Functional Analysis in Systems Engineering: Methodology and Applications

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Abstract

Functional analysis plays an increasing role in the applied sciences as well as in engineering itself. Consequently, it becomes more and more desirable to introduce the researchers to the field at an early stage of study. This paper is intended to familiarize the reader with the basic concepts, principles and methods of functional analysis and its applications.

Functional analysis is an abstract branch of mathematics that originated from classical analysis. The impetus came from applications: problems related to ordinary and partial differential equations, numerical analysis, calculus of variations, approximation theory, integral equations, and so on. In ordinary calculus, one dealt with limiting processes in finite-dimensional vector spaces (R or R n), but problems arising in the above applications required a calculus in spaces of functions (which are infinite-dimensional vector spaces).

Keywords: Functional Analysis, Applied Sciences, Systems Engineering, Methodology and Applications.

Introduction

A key technique in the design process for defining novel concepts' structures is functional analysis. When systems engineers create new products, they use functional analysis to clarify the functional requirements, map the functions of the new product to its physical components, ensure that only the necessary components are requested and listed, and to comprehend the relationships between the components of the new product. Even while functional analysis is applicable to all stages of the design process, conceptual design occurs when there are still a lot of prospective, workable solutions for the future product. The crucial task of functional analysis is to identify as many potential solutions as you can while keeping in mind any that might have major advantages. We specifically discuss the use of Functional Analysis to investigate complex systems throughout the conceptual design phase of the article.

Functional analysis in conceptual design

The role of Functional Analysis is highlighted, along with its interconnections with all other building blocks of the conceptual design approach, in Figure 1, which schematically illustrates the conceptual design process. The mission objectives can be deduced from the mission statement. The system requirements can be determined once the general system objectives, represented by the mission objectives, have been specified. The conceptual design process develops through the system architecture and mission definition based on the system requirements. Functional Analysis and System Sizing are the two primary tasks that make up the definition of the system architecture.

