

Quantitative Sequential Modelling Approach to Estimate the Reliability of Computer Controlled Pneumatically Operated Pick-and-Place Robot

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Abstract *Pneumatically controlled pick-and-place robots are an integral part of contemporary manufacturing processes and have the potential to enhance the precision and velocity of numerous production-related tasks. As automation continues to disrupt various sectors, the role of these robots is becoming increasingly crucial. Achieving peak performance in robot operations requires a relentless focus on safety and reliability. As a result, subsequence reliability should be considered carefully from the initial part of the design phase. Roboticists need to identify the dependable subsequences and parts of the robot's operational framework in prior to access the system's overall reliability. This analytical technique aids in component identification and demonstrates how to measure redundancy to ensure dependability and robustness. Based on recent theories and frameworks, the researchers can understand the factors that have more impact towards the reliability of pneumatically driven pick-and-place robots. Thus, this research work improves an exhaustive dependability analysis of a computer-controlled pneumatically operated pick-and-place robot. As part of our methodology, we use modern LabVIEW software to conduct a comprehensive failure analysis and estimate the reliability of the sequence.*

Keywords *pneumatically controlled pick-and-place robots, automation, reliability, LabVIEW software, failure analysis*

Highlights:

- *Modern factories use pneumatic robots to boost production speed and accuracy.*
- *Subsequence reliability ensures safety and optimal system performance.*
- *LabVIEW aids in dependability analysis, identifying key parts and redundancies.*
- *MRPM model focuses on redundancy and quantitative reliability calculations.*

1 INTRODUCTION

Pneumatically operated pick-and-place robots are essential components of contemporary manufacturing operations, providing accuracy and efficiency in task execution. These robots employ compressed air as propulsion, enabling them to execute rapid and precise pick-and-place operations within assembly lines and other manufacturing settings. The relevance of these entities lies in their capacity to optimize efficiency through the reduction of cycle times and the augmentation of throughput. Pneumatically controlled pick-and-place robots significantly enhance efficiency and quality assurance within manufacturing operations by effectively managing a wide range of materials and components [1].

The importance of automation in manufacturing is growing, as it brings about a significant transformation in industries by improving efficiency and production. Robots facilitate this shift by optimizing industrial processes accurately and efficiently. Their adaptability enables the completion of diverse activities, ranging from assembly to packaging, with uniformity and precision. In the current market landscape, firms are compelled to adopt automation and robots to maintain competitiveness, foster innovation, and effectively address the changing needs of consumers [2] and [3].

Safety and reliability are of utmost importance in robot activities within industrial settings, owing to the substantial hazards associated with such operations. Robots frequently collaborate with humans, operating extensive machinery and possibly dangerous substances. Using stringent safety standards mitigates the likelihood of accidents, injuries, and equipment damage. Moreover, ensuring dependable robot performance is essential for sustaining output and averting expensive periods of inactivity. The prioritization of safety and reliability serves the dual purpose of safeguarding workers and assets while cultivating a working environment that promotes efficiency and success [4].

Ensuring the entire reliability of the system is crucial during the design phase of robotics, with a particular emphasis on sequence reliability. Through careful evaluation of the dependability of each subsequence from the beginning, engineers will detect any vulnerabilities and enhance them for optimal reliability. This entails evaluating individual elements' dependability and interplay within the administrative structure. Through this approach, designers can minimize potential hazards and boost the robot's overall dependability, resulting in heightened operational availability, decreased expenses associated with maintenance, and improved efficacy in practical scenarios [5] to [7].

Analytical methodologies are of paramount importance in evaluating the dependability of robotic systems. Roboticists employ many techniques, including failure mode and effect analysis (FMEA), fault tree analysis (FTA), and reliability block diagrams (RBD), to detect potential failure modes and assess their influence on system reliability. Identifying components is a crucial aspect of this process, as it enables the recognition of essential elements and their respective probabilities of failure. Furthermore, redundancy techniques are employed to improve reliability and resilience, which may include the integration of backup components or duplicate

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systems. By utilizing these analytical methodologies, roboticists can proficiently assess and enhance the dependability of robotic systems, guaranteeing optimal functionality across a wide range of operational contexts [8].

Current studies have concentrated on comprehending the variables that impact the dependability of pneumatically operated pick-and-place robots. This entails analyzing the impact of factors such as air pressure variations, component deterioration, and environmental circumstances on the system's functioning. Researchers can build theories and frameworks to optimize these robots' design, maintenance, and operation by gaining insights into these issues. The comprehension of these factors has significant importance in enhancing the overall reliability of a system, as it empowers engineers to enact proactive steps, such as carefully selecting sturdy components and establishing regular maintenance plans, to reduce prospective concerns. Eventually, it improves the reliability and durability of pneumatically operated pick-and-place robots in many industrial settings.

The primary aim of this study is to conduct a comprehensive examination of the reliability of a computer-controlled pneumatically operated pick-and-place robot. This seeks to assess multiple elements that impact the dependability of the robot, such as its components, operational conditions, and environmental factors. Through a comprehensive examination, this research aims to offer valuable insights that can improve the design, maintenance, and operation of comparable robotic systems. Finally, the objective is to enhance the reliability and performance of these systems in industrial environments.

