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Reliability Calculation and Analysis for a Quadcopter

AmirHossein Gholami[1*], Mahdi Bagherian Dehaghi[2], Abolghasem Naghash[3] , Aliakbar Hasani[4] ,Kazem Imani[5]

1- Master of Science, Department of Aerospace Engineering, Amirkabir University of Technology, Tehran, Iran.
2- Master of Science, Department of Mechanical Engineering, K. N. Toosi University of Technology, Tehran, Iran.
3- Professor, Department of Aerospace Engineering, AmirKabir University of Technology, Tehran, Iran
4- Associate Professor, Department of Industrial Engineering, Shahrood University of Technology, Shahrood, Iran.
5- Associate Professor, Department of Aerospace Engineering, K. N. Toosi University of Technology, Tehran, Iran

AmirHossein Gholami, amir1375@aut.ac.ir

Abstract
Reliability is one of the most critical and complex issues that, if not calculated for a system, will significantly increase the possibility of reducing efficiency and wasting capital. Nowadays quadcopters due to their high functionality, the presence of various high-tech elements in them, along with certain flight standards, have set the conditions in such a way that the occurrence of any failure and problem, even a small one, involves a lot of costs. Therefore, reliability estimation is of special importance for these systems.so, In this article, an attempt has been made to calculate the failure rate of the components of a quadcopter, using the conventional reliability standards and various coefficients and factors, and then investigate the reliability of the quadcopter for a useful life of 3 years.

Keyword: Reliability,Quadcopter,Failure rate, Effective coefficients,Standarads

Introduction

Engineers and technical managers in every modern society are responsible for planning, designing, building, and operating from the most specific product to the most complex systems. The failure of the systems causes disruption on different levels and can even be a severe threat to society. And the environment is considered. Therefore, consumers expect to have reliable, reliable, and safe products and systems. This is where the importance of the science of reliability in various industries can be seen.
There are different definitions of reliability, which can be defined as the probability that the device will not fail until a certain time t, the average operating time of a device between two consecutive failures, the continuity of operation without failure, the probability of a device or system remaining in a functional condition without occurrence. But in the end, the most complete definition that can be made of reliability is the probability of satisfactory performance of the system under certain working conditions for a certain period of time. It is reliability. In the mathematical definition of probability, it is stated that it is a numerical index whose value can be from zero to one. When the probability is equal to zero, it means that there is no possibility of occurrence, and when it is one, it means that the occurrence is certain. But in the other three sections, including satisfactory performance, time, and certain working conditions, which are all engineering parameters, probability theory does not help in any way, and only engineers and experts are able to provide information related to satisfactory performance and time may be continuous, or Discontinuity may be considered, and finally, the work conditions may be completely uniform or strongly changing. Therefore, probability theory is only a tool to convert the information of a system into possible performance prediction.
On the other hand, today, Quadcopters due to their high functionality, the presence of different high-tech elements in them, along with specific flight standards and... .They have determined that any failure and defect, even a small one, will involve a lot of costs. Therefore, reliability estimation is of particular importance for these systems.[1,2]

Reliability prediction

Unique relationships are used to correctly predict the failure rate of components or systems.These relationships have been developed with statistical models and based on environmental parameters affecting the performance of components. Two crucial standards, NSWC-98/LEI for mechanical parts and MIL HNBK- 217 for electronic components, and the IEC-62380 document, have fully expanded these relationships. In this project, the MIL HNBK-21 standard and the IEC-62380 document have advanced the reliability plan.

Calculating quadcopter reliability

Estimating the reliability of the steering wheel The command and data management board include several main and vital components on the printed circuit fiber. Next, the reliability of the crucial features and the printed circuit fiber is calculated.
After calculating the reliability of various components, the reliability of the data command management board is calculated using the following relationship[1,3].

$$R_{board} = R_{PCB} \times R_{soldred\ components}$$
$$R_{soldred\ components} = R_{computerscomponents} \times R_{connections} \quad (1)$$

Processor

To design and build the command board and data management, a processor with good processing power and, at the same time, low power consumption, which also has a hardware decimal computing unit, should be used. This processor is intended for use in applications with high power consumption. Designed. This processor uses the ARM-Cortex R4F architecture and is a Texas Instruments product. The FIT value of this part is 2.41. The component reliability is calculated as follows.

