Edinburgh Napier University

Mechatronic Systems

MEC10105

Coursework 1: 2-DOF Helicopter System Research Report.

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February 2020

Abstract:

This report gives details about the preliminary work (Design methodology, Product Design Specifications and Project Management) realised to answer the technical problem of a 2-DOF Helicopter system.

It describes the W-model as a mechatronics product design methodologies. Reasons as to why it represents a superior design process model for the development of a product: Holistic and integrated methods, efficient team work management and the power of virtual Integration prior to physical manufacturing.
The W-Model is then applied to the development of the Helicopter system with a Gantt chart representation (10 week project duration).

The report also gives detailed product design specifications for a 2-DOF helicopter system with an Arduino Uno controlling a four fan system through angle measurement with an IMU sensor and rotary encoder.

This report will present a summary of the preparatory investigative work realised to answer the technical problem offered by Flight Academic Training Ltd. The company is looking to acquire a 2 degree of freedom helicopter system model allowing for automated pitch and yaw positioning. First, a description and application of the design process model steps will be given, as well as the reasons for choosing the design methodology. Then, a preliminary product design specification for the 2-DOF Helicopter system will be offered. Finally, a Gantt chart of the tasks to be undertaken will be drafted to give an overview of the project.

I. Design Process Model: Improved W-Model.

This section describes how the W design model can be applied to the development of the 2-DOF helicopter system. Then an explanation of the reasons for selecting such a design model will be given.

A. W-Model Design Methodology and Application.

The W-Model is an evolution of the V-Model. In its article PLMPortal (2020), explains the main difference between two methodologies is the W model offers a method for developing component solutions concurrently rather than for each engineering domain.

The W-Model is broken down in 5 phases (as seen in fig I.1): System analysing, Specific solutions and dependency analysis, Virtual system integration, Model analysis and detailed development and System integration (Nattermann, 2013). It was agreed by the project team that an additional phase would be added as “Deployment and support” to help complete the product life cycle. The implementation of the process is reflected in the project management section later in this report.