The research approach employed in this study entails the utilization of contemporary LabVIEW software to perform an exhaustive failure analysis and assess the reliability of sequences. LabVIEW is a robust programming environment that empowers researchers to create customized programs to accomplish their research requirements. In our research, it enables the examination of several failure modes and their influence on the dependability of the pneumatically controlled pick-and-place robot. Using LabVIEW's functionalities, researchers can effectively collect and analyze data, enabling a comprehensive assessment of the system's reliability [9] and [10].

2 METHODS AND MATERIALS

The computer-controlled robot uses three pneumatic cylinders to rotate its base, lift things, and clamp them. The movable arm of the robotic system is fixed on a rotating base that can move from the source point to the target point in the appropriate locations. The base rotation is controlled by rack and pinion mechanism, which is fully operated by pneumatic cylinders and controlled with computers through solenoid direction control valves (DCV) [11]. The electrical relays and data acquisition cards (DAQ cards) with hardware interfacing circuits are connected with LabVIEW software are used to control the robot. The major components in automatic robot are shown in the Fig. 3.

The pneumatic cylinders 1, 2, and 3 in the pick-and-place robot are sequentially activated by energizing the solenoid coils 1, 2, and 3. The first cylinder serves the purpose of securing the objects within the conveyor line. In contrast, the second cylinder elevates the robotic arm to a predetermined height, preventing potential collisions with other peripherals linked to the machining center. Subsequently, the third cylinder is engaged to rotate the base to the designated position to position the components. The operational sequence exhibits a uniform temporal delay of five seconds. To obtain the reverse sequences in the pick and place robot, the computer consecutively energizes solenoid coils 2, 1, and 3 with a time delay of five seconds.

Fig. 1 depicts the connectivity diagram of a computer-controlled pick-and-place robot [12].

The successive parts encompass the steps involved in sequence reliability estimation, the collection of failure data for each subsequence, the experimental test, the assessment of the failure probability function, the analysis of computer reliability, the subsequence reliability model, the results obtained, and the subsequent analysis and interpretation.

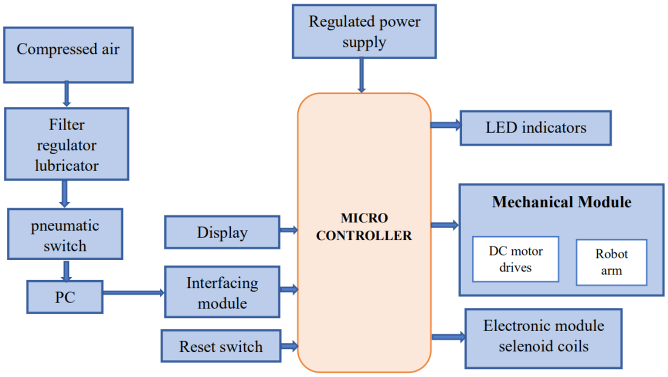

Fig. 1. Connectivity diagram of computer-controlled pick and place robot

The concluding section elucidates the outcome of this endeavor. The image of the pick and place robot (prototype) is taken for reliability analysis is shown in Fig 2.

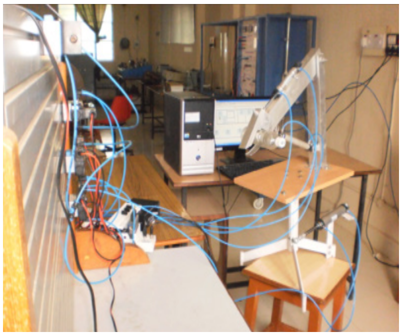

Fig. 2. Computer controlled pick and place robotic arm

2.1 Steps in Sequence Reliability Estimation

Sequential reliability estimation is a process used to assess the reliability of a system or process over time, often in the context of ongoing operation or testing [13] and [14]. Here are the general steps involved in sequential reliability estimation:

- Define the system: Clearly define the system or process you are evaluating for reliability. This includes identifying all components, subsystems, and their interconnections.
- Identify failure modes: Determine the potential failure modes of each component or subsystem within the system. This entails knowing the circumstances or stresses that can lead to failure as well as how each component can fail.
- Define reliability metrics: Establish the reliability metrics that will be used to evaluate the system. Common metrics include mean time between failures (MTBF), probability of failure within a given time frame, or reliability function over time.
- Data collection: Collect data on system performance and failures over time. This data may come from field observations, testing, or

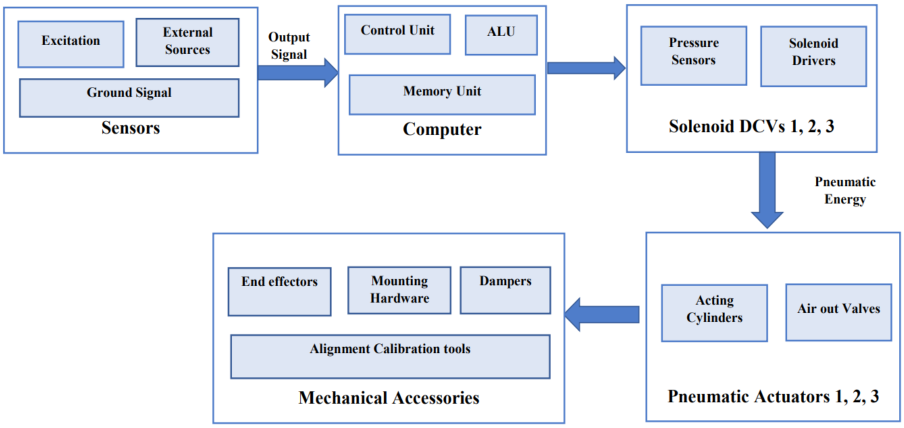

Fig. 3. Major components of automatic pick and place robot

simulations. Ensure that the data is comprehensive and accurately reflects the operational conditions of the system.