$$FIT = \lambda_{hours} \times 10^9 \rightarrow \lambda_{hours} = \frac{FIT}{10^9} = \frac{2.41}{10^9} = 2.41 \times 10^{-9} \frac{Failure}{Hour} \quad (2)$$

$$R = e^{-\lambda t} = e^{-2.41\times10^{-9}\times365\times3} = 0.999976249 \quad (3)$$

Flash memory AT45

This part is made in Atmel technology company. The information on the various components of the quadcopter is stored in this part. The FIT of this part is equal to 1.3. The reliability of this part is calculated as follows:

$$R = e^{-\lambda t} = e^{-1.3\times10^{-9}\times365\times3} = 0.999998576 \quad (4)$$

Sender and Receiver

This part is a product of Texas Instruments Company with FIT 4.65. The reliability of this part can be calculated as follows:

$$R = e^{-\lambda t} = e^{-4.65\times10^{-9}\times365\times3} = 0.999999490$$

Driver of Motors

This part is a product of Analog Devices company with FIT 1.44. The reliability of this part is calculated as follows:

$$R = e^{-\lambda t} = e^{-1.44\times10^{-9}\times365\times3} = 0.9999984232$$

The reliability of the command board and data management components, along with the number of parts, are listed in the following table 1:

Table 1. Reliability of electrical components

number of parts	Reliability	FIT	Part type
1	0.9999985762	1.3	flash memory
2	0.9999998423	1.44	driver
1	0.9999994908	4.65	Sender and receiver
1	0.9999762494	2.41	Processor
1	0.9999970437	2.7	Flow sensor
1	0.9999967155	3	temperature sensor
1	0.9999983516	1.5	ECS

Reliability estimation of printed circuit fiber and connections

Estimating the reliability of connections

The reliability between the board and the components are sensitive to heat and the type of connections.The sensitivity can be expressed in the form of a relationship:

$$\lambda_{Fibr} = (1 + 3 \times 10^{-3} \times [\sum_{1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}] \times \sum \lambda_d \quad (5)$$

Coefficients and impact factors are obtained using the following table:
obtained using the Table 2.

Table 2. Connections on board [4,5,6]

Effective Coefficient $(\pi_n)_i$	$n_i \leq 8760$ Cycles/Year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/Year	$(\pi_n)_i = 1.7 n_i^{0.6}$
n_i: Number of cycles including turning the board off and on in a year with temperature range of $\mathbf{\Delta T_i}$		
$\Delta T_i = (T_{ac})_i - (T_{ae})_i$		ΔT_i
$(T_{ac})_i$: Outdoor environment temperature in the ith phase of operation	$(T_{ae})_i$: Indoor environment temperature, near the components in the ith phase of operation	
For solder joints in each 1 billion hours equal 0.5	λ_d	

Due to the small space between the board and the box, the temperature of the environment near the components is the same as the temperature around the board. As a result, the failure rate and reliability of connections are calculated as follows:

$$\lambda_{Fibr} = 5 \times 10^{-12} \times \pi_T \times \pi_C \times \left[N_t \sqrt{1 + \frac{N_t}{S}} + N_P \times \frac{1 + 0.1\sqrt{s}}{3} \times \pi_L \right] \times \left(1 + 3 \times 10^{-3} \times \left[\textstyle\sum_1^j (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \quad (6)$$

$$R_{Fibr} = e^{-\lambda t} = e^{-3.92 \times 10^{-7} \times 365 \times 2 \times 24} = 0.9931 \quad (7)$$

The reliability of a printed circuit fiber depends on the area of the fiber openings, the number of circuit layers, the width of the signal path on the board, and the number of connections.

$$\lambda_{PCB} = 5 \times 10^{-12} \times \pi_T \times \pi_C \times \left[N_t \sqrt{1 + \frac{N_t}{S}} + N_P \times \frac{1 + 0.1\sqrt{s}}{3} \times \pi_L \right] \times \left(1 + 3 \times 10^{-3} \times \left[\textstyle\sum_1^j (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \quad (8)$$

Coefficients and impact factors can be calculated using the table below.

