacturing because of their repeatability and versatility in performing manufacturing tasks. However, robots have not been widely used due to cumbersome programming effort and lack of operator skill. Augmented Reality (AR) assisted robot programming system (ARRPS) that provides faster and more intuitive robot programming than conventional techniques. ARRPS is designed to allow users with little robot programming knowledge to program tasks for a serial robot. The system transforms the work cell of a serial industrial robot into an AR environment. Sensor data and algorithms are used for robot motion planning, collision detection and plan validation. The proposed approach enables fast and intuitive robotic path and task programming, and allows users to focus only on the definition of tasks.

S.P. Gaskil 1996 **– SAFETY ISSUES IN MODERN APPLICATIONS OF ROBOTS**

The machinery directive means a fundamental change in the way that new machinery is developed for safety. Prior to the directive, in the UK it was possible for manufacturers to meet safety requirements by following detailed, prescriptive standards, the manufacturer did not need to assess if those measures were adequate or evaluate risks. The machinery directive, in setting out broad EHSRs and requiring technical documentation relating to safety, will enhanced safety awareness and ensure that manufacturers and their agents will have a sound understanding of the risks. The complexity of modern control systems means that it is becoming increasingly difficult to assess machinery safety. Not only is the number of failure modes so high it is impossible to identify them, never mind test their effect on safety, but the complexity increases the susceptibility to dangerous systematic faults, inadvertently design into the system. It is therefore not practicable or may be even impossible to test for all possible dangerous faults. Also because of their nature, it is not possible to predict when or where systematic faults my arise.

III. CONCLUSIONS

1. SAFE AND RELIABLE PERFORMANCE OF ROBOT SYSTEMS DEPENDS ON MANY FACTORS INCLUDING THE INTEGRITY OF THE ROBOTS HARDWARE AND SOFTWARE, THE WAY IT COMMUNICATES WITH SENSOR AND OTHER PRODUCTION EQUIPMENT
2. RELIABILITY PERFORMANCE INDEX IS A USEFUL EMPIRICAL TOOL DURING THE SELECTION AND DESIGN OF CONFIGURATION OF ROBOTICS MODULES OF VARYING RELIABILITY AND PRECISION
3. THE ROBOT SAFETY STUDIED BY VARIOUS ASPECTS OF ROBOT GENERAL SAFETY, SAFEGUARDING TECHNIQUES AND METHODS, ROBOT ACCIDENTS, ROBOT SAFETY STANDARDS, SAFETY TECHNOLOGIES AND HUMAN FACTOR.
4. PROPER FAULT DIAGNOSIS IS ESSENTIAL FOR EASY REPAIR OF ROBOTS

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