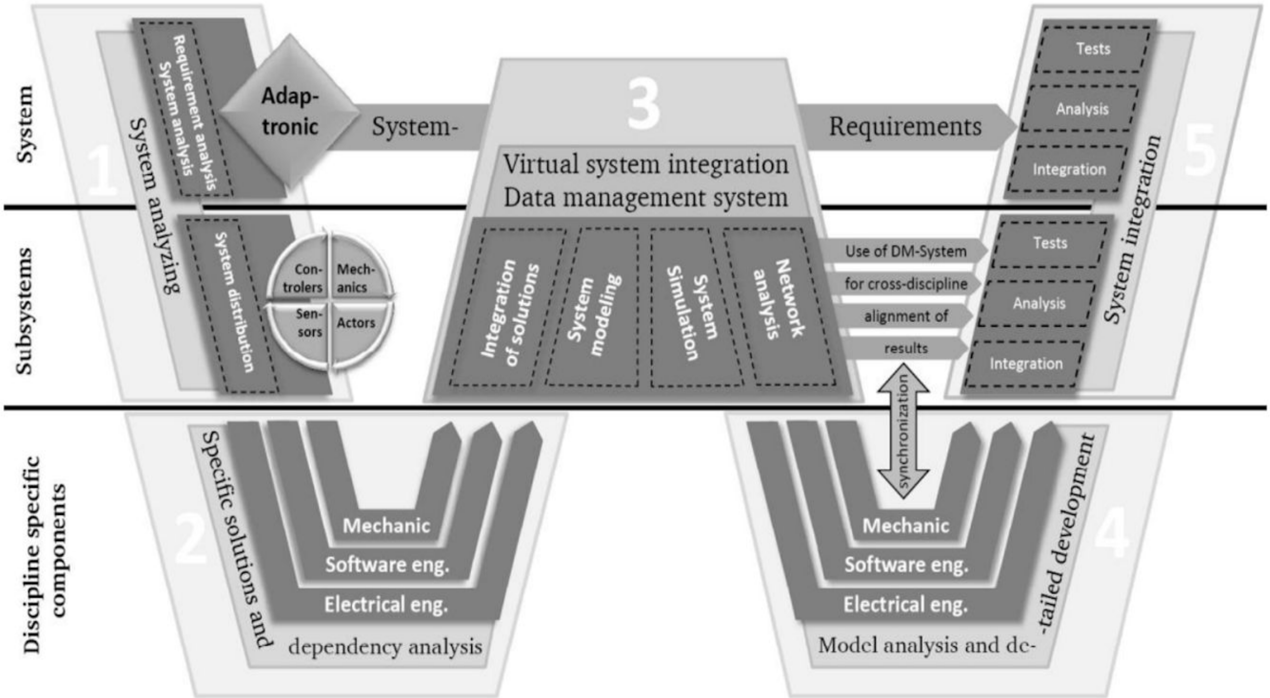

fig I.1 *W-model for the development of adaptronic systems* (Nattermann, 2013).

Applying the chosen W-Model to the 2-DOF helicopter system project development:

Step 1 - System Analysing.

In this first step of the development process Barbieri (2014) advises the focus should on defining the system requirements, the functions it needs to perform and identifying subsystems.

Effectively the tasks to achieve in this step can be broken down as such:

Brief Analysis - The team has a read through the brief and discusses its understanding of the problem. The discussion about the brief is general and serves to identify if any questions need to be asked to the client to shed light or develop the problem.

Requirements Identification - From the team discussion and questioning/interview with the client it is possible to identify the first requirements of a potential solution.

Product Design Specifications (PDS) - From the first requirements and understanding of the technical problem a draft of specifications can be drawn (available in section II of this report). This document evolves as the understanding of the problem and solution development are proceeding.

Identification of System and Subsystems - Defined specifications enable the development of a system solution and identifying subsystems meeting the criterias defined in the PDS. Those are general concepts and ideas about how the 2-DOF system can be implemented within the constraints established.

Functional Structure Generation - From the PDS it is possible to identify the functions of the system and subsystems (Mechanical joints, fans control, angle position sensors…) . How do subsystems relate to another to fulfil the main functional aspect. This is a flow chart identifying links and effects between and on the subsystems.

Classification of Requirements and Functions - From the previous tasks the requirements and functions can be assigned to system and subsystems according to engineering domains (Electrical, software, mechanical…). The purpose is to share the work and allocate team members according to their knowledge and skills in order to use time and resources efficiently.

Step 2 - Specific Solutions and Dependency Analysis.

In this step of the design the purpose is to start deriving a suitable mathematical model allowing to understand the dynamics of the technical possible solutions in development (Barbieri, 2014).

Tasks to be realised in this step:

Identification of Solution and Critical Parameters - Using the classification work realised at the end of step 1, it is possible to understand the function to be fulfilled by the various subsystems composing the 2-DOF helicopter system. It is then possible to derive mathematical models of each of the subsystems.

Creation of a Multidisciplinary Dependency Network - From the previous task, it possible to realise a global mathematical model of the system showing the interdependencies between each of the subsystems.

Select Appropriate Solution(s) - By comparing the different model dynamics to the previously defined requirements and functions a or some solutions can be selected to be used in the following design process step.

Step 3 - Virtual System Integration.

Barbieri (2014) explains this step is one of the major differences with V-model. In the W-model the multidisciplinary dependency network is virtually implemented prior to physical prototyping.

Tasks to be realised in this step:

System Modeling - In the case of the 2-DOF helicopter system, the mathematical model is implemented in MatLab to obtain a full virtual model of the system dynamics.

System Simulation - Thanks to the virtual model it is possible to check the assumptions made and dependencies in the mathematical model(s) are correct.

Network Analysis/Updating - From the simulation it is possible to identify the limits of the system, identify points of improvement and fix an issue that appears in the system. From there a solution to carry on to the next step will be selected. At this point, it is also recommended to start identifying the best control method since the dynamics are better understood in terms of high level input and output of the system.

Step 4 - Model Analysis and Detailed Development.

In this step the concurrent development of the various subsystems starts. The simulation results are used to update the parameters of any of the subsystems. (Nattermann, 2013)

From then a defined solution is finalised and can proceed onto the next step. CAD drawings and electrical wiring diagrams are prepared for manufacturing. The control method and Interface requirements are passed on to the software team.