- Model development: Develop a statistical model to represent the reliability of the system based on the collected data. This model describe factors such as time, usage, environmental conditions, and maintenance activities.
- Initial reliability assessment: Use the initial data and model to estimate the current reliability of the system. This provides a baseline for comparison as the analysis progresses.
- Continuous monitoring: Continuously monitor the system for additional failures and collect updated data. This may involve real-time monitoring, periodic inspections, or ongoing testing
- Update model: Incorporate new data into the statistical model and update the reliability estimates accordingly. This allows the reliability assessment to adapt to changes in the system's performance over time.
- Evaluate trends: Analyze the trend of reliability over time to identify patterns or anomalies. Look for factors that may be influencing reliability, such as changes in operating conditions or maintenance practices.
- Risk assessment: Assess the implications of the observed reliability trends on system performance, safety, and cost. Identify potential risks associated with ongoing operation and determine if any corrective actions are necessary.
- Decision making: Use the reliability estimates and risk assessment to inform decision-making processes regarding system maintenance, repair, or replacement. Consider factors such as cost-effectiveness, safety, and operational requirements.
- Iterative process: Sequential reliability estimation is an iterative process that may require periodic updates and adjustments as new data becomes available or as the system undergoes changes. Continuously refine the analysis to improve the accuracy of reliability assessments and optimize system performance.

By following these steps, organizations can effectively assess and manage the reliability of their systems over time, helping to ensure safe and efficient operation.

Fig. 5 illustrates the systematic failure analysis of each subsequential component in the computer-controlled pick-and-place robot as part of the reliability analysis.

2.2 Connectivity of the Sequences

The concept of connectivity within a pick and place robot system pertains to the coherent integration and synchronization of diverse

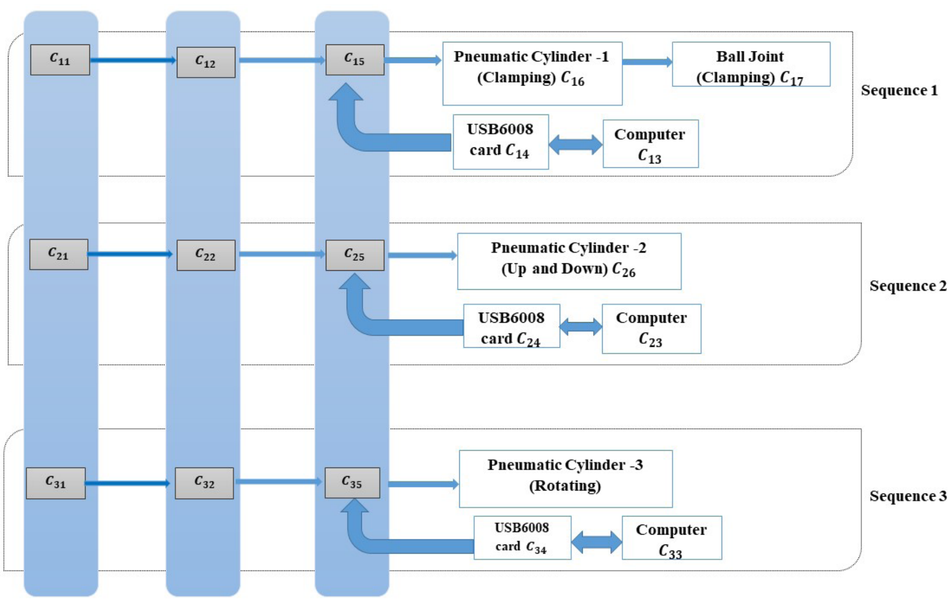

Fig. 4. Connectivity diagram of the sequences

components and processes that are fundamental to the functioning of the system [15]. The major components in the sequences are illustrated in Fig. 4.

2.2.1 Sequence 1

The activation of the solenoid DCV is accomplished by the computer, which transmits a signal to the universal serial bus (USB) card [16]. The solenoid DCV is responsible for starting pneumatic cylinder 1, which facilitates the execution of the clamping action via the ball joint. Activating the pneumatic module involves using pneumatic accessory components, including an air compressor, filter, and solenoid DCV.