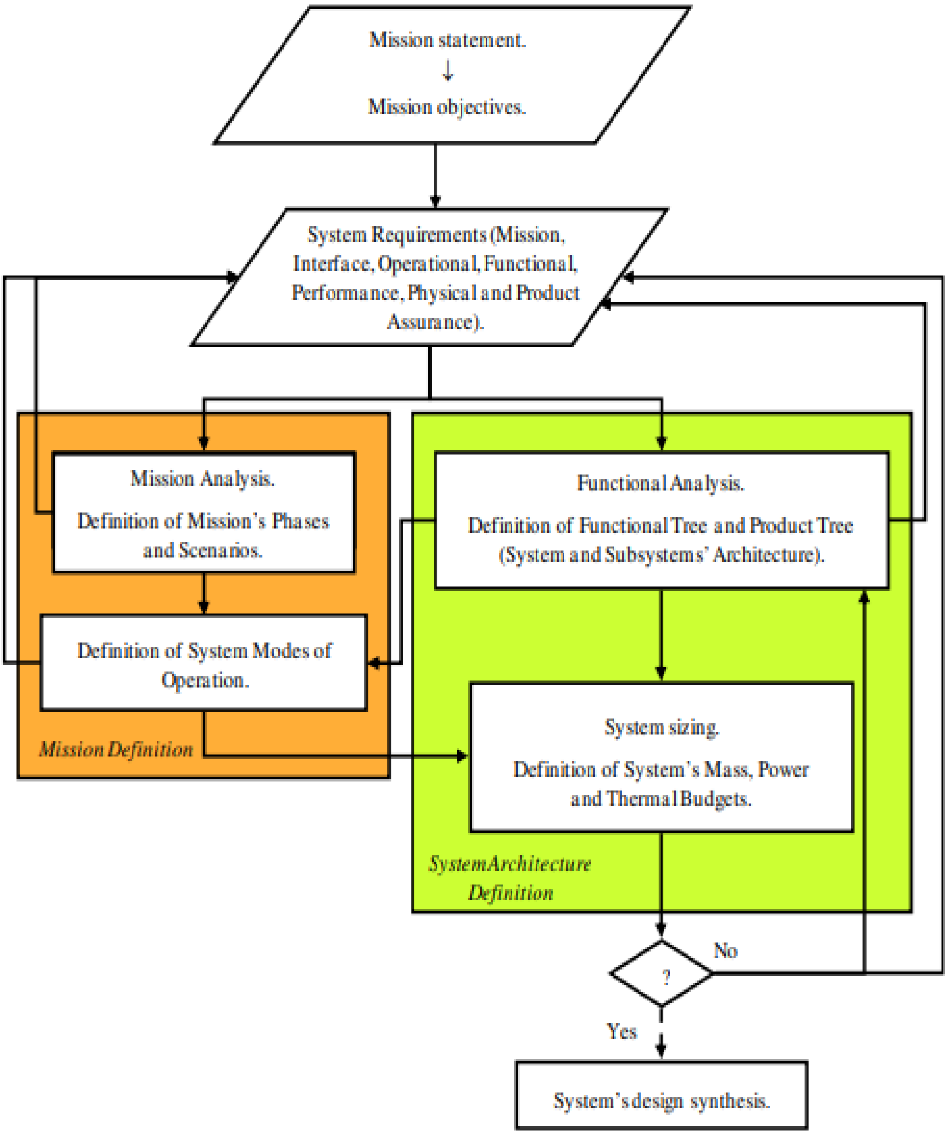

Fig. 1. Conceptual design process flow-chart

The functional tree and the product tree are the two main outputs of functional analysis: the former defines the fundamental functions that the system must be able to carry out, while the latter identifies all of the system's physical components that are capable of doing so. In other words, these parts could be the devices or the systems that make up the entire setup. Once the parts of the product tree have been identified, it is possible to look at the connections that bring the system as a whole together. Thus, it is feasible to create both the physical block diagram and the functional block diagram of each subsystem as well as the functional block diagram (secondary or supplementary result of Functional Analysis).

The definition of the system budgets (mass, electric power, thermal power budgets, etc.) is necessary to finish the system architecture. However, this process cannot be completed until the system's operational modes have been created. The mission definition includes the modes of operation, which can only be set up if the subsystems and their associated equipment have been recognised. It is crucial to confirm that all system requirements have been met after the mission system architecture has been tentatively specified before moving on to the system design synthesis. Before reaching the system design synthesis and freezing the system design, multiple iterations may be required because the design activity is often a process of sequential revisions.

Functional Analysis: Methodology

The Functional Analysis enables identifying the physical components, the so-called building blocks, that constitute the future product and how they are interrelated to build up the functional architecture of the future product, starting from the mission objectives/top level system requirements or directly from the mission statement. Additionally, functional requirements can be defined or otherwise improved by functional analysis.

Functional analysis can be used in conceptual design at three different levels: subsystem, system, and system of systems. An example of a subsystem at the subsystem level would be the avionic subsystem of an aircraft, which is made up of various pieces of equipment. Equipments, subsystems, or systems are the structural elements or building blocks that make up the future product, depending on the level being considered.

