

INTEGRATION OF EVALUATION AND SIMULATION METHODS FOR VIRTUAL PROTOTYPES

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ABSTRACT

This article combines evaluation and selection of early design concepts into a methodology at different stages of the development process. A web-based evaluation environment to support this methodology has been developed including Kurtoglu's component taxonomy. In addition, the Taguchi's design of experiments approach has been used to virtually assess all feasible combinations generated from Zwicky matrix. This evaluation methodology is applied to the case study of an autonomous robot for Eurobot competition. The virtual environment was useful to provide a fast visual representation of the different robot concepts and their behaviours. This evaluation methodology was compared with AHP and Pareto optimality evaluation methods.

The main contribution of this paper is to develop a methodology and a computer tool integrating virtual simulation associated with a design of experiments providing a visual representation of the concepts. These concepts can be simulated according to situations they would face in reality. This enables the evaluation of concepts according to non-subjective criteria and it could assist the decision making process at early design stage. Furthermore, this evaluation method enables preliminary selection in a concurrent manner during the phase of concept generation. The goal is to integrate the entire approach as a web-based platform supporting the early design process. This work is developed for pedagogical purpose in the context of an EU project.

Keywords: Virtual prototyping, design, simulation and evaluation, design methodologies

1 INTRODUCTION

The rapid expansion of the Internet and its related hardware and software technologies has increased the possibilities for sharing virtual distance lab hardware between different institutions as shown by the example of NetLab [1, 2]. Accessing remote and virtual laboratories allows provision of practical skills to students due to the lack of equipment and funds in educational institutions. However, mostly every institution has its own technological approach, so sharing is very complicated since external software components and data sources cannot be integrated into existing platforms without major expenses. The approaches towards the development of virtual laboratories as a collection of light-weight Web Services proposed by Dutta et al and Tawfik et al. in [3, 4], are considered valuable for the development of the research presented here.

This paper presents the development of a virtual distance lab containing different tools and methods for students to practice on the design and simulation of mobile robots. Each computer tool is implemented as an independent web service so as to enable the evolution of the distance virtual lab. More precisely, the focus of this paper is on two tools developed independently for the evaluation of early design concepts of autonomous robot for eurobot competition. The first tool is implemented based on the work of Kurtoglu et al. [5] for pruning non viable concepts within a Zwicky matrix [6] associating potential components to the robot functions. The second tool is based on Taguchi method [7] used for designing simulations of various robot concepts in a virtual environment proposed by Seppälä during his Master thesis in [8, 9]. These two tools are combined into a methodology for evaluating design concepts proactively during concept generation.

The rest of this paper is organized as follows. Section 2 presents the background of this research on the development of virtual lab for pedagogical purpose. Section 3 presents the methodology proposed as a combination of virtual lab tools for evaluating design concepts. Section 4 details this methodology

through the case study of evaluating concepts of solution for the development of an autonomous robot. Conclusions and future work are drawn in section 5.

2 RESEARCH BACKGROUND

Recent researches have introduced the concept of “experiment as a service” and developed service-based software infrastructure for remote laboratories, called also DCL (Distributed Control Lab) [9, 10]. Even though the platform used in this paper to develop tools for students is not based on DCL, the approach presented here of offering different services for design to students is similar to the one proposed with DCL. In [11, 12], an open source Web application providing access to LabView-controlled instruments was developed. It includes a Web Service and a web interface to allow users to acquire measurements from instruments remotely in real time, using standard browsers and also exploiting mobile devices. However, the wide range and diverse proprietary interfaces and implementations for each experiment are a problem for learners. Therefore, it is hard to integrate new remote labs or create virtual labs from different organizations and universities. To this regard, the motivation behind using Web Services in different remote laboratories is just to allow easily the introduction of new technologies, new laboratories and services. Indeed, one of the advantages of Web services is the interoperability with different software platforms. Furthermore, Web applications can be developed easily on diverse server platforms and client interfaces, and realized in different software environments. In this way, different institutions can share their laboratory resources and make them accessible to a wide range of users via web interfaces.

The web based approach developed in this research project is used for student project management. Teacher or Administrator of the website uploads the project and its task description. Task description provides the information of required skilled to enrol for the project. Students can register in the system mentioning their specific set of skills. Then they enrol for the project tasks that are suitable for them. This web based system provides students different methodologies and tools to solve the assigned design tasks, based on information stored in databases. In the focus of this paper, students use the proposed methodology to evaluate and select concepts of solution for the design of an autonomous robot. Java script and PhP/MySQL database were used to build this webpage. Students from partner EU universities can also use this web based system. Figure 1 presents the architecture of this web platform. The intent is for groups of students to work in a distributed manner and to share their results as a group.