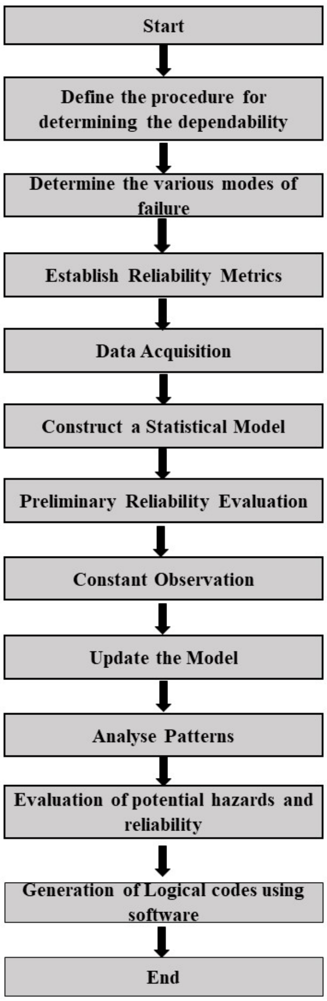

Fig. 5. Steps in sequential reliability estimation

Let, P_{11} probability of failure for component C_{11}, P_{12} probability of failure for component C_{12}, P_{13} probability of failure for component C_{13}, P_{14} probability of failure for component C_{14}, P_{15} probability of failure for component C_{15}, P_{16} probability of failure for component C_{16}, and P_{17} probability of failure for component C_{17}.

2.2.2 Sequence 2

In sequence 2, the robot comprises a pneumatic module and a USB acquisition card connected to a computer. This configuration is similar to sequence 1, except for the ball joint.

Let, P_{21} probability of failure for component C_{21}, P_{22} probability of failure for component C_{22}, P_{23} probability of failure for component C_{23}, P_{24} probability of failure for component C_{24}, P_{25} probability of failure for component C_{25}, and P_{26} probability of failure for component C_{26}.

2.2.3 Sequence 3

Sequence 3 encompasses all the constituent elements included in sequence 1 except the ball joint. Additionally, it incorporates the rack and pinion, base, and column structures.

Let, P_{31} is probability of failure for component C_{31}, P_{32} probability of failure for component C_{32}, P_{33} probability of failure for component C_{33}, P_{34} probability of failure for component C_{34}, P_{35} probability of failure for component C_{35}, P_{36} probability of failure for component C_{36}, P_{37} probability of failure for component C_{37}, and P_{38} probability of failure for component C_{38}.

2.3 Failure Data Collection for Each Sub Sequence

The failure rate for each sub-sequential component of sequences 1, 2, and 3 is measured in million hours. The fault data is obtained by measuring the difference between the necessary output value and the actual output value of the subcomponents under the condition of random input values. The robot's overall functioning primarily relies on a computer connected to a USB 6008 DAQ card. It is necessary to employ a distinct evaluation approach to assess the reliability of both the computer and the USB DAQ card. This dependability prediction model is beneficial for obtaining accurate outcomes in analytical tasks [17]. Except for the failure rate data for the computer and USB DAQ card, the remaining component data is presented in the subsequent table, arranged sequentially, specifically numbered 1, 2, and 3.

3 EXPERIMENTAL

Accurate prediction of reliability in mechanical subsystem is crucial for the robot as it significantly influences its total functionality. The reliability of each material in the mechanical structure is computed and utilized as input values to forecast the entire automatic machine using the merged reliability prediction model (MRPM). Tension and torsion tests are performed on various materials, including mild steel, cast iron, and aluminum. Subsequently, to determine the failure probability and dependability for each material, obtaining the failure rate distribution for different load circumstances is necessary. Therefore, the probability distribution is employed to represent the distribution of failure rates. The selection of the appropriate material for constructing the mechanical frame structure of automatic machines based on the failure probability and reliability values.

Computer-based pneumatically controlled pick and place robots utilize materials such as mild steel, cast iron, and aluminum due to their adequate mechanical strength and stress resistance for various operating load circumstances at each structural point. Furthermore, these components can endure thermal characteristics, such as heat capacity, thermal expansion, thermal conductivity, and thermal stress, at the operational temperature of the automation system within each sub-module. Therefore, the materials mentioned above are chosen to conduct tension and torsion tests to analyze reliability [18].

3.1 Failure Probability Function

Probabilistic distribution for loads

$$P(X_X < X_S) = F(X_S) = \frac{e^{\left[\frac{-(X_X \mu)}{2\sigma^2}\right]^2}}{\sigma\sqrt{2\pi}}. \quad (1)$$

Standard deviation of load

$$(\sigma_{load}) = X_S - X_X . \quad (2)$$

Failure probability

$$(P_X) = 1 - F(X_S). \quad (3)$$

The given equation, Eq. (1) uses the normal probability distribution function to characterize the distribution of loads on the materials. This distribution, which spans the range between the ultimate load and the actual load, determines the materials' failure rate. When the load fluctuates within its elastic limit about the mean load, every material undergoes a failure rate. The average probability distribution determines the probabilistic distribution of failure rates for the actual load applied during material testing [19]. The failure rate and reliability data for the selected materials and standard mechanical accessories are presented in Tables 1 and 2.