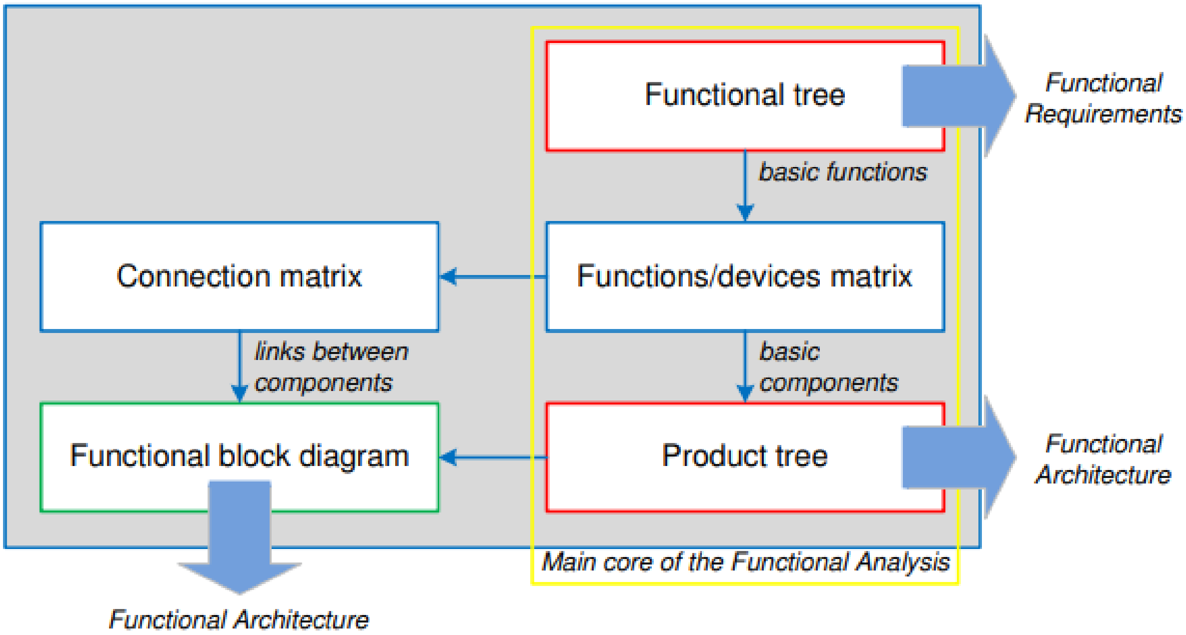

Fig. 2. The Functional Analysis

Figure 2 shows the flow-chart of the proposed Functional Analysis methodology, illustrating all its tasks, how the various tasks are related one another and the inputs/outputs of each task. The tasks, which have to be accomplished in order to carry out Functional Analysis, are listed hereafter:

- functional tree;
- functions/components (or functions/devices) matrix;
- product (or physical) tree;
- connection matrix;
- functional block diagram.

Functional tree

A product can be represented using the functional perspective instead of the more prevalent physical view thanks to the functional tree. The functional and physical points of view are complimentary rather than conflicting. In reality, when we look at a new product from its functional perspective, we ask ourselves, "What does it do?," whereas when we look at it from its physical perspective, we ask ourselves, "What is it?," which is without a doubt the first question that comes to mind when we see something new. Both perspectives are valid since they are fundamental methods for breaking down large systems into parts and analysing them. Depending on the amount of detail required for thoroughness and/or the level of the analysis itself, these methods are characterised by a low or high level of details.