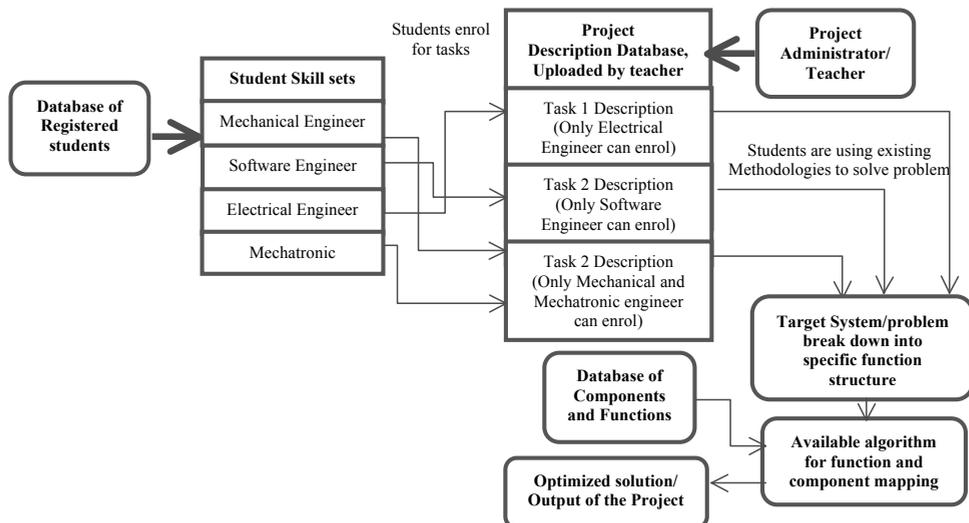


Figure 1. Web architecture for students of mechatronic system design project

3 EVALUATION METHOD PROPOSED

This section presents the proposed methodology, as in Figure 2, for evaluating proactively design concepts at early design stage. This methodology combines a method for pruning non viable concepts during concept generation by the analysis of compatibility between components [5] and a method for defining the minimum set of simulation necessary to evaluate concepts according to the number of design variables [7]. The latter was used by Seppälä in [8, 9] to evaluate different design concepts through simulations in a virtual environment (VE) with Physics engine. In his work Seppälä has utilized modern simulation tools for robotics that enable fast virtual implementation of the rough robot structure and functionality in dynamic environment. Seppälä has been using AnyCode Marilou [13] software to implement the virtual prototypes and used them to evaluate the performance of different conceptual designs for robots. In this paper, the work of Seppälä is being integrated into the proposed methodology. Further description of this dynamic VE is shown in the following section presenting the case study.

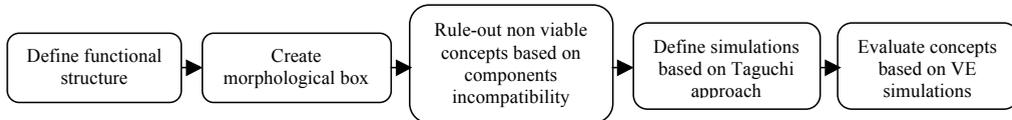


Figure 2. Description of steps proposed in methodology

4 CASE STUDY

This section presents the application of the proposed methodology applied to the development of concepts for a mobile robot for eurobot competition. This competition consists in two autonomous robots competing for harvesting as many fake fruits and vegetables (playing elements) on a playing field within a playing time of 90 seconds. During this time, the robots should place these playing elements in their own container. At the end, the robot having collected the most playing elements wins the game. Figure 3 shows a representation of the playing environment for the robots modelled with Marilou software.

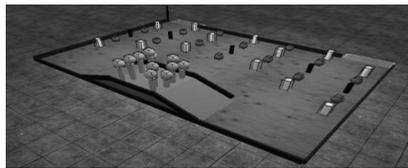


Figure 3. Model of the eurobot field and playing elements

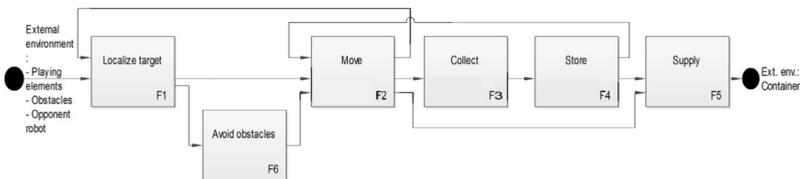


Figure 4. Functional representation of robot actions

The first step for the synthesis of concepts proposed in this method consists in a functional analysis of the functions required from the robot in order to accomplish the global objective of harvesting playing elements and dispensing them into the container. This analysis is presented in Figure 4 and shows the main functional chain considered for the development of this robot.