Table 1. Failure rate and reliability of various materials

Material	Predicted operating load, X_X [kN]	Probabilistic distribution for actual load, P_X	Actual stress [N/mm²]	Probabilistic distribution for actual stress	Reliability 1–$P(X)$
Mild steel	30	9.973×10^{-3}	149.2	2.005×10^{-3}	0.99899
Cast iron	5	0.1101	10.1859	0.06228	0.8899
Aluminum	0.8	0.054200	15.915	0.07574	0.92426

Table 2. Failure rate and reliability data for common Mechanical parts

Components	Time [10^6 h]	No. of failures	Failure rate	Probability of failure rate* $\times10^{-4}$	Reliabiltiy**	Average reliability
Directional control valves (solenoid), C_{14}	1	8.993	8.993	0.09	0.999991	0.999901
	2	35.972	17.986	0.36	0.999964	
	3	80.937	26.979	0.81	0.999919	
	4	143.888	35.972	1.44	0.999856	
	5	224.825	44.965	2.25	0.999775	
Pneumatic actuators, C_{15}	1	11.498	11.498	0.12	0.999988	0.9998848
	2	45.992	22.996	0.46	0.999954	
	3	103.482	34.494	1.04	0.999896	
	4	183.968	45.992	1.84	0.999816	
	5	287.45	57.490	2.3	0.999770	

*$(P_{kl} = 1 - e^{-\lambda t})$, **$(R_{kl} = 1 - P_{kl})$

Table 3. Probability of failure and reliability data for accessories

Component	Probability of failure (P)	Reliabiltiy (R)
Compressor	0.00621	0.99379
Filter	0.00600	0.99400
Ball joint	0.00300	0.99700
Rack and pinion	0.10194	0.89806
Base and column	0.10840	0.89150

Table 4. Failure rate and reliability data for DAQ card

Components	Failure rate (λ)	Probability of failure $(P_{kl} = 1 - e^{-\lambda t}) \times 10^{-4}$	Reliabiltiy $(R_{kl} = 1 - P_{kl})$
DAQ card (C36)	0.035	0.0343	0.9657

All components' reliability and failure statistics, except for the ball joints, are extracted from the table above and recorded in sequence 2. The compressor and filter unit failure rate was obtained from Tables 3 and 4 and recorded.

3.2 Reliability Analysis of Computer

The assessment of computer reliability comprises the analysis of the stability and dependability of computer systems, hardware, software, and networks to ensure consistent and error-free operation over the course of their lifetime [20] to [22]. Computer engineering and system design play a crucial role in various businesses, mainly where downtime or malfunctions can result in substantial financial losses, safety risks, or data breaches.

3.2.1 Reliability Prediction Model for Computer

The non-Poisson process model has been chosen as the framework for assessing the performance and measuring the reliability of the computer system. To evaluate the reliability of a computer system, the likelihood of failure is determined by calculating the anticipated number of failures. During the testing phase, data is collected periodically and utilized in the non-homogeneous Poisson process (NHPP) and programmable logic controller (PLC) prediction models.

3.2.2 Failure Data Collection of Computer

The calendar testing method involves providing input values to the system and collect the data on certain computer failure. This aids in identifying certain failure issues under vaious scenarios within the system. The quantity of disparities between the actual and desired production is recorded and organized in the Table 5.

Table 5. Fault data of computer in testing phase

Week	No. of failures	Actual failure rate (λ)	Week	No. of failures	Actual failure rate (λ)
1	4	0.066	9	3	0.05
2	3	0.05	10	5	0.0833
3	2	0.033	11	6	0.100
4	6	0.100	12	8	0.133
5	1	0.0166	13	4	0.066
6	7	0.1166	14	3	0.05
7	4	0.066	15	2	0.033
8	2	0.033			

3.3 Goodness of Fit Test

The goodness of fit test is used to determine whether the failure data obtained is sufficient to anticipate the computer's reliability. In this experiment, the hypothesis is chosen based on the adequacy of the acquired data for predicting dependability.

As computed, the total difference between F and F^* is compared with the standard values in the Table 6. The computed $(F - F^*)$ value is lower than the critical value of 3.5 (0.3740) found in the Table 6. As a result, the above hypothesis is accepted and the reliability calculation use the data above. The hypothesis test's outcomes indicate that the failure data gathered has enough predictive power to estimate the computer's reliability. Therefore, the reliability model that follows predicts the computer's reliability [23].

The model computes the reliability R_i and the $P_i(x)$ probability of failure.

Expected number of failures is defined in Eq. (4) as follows

$$\mu_w = \lambda \theta t_w + \frac{1}{\theta}. \quad (4)$$

Failure probability is calculated by Eq. (5) as

$$P_w = \frac{\mu_w}{t_{CPU}}, \quad (5)$$

and the reliability as in Eq. (6)

$$R_w = 1 - P_w , \quad (6)$$

where, t_{CPU} is CPU execution time for week, and θ probability parameter (assumed as 0.16). Sample calculation to find R_w using Eq. (6), and to find P_w we have to calculate μw as given in Eq. (5) as follows. For $t_w = 5$, $\lambda = 0.0714$ and $\theta = 0.16$, μw is calculated as

$$\mu_w = \frac{(0.0166 \times 0.16 \times 5) + 1}{0.16} = 6.333,$$

where $t_{CPU} = 8\times7\times5 = 280$, $P_w = 6.333/280 = 0.0226$, and $R_w = 1 - 0.0226 = 0.9774$.