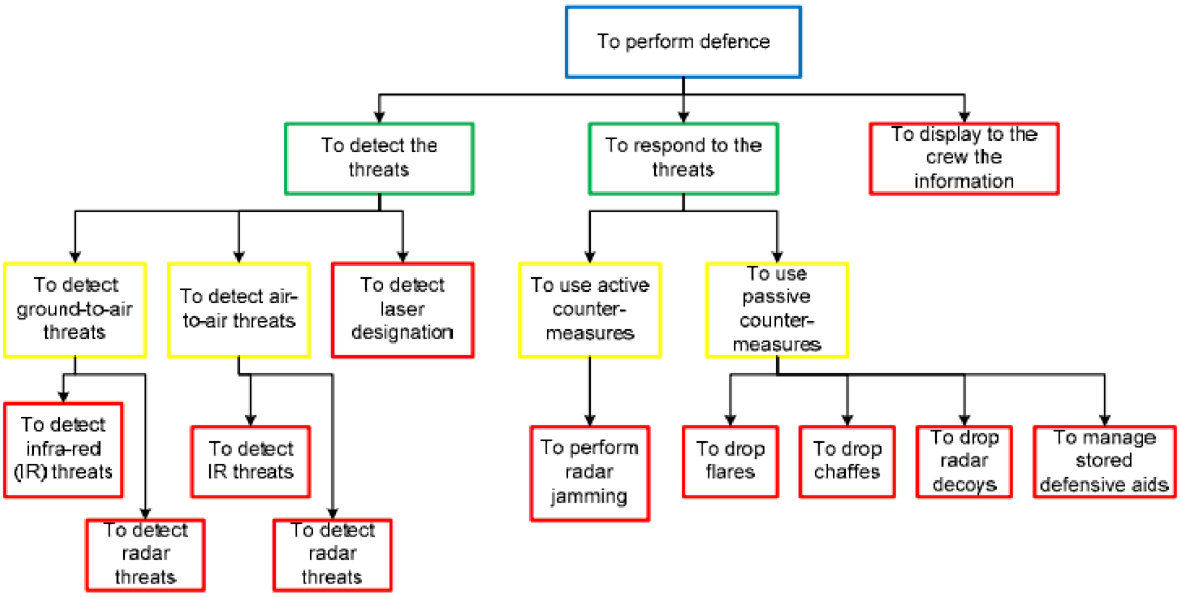

Fig 3. Functional tree

Functions/devices matrix and product tree

Once the fundamental functions have been determined, the functions/components (or functions/devices) matrix can be used to select the components that will carry out those functions. As a result, functions are mapped to physical components using the functions components matrix.

Looking at Table 1 and remembering the logical decomposition of the top level function reported in Figure 3 ("to get information": "to detect the threats", "to process information": "to respond to the threats", "to provide something with that information": "to respond to the threats" and "to provide somebody with that information": "to display to the crew the information"), we note that:

- sensors are equipments that detect threats (sensors are highlighted in red colour in Table 1);
- processors are equipments that process information (processors are highlighted in orange colour in Table 1);
- passive or active counter-measures are equipments that respond to threats (passive and active counter-measures are highlighted in blue colour in Table 1);
- displays are equipments that display to the crew the information (displays are highlighted in green colour in Table 1).

		Basic functions								
		To detect infra-red (IR) threats	To detect radar threats	To detect laser aiming	To perform radar jamming	To drop flares	To drop chaff	To drop radar decoys	To manage stored defensive aids	To display to the crew the information
Basic devices	Missile warning receiver	X								
	Infra-red (IR) warning system	X								
	Radar warning receiver		X							
	Laser warning system			X						
	Jammer decoy dispenser				X			X	X	
	Jamming system				X					
	Chaff/flares dispenser					X	X		X	
	Store management system								X	
	Multi Function Display (MFD)									X