Table 3. Effective coefficients and factors in calculating the reliability of printed circuit fiber [4,5,6]

Effective Coefficient π_c	Number of Layers ≤ 2	$\pi_c=1$			
	Number of Layers > 2	$\pi_c = 0.7 \times \sqrt{\text{Number of Layers}}$			
Np: Number of Signal Paths Nt: Number of holes in the board S: Board Area (120 cm2)					
$\pi_t = e^{1740(\frac{1}{303} - \frac{1}{273+t_A})}$					
0.56	0.35	0.23	0.15	0.1	Width of the maximum flow path
1	2	3	4	5	π_L

For the proper analysis of the temperature coefficient, the maximum temperature of the device must be taken into account, and for this purpose, the diagram in Figure 1 is used:

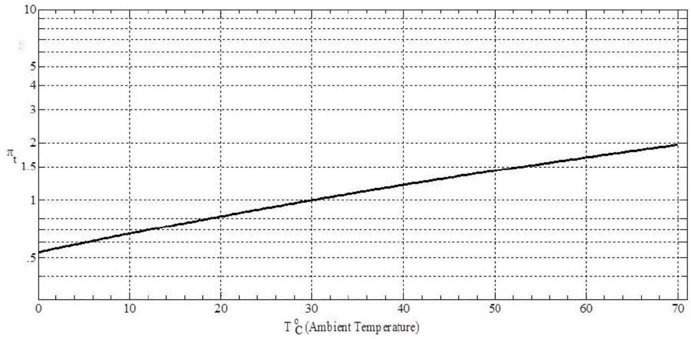

Fig. 1. Temperature factor changes in the range of 0-70 degrees Celsius

$$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+13}\right)} \quad (9)$$

The fiber-printed circuit board for the control board has 19 apertures, including embedded cracks for screws, connecting parts, and connectors. Also, 53 signal paths in all layers of the board connect different elements.

$$\lambda_{PCB} = 5 \times 10^{-12} \times 0.710 \times 1 \times \left[19 \times \sqrt{1 + \frac{19}{90}} + 53 \times \frac{1 + 0.1\sqrt{90}}{3} \times 3 \right] \times 1.0260 = 6.801 \times 10^{-9} \frac{f}{h} \quad (10)$$

$$R_{PCB} = e^{-\lambda t} = e^{-6.801 \times 10^{-9} \times 365 \times 24} = 0.94946346 \quad (11)$$

Finally, the reliability of the dashboard is equal to 0.9855647

battery

The batteries in the quadcopter are the only generators of electrical energy. Most of the batteries are of the lithium polymer (LiPo) type. The reason for using these batteries is because of their high energy density and high discharge rate.

The reliability relationship of the SB part is defined as follows[7]:

$$R_{SB} = \sum_{j=bm}^{nb} \frac{nb!}{j!(nb-j)!} \times R_{BC}^{j} \times (1-R_{BC})^{nb-j} \quad (12)$$

nb is the number of batteries, which is equal to 4, and kb is the excess number of batteries which is equal to one.
mb = nb - kb
From an analysis of possible sudden failures of such sections, the following failures generated lead to a complete failure of each section:
Now the reliability equation of each battery is as follows:

$$R_{BS} = R^{\oplus}{}_{BC} \times [1-((1-R_{BC}).(1-R_{CEU}))] \quad (13)$$

Where R_{BC} is Reliability of batteries not being damaged, and $R^{\oplus}{}_{BC}$ is Reliability of not shorting circuit the batteries, and R_{CEU} is Reliability of not breaking down CEU.so:

$$R_{BC} = 0.995 \times \left[1-\left((1-0.98)\times(1-0.97)\right)\right] = 0.9944 \quad (14)$$

So:

$$R_{SB} = \sum_{j=1}^{4} \frac{4!}{j!\,(4-j)!} \times R_{BC}^{j} \times (1-R_{BC})^{4-j} = 0.99328 \quad (15)$$

Conclusion

Today, we are witnessing the emergence of new and different generations of birds in the aviation and flight industry, which have caused tremendous changes in this field. Among these new types of equipment, quadcopters, which due to their special features, such as high stability, controllability, and small dimensions, have caused them to be used in various industries. Quadcopters have received a lot of attention due to having various applications in various fields. Quadcopters, due to their high functionality, the presence of different high-tech elements in them, along with particular flight standards, etc, have set the conditions in such a way that the occurrence of any breakdown and fault, even a small one, will incur huge costs.Therefore,reliability estimation is of particular importance for these systems. For this reason, in this research, an attempt was made to examine a quadcopter in terms of reliability and failure modes.

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