Table 6. Goodness of fit test

Week	Number of failures	F	Expected number of failures	F^*	$D = \lvert F-F^* \rvert$
1	4	0.066	6.316	0.0619	0.0041
2	3	0.05	6.35	0.0623	0.0123
3	2	0.033	6.349	0.0623	0.0293
4	6	0.100	6.650	0.0652	0.0348
5	1	0.0166	6.333	0.0621	0.0455
6	7	0.1166	6.949	0.0682	0.0484
7	4	0.066	6.712	0.0658	0.0002
8	2	0.033	6.514	0.0639	0.0309
9	3	0.05	6.70	0.0657	0.0157
10	5	0.0833	7.083	0.0695	0.0138
11	6	0.100	7.35	0.0721	0.0279
12	8	0.133	7.846	0.0770	0.0560
13	4	0.066	7.108	0.0697	0.0037
14	3	0.05	6.95	0.0682	0.0182
15	2	0.033	6.745	0.0662	0.0332
Total ($F-F^*$)					0.3740

Table 7. Failure rate and reliability data of computer

Week (w)	No. of failures	Actual failure rate for CPU hours (λ)	Expected failures (μ)	Pobability of failure (P_w)	Reliabiity (R_w)	Reliabilty of computer (R_{com})
1	4	0.066	6.316	0.1127	0.8873	
2	3	0.05	6.35	0.0566	0.9434	
3	2	0.033	6.349	0.0377	0.9623	
4	6	0.100	6.650	0.0296	0.9704	
5	1	0.0166	6.333	0.0226	0.9774	
6	7	0.1166	6.949	0.0206	0.9794	
7	4	0.066	6.712	0.0171	0.9829	
8	2	0.033	6.514	0.0145	0.9855	0.9742
9	3	0.05	6.70	0.0132	0.9868	
10	5	0.0833	7.083	0.0126	0.9874	
11	6	0.100	7.35	0.0119	0.9881	
12	8	0.133	7.846	0.0116	0.9884	
13	4	0.066	7.108	0.0097	0.9903	
14	3	0.05	6.95	0.0088	0.9912	
15	2	0.033	6.745	0.0080	0.992	

3.4 The Reliability of Computer, R_{com}

The reliability values for each week execution hours are taken from the Table 7 and average reliability of computer is calculated as R_{com} = 0.9742.

3.5 The Reliability Model for Sub Sequences

For sequence 1:

$$RS_1 = \frac{[1-P_{11}]\cdot[1-P_{12}]\cdot[1-P_{13}]\cdot[1-P_{14}]\cdot[1-P_{15}]\cdot[1-P_{16}]+[1-P_{17}]}{2}$$
$$= \frac{[R_{11}]\cdot[R_{12}]\cdot[R_{13}]\cdot[R_{14}]\cdot[R_{15}]\cdot[R_{16}]+[R_{17}]}{2}. \quad (7)$$

For sequence 2:

$$RS_2 = \{[1-P_{21}]\cdot[1-P_{22}]\cdot[1-P_{25}]\cdot[1-P_{26}]\}\cdot\{[1-P_{23}]\cdot[1-P_{24}]\}. \quad (8)$$

here, $P_{21}=P_{11}$, $P_{22}=P_{12}$, $P_{23}=P_{13}$, $P_{24}=P_{14}$, $P_{25}=P_{15}$, and $P_{26}=P_{16}$.

$$RS_2 = \{[R_{21}]\cdot[R_{22}]\cdot[R_{25}]\cdot[R_{26}]\}\cdot\{[R_{23}]\cdot[R_{24}]\}. \quad (9)$$

For sequence 3:

$$RS_3 = \frac{\left(\begin{array}{l}\{[1-P_{31}]\cdot[1-P_{32}]\cdot[1-P_{33}]\cdot[1-P_{34}]\cdot[1-P_{35}]\cdot[1-P_{35}]\}\\ \cdot\{[1-P_{37}]\cdot[1-P_{38}]\}\end{array}\right)}{2}, \quad (10)$$

here, $P_{31}=P_{11}$, $P_{32}=P_{12}$, $P_{33}=P_{13}$, $P_{34}=P_{14}$, $P_{35}=P_{15}$, and $P_{36}=P_{16}$.

$$RS_3 = \frac{\{[R_{31}]\cdot[R_{32}]\cdot[R_{33}]\cdot[R_{34}]\cdot[R_{35}]\cdot[R_{36}]\}+\{[R_{37}]\cdot[R_{38}]\}}{2}. \quad (11)$$

Table 8: Reliability for all the sequences

Sequences	Components (C_{kl})	Reliability of each component	Reliability of sequences (RS)
Sequence 1	Air compressor (C_{11})	0.9938	0.9631
	Filter (C_{12})	0.9940	
	Computer (C_{13})	0.9742	
	USB 6008 DAQ (C_{14})	0.9657	
	Solenoid DCV (C_{15})	0.9999	
	Pneumatic actuator (C_{16})	0.9999	
	Ball joint (C_{17})	0.9970	
Sequence 2	Air compressor (C_{21})	0.9938	0.9291
	Filter (C_{22})	0.9940	
	Computer (C_{23})	0.9742	
	USB 6008 DAQ (C_{24})	0.9657	
	Solenoid DCV (C_{25})	0.9999	
	Pneumatic actuator (C_{26})	0.9999	
Sequence 3	Air compressor (C_{31})	0.9938	0.8650
	Filter (C_{32})	0.9940	
	Computer (C_{33})	0.9742	
	USB 6008 DAQ (C_{34})	0.9657	
	Solenoid DCV (C_{35})	0.9999	
	Pneumatic actuator (C_{36})	0.9999	
	Rack and pinion (C_{37})	0.8981	
	Base and column (C_{38})	0.8915	

The equation provided above is used to evaluate the reliability of each sequence for the computer-controlled pick-and-place robot by assessing the chance of failure with reliability. Table 8 displays the computed dependability of sequences 1, 2, and 3.