Step 5 - System Integration.

Here the various final subsystems solutions are manufactured and assembled to form a prototype of the system (Nattermann, 2013). The prototype of the solution being available, it is possible to test its functions against the requirements and virtual model defined previously.

Step 6 - Deployment and Support.

This step is an add-on to the W-model. It involves preparing the documentation and user guide, apposing health and safety indicators on the system and finally realising a demonstration with the client. Potentially, this step could also include activities such as maintenance and end of life recycling of the system.

B. Reasons for selecting the Methodology.

This section of the report will expose some reasons why the team decided to select the W-Model as a design methodology for completing the helicopter system project.

Holistic and Integrated Design Approach.

The W-Model offers a defined holistic logical design process which allows for solutions to be developed concurrently within the different engineering domains (Mechanical, Electrical and Electronics, Software…). This allows for faster and easier implementation of system solutions by avoiding dependency issues between domains and subsystems early in the development.

Team Project Management.

The solution generation process being broken down in steps, system and subsystem offers the possibility of identifying tasks and organising the development more efficiently within the team(s). This also allows for multidisciplinary teams to work together and solve technical problems creatively using the different perspectives and knowledge background of the engineering team for each subsystems and system.

Simulation, Testing and Feedback Loops.

At every step of the solution development process, the work in progress is tested against the requirements and functions defined for the technical solutions. This insures the project does not digress from its objective but also allows for continuous improvement in the solution as the understanding of the project increases or technical problems appear.

A large part of the project is focused on creating a mathematical model of the solution then applied as a virtual simulation to test the solution potential and system limits. This allows for a better use of resources and time.

Altogether, the W-Model process creates reliable creative solutions to technical problems more efficiently with the aim to engineer superior products.

II. Product Design Specifications: 2-DOF Helicopter System.

The product design specifications give an overview of the requirements, constraints and functions of the technical solution. They are derived from the client's design brief and subsequent interviews. They are then completed all through the first phases of the project as the problem is better understood and requirements and functions become more defined.

The product design specifications document has been organised around 5 main axis: Mechanical, Electrical and Electronics, Operation and Performance, Ergonomics and Interface, Manufacturing Capabilities.

A copy of those specifications can be found in appendix A of this report.

III. Project Management and Gantt Chart.

The tasks to be accomplished in the project follow the process offered by the W-model methodology and have been assigned to working groups within the project team:

Technical Drawings and Manufacturing - Jamie and Kristaps.

Modelisation - Yash and Olivier.

Software and Control - Kristaps and Olivier.

Testing and Documentation - Yash and Jamie.

The tasks have been organised in a logical order using a Gantt chart which will be updated throughout the project. A Gantt chart of the project is available in Appendix B of this report.

Conclusion.

This report presented an improved version of the W-Model design process incorporating post manufacturing elements such as demonstration and support. It gave some reasons why this methodology is particularly suited to mechatronics system development to provide superior technical solutions. The model was applied to the 2-DOF Helicopter project. Its implementation was demonstrated in a Gantt chart. Additionally a product design specifications was provided for the 2-DOF Helicopter system.

Bibliography.

Barbieri, G., Fantuzzi, C. and Borsari, R. (2014). A model-based design methodology for the development of mechatronic systems. Mechatronics, 24(7), pp.833-843.

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Plmportal.org. (2020). The “W-Modell” – A Systems Engineering based Approach to Active Systems Development - News and background. [online] Available at: https://www.plmportal.org/en/research-detail/the-w-modell-a-systems-engineering-based-approach-to-active-systems-development.html [Accessed 12 Feb. 2020].

Appendices.

Appendix A - Product Design Specifications.

Mechanical:

Size: The prototype needs to fit within the box provided with internal measurements: 310 x 250 x 225 mm.

Weight: Should be light enough to be carried in the box (below 10kg).

Materials: The base, the housing for the bearings and the housing for the hinge will be made from 6mm thick PVC.

The vertical shaft will be made from 20mm diameter steel. The horizontal beam will be made from an aluminum bar.