Table 1. Example of functions/devices matrix

Product tree and costs/functions matrix

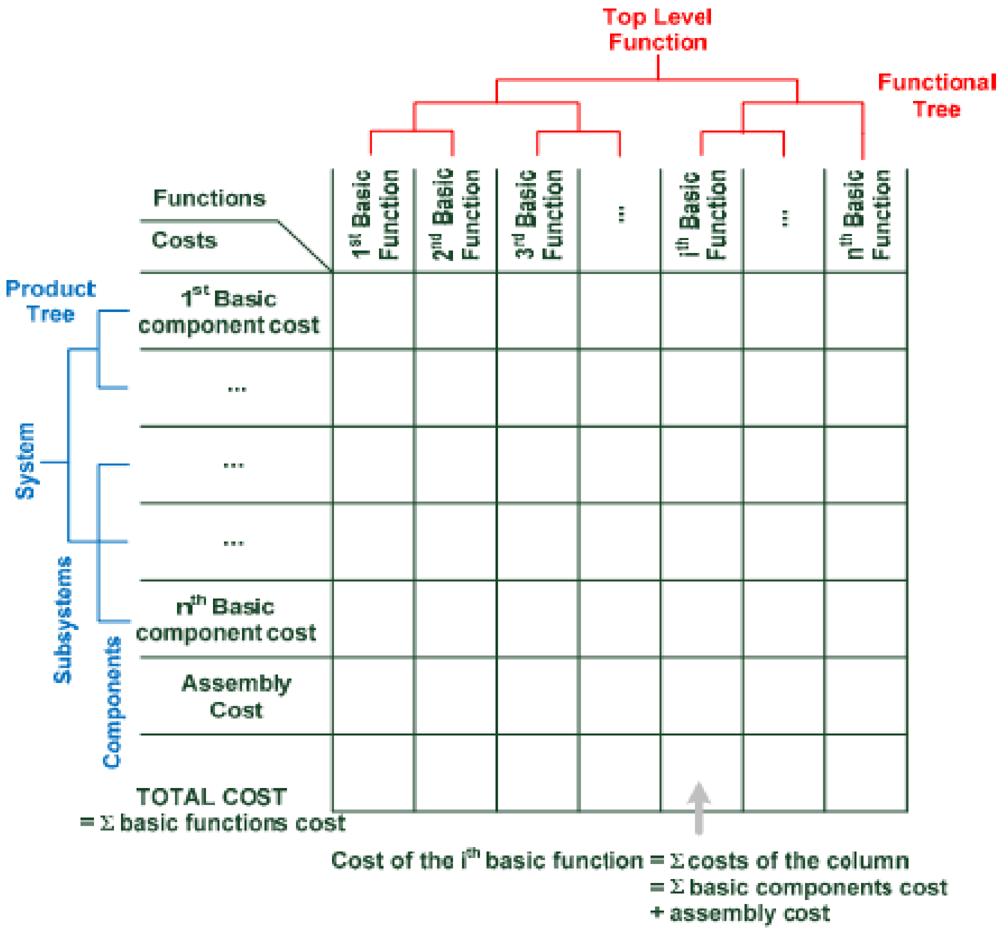

Fig. 4. Product tree and costs/functions matrix

Connection matrix and functional block diagram

The connections between the various components inside the system can be established once the fundamental components have been recognised. The connection matrix, which, as its name suggests, emphasises the relationships between all building elements, is used to accomplish this purpose.