3.6 Reliability Calculation for Each Sequence

Reliability calculation for each sequence can be calculated using Eqs. (7) to (10):

For sequence 1:

RS_1 = {{0.9938×0.9940×0.9742×0.9657×0.9999×0.9999} +0.9970} / 2 = 0.9631.

For sequence 2:

RS_2 = {0.9938×0.9940×0.9999×0.9999} × {0.9742×0.9657} = 0.9876×0.9408 = 0.9291.

For sequence 3:

$$RS_3 = \{\{0.9938\times0.9940\times0.9742\times0.9657\times0.9999\times0.9999\} + \{0.8981\times0.8915\}\}/2 = 0.8650.$$

The average values of the above sequential reliabilities are used to quantify the overall robot system reliability as follows:

Total Reliability of robot

$$R = (RS_1 + RS_2 + RS_3)/3 = (0.9631+0.9291+0.8650)/3 = 0.9191.$$

4 RESULTS AND DISCUSSION

The equation provided above is utilized to evaluate the reliability of each sequence for the computer-controlled pick-and-place robot by assessing the chance of failure. Figs. 6 to 8 display the computed dependability of sequences 1, 2, and 3.

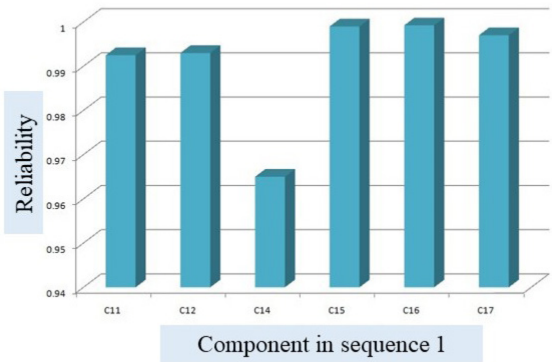

Fig. 6. Reliability of each sub component in sequence 1

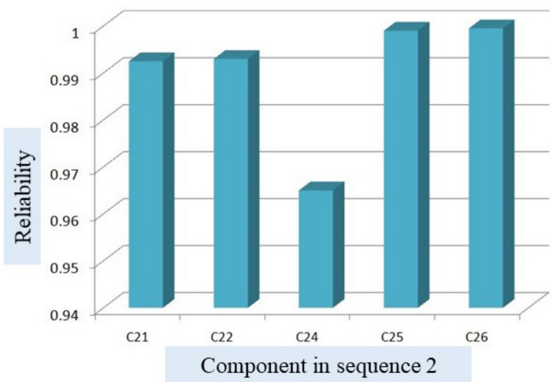

Fig. 7. Reliability of each sub component in sequence 2

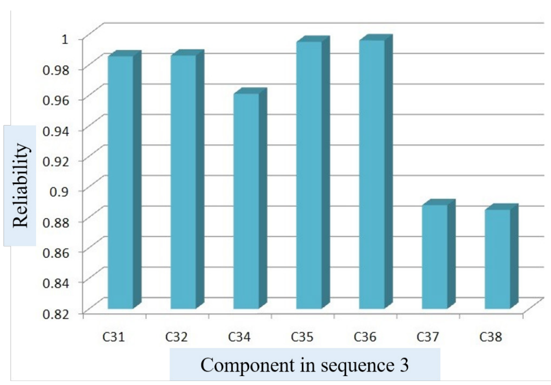

Fig. 8. Reliability of each sub component in sequence 3

The Figs 6 and 7 presents the specifics of sequences 1 and 2. The USB DAQ card (C_{14}) exhibits a imperfect level of reliability compared to other subcomponents utilized in the primary rotation of sequence 1 within the pick and place robot. In sequence 1, the solenoid DCV (C_{15}) and pneumatic actuators (C_{16}) exhibit superior dependability compared to other components, including the compressor (C_{11}), filter (C_{12}), and ball joint (C_{17}).

The Fig. 8 presents the following data for sequence 3. The base and column structure (C_{38}) and rack and pinion (C_{37}) exhibit the lowest reliability compared to the other components.

The USB DAQ card (C_{34}) demonstrates the second lowest reliability in this sequence when compared to other components such as compressors (C_{31}), filters (C_{32}), solenoid DCVs (C_{35}), and pneumatic actuators (C_{36}).