Assembly: The prototype will require assembly to allow it to fit in the box. The fans will be mounted on the horizontal beam. The horizontal beam will be detachable from the main vertical shaft.

Joints and Motion: The mechanical joints will allow the system to pitch and yaw simultaneously through rotation movements.

Electrical and Electronics:

Power: The system should be able to operate on a 12V DC supply.

Actuators: Two 16 inch rotor fans (1500rpm), and two 80 mm rotor fans (2000rpm).

Sensors: Rotary encoder for yaw motion monitoring. Inertial Measurement Unit sensor for pitch motion measurement.

Controller: The system will be controlled by an Arduino Uno (microcontroller: ATmega328P) and a motor drive board.

Display: Information will be displayed on a 16x02 LCD screen.

Buttons: Two control push buttons and one emergency stop.

Operation and Performance:

Automatic Mode: Pitch and Yaw axes (2-DOF) have to be controlled in order to let the helicopter maintain different positions for 10 seconds each in an automated sequence:

1) Pitch = 0º, Yaw = 0º.
2) Pitch = 0º, Yaw = 30º.
3) Pitch = 0º, Yaw = -30º.
4) Pitch = 15º, Yaw = 0º.
5) Pitch = -15º, Yaw = 0º.
6) Pitch = -15º, Yaw = -30º.
7) Pitch = 15º, Yaw = 30º.

Manual Mode: Defined positions can be selected independently through the system interface.

Control technique: Two PID controllers will control pitch and yaw to put the system in position. The system controller should absorb some light disturbance.

Operation Safety: The operational angles will be restricted to an operational angle of 180 degrees yaw and operational angle 90 degrees pitch.

Testing: A MatLab model will be used to determine the system limitations and determine PID parameters values.

The physical prototype will be tested, against the simulated model, thanks to data collected from serial readings from the IMU sensor and encoder.

A Functional Test Specifications document will be provided to demonstrate how the operational functions are tested and met.

Reliability: The system should operate with some non-compromising defects.

Environment: The system should operate at normal room setting: 15 to 25ºC, 50% Relative humidity.

Light physical protection will be provided to protect components from dust and physical access.

Ergonomics and Interface:

Display and buttons: The interface will be operated using two push buttons with live information (live measurements, programme selection, menus…) displayed on the LCD screen.
Assembly: Assembly should be minimal, simple and require a low amount of tools.
User Documentation: This documentation will include the Functional Testing Specifications, Technical specifications, Safe Operation Procedures and Health & Safety Recommendations.
Health and Safety: Warning and safety labels apposed where necessary. Electrical components protected from finger access.

Manufacturing Capabilities:

Manufacturing: Limited time with technician and machine shop.
Set kit of components and materials available.
Time frame: 10 Week turnaround time.
Budget: £20 available for additional components and/or parts.

Appendix B - Gantt Chart.

Weeks Countdown to Project Submission:	11	10	9	8	7	6	5	4	3	2	1	0
Weeks	20.01.20	27.01.20	3.02.20	10.02.20	17.02.20	24.02.20	02.03.20	09.03.20	16.03.20	23.03.20	30.03.20	06.04.20
Deliverables - Objectives												
System Analysing.												
Brief analysis.												
Requirements Identification.												
Product Design Specifications												
Identification of System and Subsystems.												
Functional Structure Generation.												
Distribution of requirements and functions according to domains and System/Subsystem.												
Specific Solutions and Dependency Analysis.												
Identificiation of solutions and critical parameters for each domain:												
- Electrical and Electronics.												
- Mechanical.												
- Software and Control.												
Creation of a multidisciplinary dependency network.												
Select appropriate solutions												
Virtual System Integration.												
Integration of Solutions												
System Modeling												
System Simulation												
Network Analysis/Updating												
Model Analysis and Detailed Development for each domain:												
- Electrical and Electronics.												
- Mechanical.												
- Software and Control.												
Identify potential solution improvements.												
System Integration.												
Manufacturing and assembly of subsystems.												
Testing against virtual simulation and functional requirements.												
System Deployment.												
Documentation and User Guide.												
Health and Safety recommendations.												
Demonstration.												
CW1 - Research Report (21.02.20)												
CW2 - Design Report (9.04.20)												