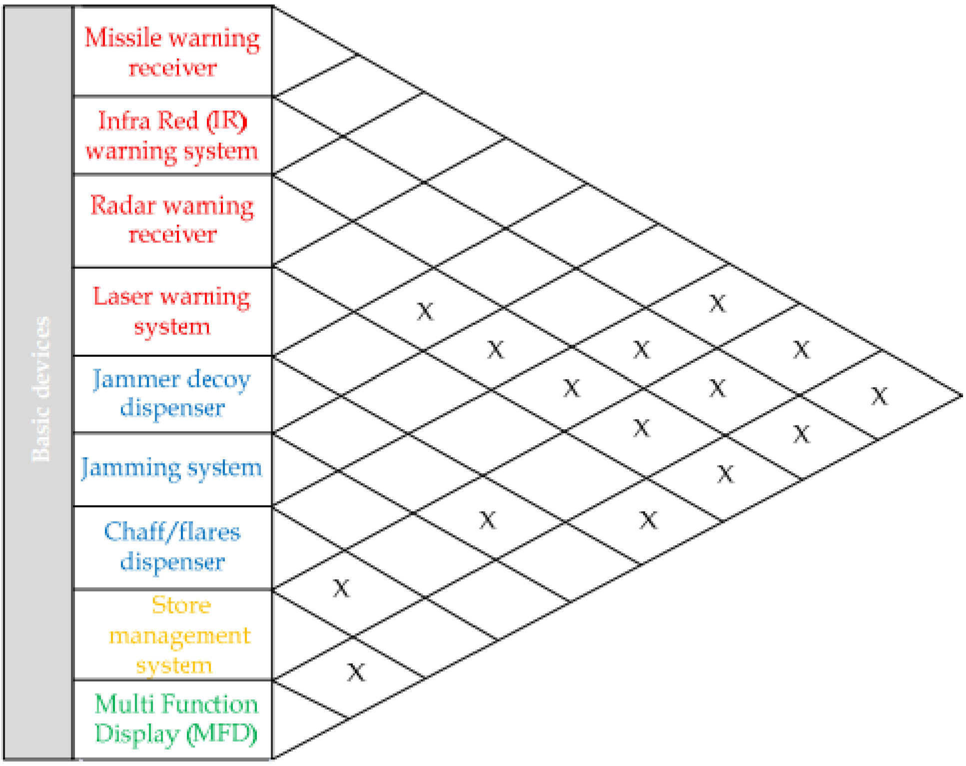

Fig 5.Connection matrix and functional block diagram

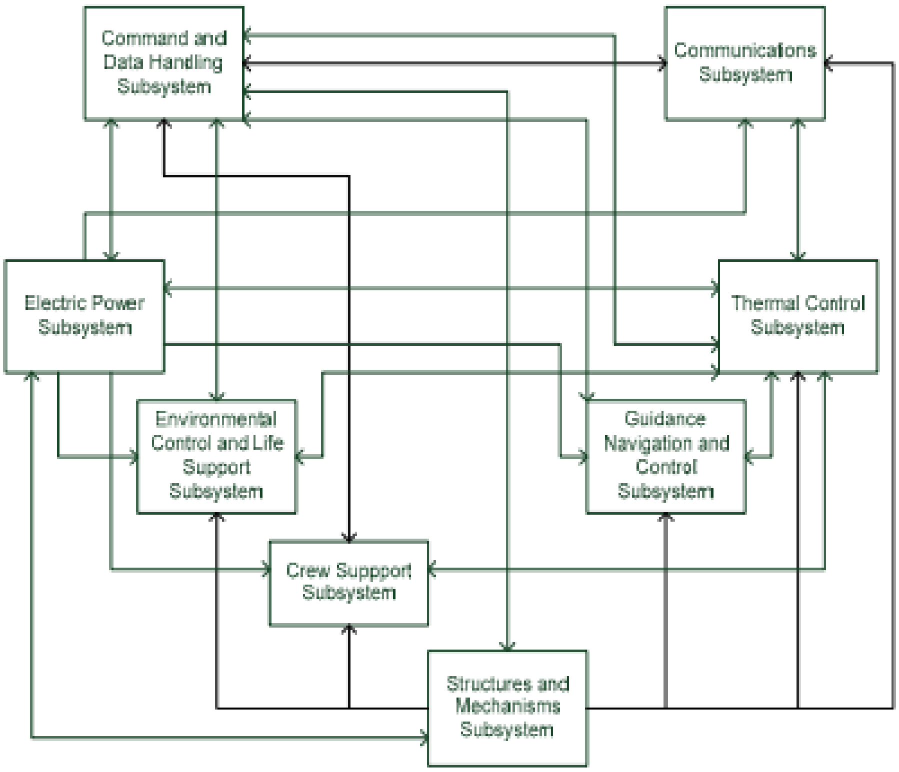

Fig. 6. The functional block diagram

Functional Analysis: Applications

As the Functional Analysis can be applied at different levels;

- Functional Analysis at subsystem level to define the avionic subsystem
- Functional Analysis at system level
- Functional Analysis at system of systems level

Conclusion

Without a doubt, one of the most important systems engineering design tools for creating a new product is the functional analysis. It ensures a thorough analysis of the requirements, encourages the search for alternative solutions, reducing or eliminating the possibility of overlooking important options, and, in the end, enables the identification of the physical components of the future product and their relationships. Therefore, it is crucial that every systems engineer knows how to use functional analysis to explore novel ideas and successfully produce creative structures. After a brief introduction emphasising the crucial role that functional analysis plays in conceptual design, the article goes into great detail on all the processes that must be taken and the regulations that must be adhered to in order to complete functional analysis. The article concludes with three distinct examples of the methodology's use at the subsystem, system, and system of systems levels.

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