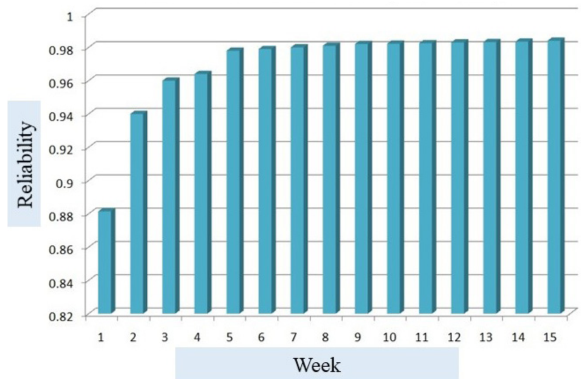

Fig. 9. Reliability of computer (C_{13}, C_{23}, and C_{33}) from testing data

Fig. 9 illustrates that a computer's reliability increases as the testing duration is extended. This is because faults or bugs are identified and rectified weekly during testing. Hence, the dependability of a computer is enhanced before its integration with operational components.

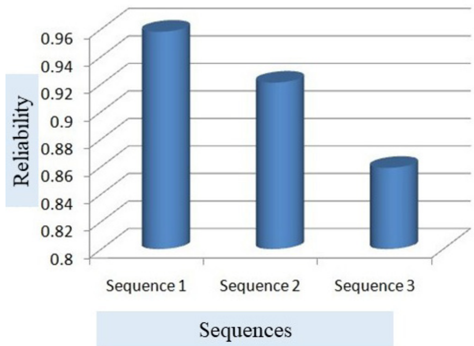

Fig. 10. Reliability for each sequence

In computer-controlled pick-and-place robots, the graph presented above serves the purpose of identifying the essential sequence. The pick and place robot utilizes the sequence 3 for base rotation, which exhibits comparatively lower reliability when compared to other sequences such as lift and down actuation and clamping. The crucial sequence for the autonomous pick-and-place robot in this case study is sequence 3. The key subcomponents of a computer-controlled pick-and-place robot are determined by utilizing the prior probability of failures derived from expert data and the failure rate data obtained from testing [24] to [25]. The failure probability distribution function and previously computed failure probability are used to rank all the modules in the provided graph in Fig. 10.

5 CONCLUSION

To enhance the dependability of the automation system, it is necessary to identify the intricacies of its functional components and develop a reliability model to measure its reliability. Using the MRPM model enables the designer to focus on the redundancy design. Quantitative reliability calculations are employed to ascertain the sequences with the highest criticality level. Qualitative and quantitative evidence can also be used to forecast prior and posterior reliability. The total reliability of the real-time mechatronic system was assessed throughout the design phase through a comprehensive failure analysis and a merged reliability prediction model. The absolute reliability of the robot was evaluated by estimating the reliability of its mechanical accessory components and materials. A number of materials, such as aluminium, cast iron, and mild steel, have their likelihood of failure assessed using the failure probability distribution function that was created from experimental test data from the tensile test. The test is performed on all materilas under operational load situation to find the probability distribution function for failure. The reliability of all materials pertaining to mechanical components is also evaluated by the computation of failure probability. The selection of the appropriate material for the material's structure was determined using a dependability calculation, as outlined in this research article. Furthermore, it was determined that the base rotation sequences (sequence 3) hold the utmost significance in the computer control pick and place robot.

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Data availability The data used in this study are not available for sharing or distribution, as they are subject to confidentiality agreements and restrictions.

Author contributions Satheesh Pandian Durairaj: Conceptualization, Methodology, Data curation, Writing – original draft, Software, Formal analysis, Visualization.

Kvantitativno modeliranje sekvenc za ocenitev zanesljivosti računalniško vodenega pnevmatskega prijemalno-polagalnega robota

Povzetek *Pnevmatski prijemalno-polagalni (pick-and-place) roboti so ključni v sodobni proizvodni industriji, saj omogočajo natančno in hitro delo. Ker avtomatizacija še naprej spreminja različne sektorje, postaja vloga teh robotov vse pomembnejša. Doseganje vrhunske učinkovitosti pri delovanju robotov zahteva nenehno osredotočanje na varnost in zanesljivost. Zato je treba želeno zanesljivost skrbno preučiti že v začetnem delu faze načrtovanja. Izziv pa predstavlja identifikacija zanesljivih podsekvenc in kritičnih komponent v operativnem okvirju robotov za zagotavljanje celotne zanesljivosti in robustnosti sistema. Za naslovitev omenjenega izziva in potencialnih dvomov v zvezi z zanesljivostjo je potrebna podrobna analiza načinov odpovedi in ukrepov za zagotavljanje redundance. V raziskavi je bila zato opravljena identifikacija kritičnih komponent in delovnih podsekvenc, ki vplivajo na zanesljivost robotov. Razviti so bili ukrepi za redundanco, ki izboljšujejo robustnost sistema. Celovita analiza odpovedi je bila opravljena s programskim paketom LabVIEW. S simulacijo in analizo sekvenc robota je bila ocenjena zanesljivost različnih delovnih podsekvenc in komponent za podrobno oceno celotne zanesljivosti sistema.*

Ključne besede *pnevmatski prijemalno-polagalni (pick-and-place) roboti, natančnost, hitrost, avtomatizacija, varnost, zanesljivost, analiza odpovedi*