After this step, the morphological box is derived from the necessary functions and is associating available components from a library to these functions as shown in Table 1. Nevertheless, an exhaustive exploration of the design space is not guaranteed as it relies on existing components. In table 1, the first column represents functional parameters and the following rows contain the options of components enabling this function. In this example, the moving function is implemented with a differential drive, and store and supply functions are regrouped into one function, for simplification

reasons. Table 1 shows that the combinations of different options for each function provides a large amount of possible concepts of solution, more precisely, there are 54 possible concepts when considering only 4 functions and a maximum of 3 components associated to each function. The last row of table n presents example of the possible combinations of options to create concepts of solution.

Table 1. Morphological box for generating autonomous robot concepts

Function	Option 1	Option 2	Option 3
Localization	c1: Beacons	c2: Odometry	
Obstacle avoidance	c9: Sonar array	c10: Bumper array	c11: Static map
Collecting	c3: 1-DOF grabber	c4: Fork	c5: Fork + grabber
Store and supply	c6: Tip-truck	c7: Ramp	c8: Tip-truck + pusher

Concepts	Solution 1	Solution 2	Solution 3

The database developed in this research contains information about compatibility of the flows between components. Table 2 presents the compatibility between components considered as possible use in this case study.

Table 2. Representation of compatibility between components

Component	is compatible with
c1	c3, c4, c5, c6, c7, c8, c10, c11
c2	c3, c4, c5, c6, c7, c8, c9, c11
c3	c1, c2, c8, c9, c11
c4	c1, c2, c6, c7, c9, c11
c5	c1, c2, c6, c7, c8, c9, c11
c6	c1, c2, c4, c5, c9, c11
c7	c1, c2, c4, c5, c9, c11
c8	c1, c2, c5, c9, c11
c9	c2, c3, c4, c5, c6, c7, c8
c10	c2, c5, c6, c7, c8
c11	c1, c2, c3, c4, c5, c6, c7, c8

The application of the methodology proposed by Kurtoglu et al. in [5] enables pruning potential solutions from the initial design space (54 potential concepts) defined by the morphological box presented in Table 1. This methodology has been developed as a web-application tool for student use in the virtual lab. Figure 5 presents the graphical interface of this web-application tool. Using this tool, students can define functions and their interactions in the form of a matrix. The tool associates automatically functions to specific components defined in a database and provides students with the remaining concepts after pruning in the form of design structure matrix. After this step, there are only 24 viable concepts remaining as shown in Table 3.

The number of experiments designed by Seppälä in [8] can be reduced with the results obtained from compatibility analysis between components as shown in Table 4. From this plan of experiments, Seppälä ran the corresponding simulations with the concepts presented in Figure 6 and selected a concept based on the score given to each design option. The new concept recommended for further design contains a beacon system, a static map, both grabber and forklift as tools and a tip-truck for storing fruits and vegetables.

Function-Component Mapping

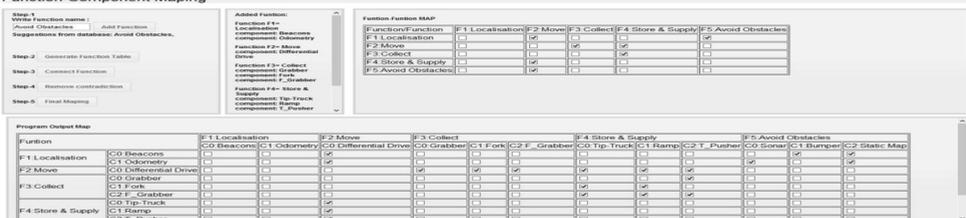


Figure 5. Web application tool for mapping functions with components

Table 3. Remaining viable concepts after pruning

	Localisation	Move	Collect	Store & Supply	Avoid obstacles
Concept1	Beacons	Diff. drive	Grabber	Pusher	Bumper
Concept2			Fork	Tip-truck	
Concept3			Fork	Ramp	
Concept4			Fork+ Grabber	Tip-truck	
Concept5			Fork+ Grabber	Ramp	
Concept6			Fork+ Grabber	Pusher	
Concept7			Grabber	Pusher	Static Map
Concept8			Fork	Tip-truck	
Concept9			Fork	Ramp	
Concept10			Fork+ Grabber	Tip-truck	
Concept11			Fork+ Grabber	Ramp	
Concept12			Fork+ Grabber	Pusher	
Concept13	Odometry	Diff. drive	Grabber	Pusher	Sonar
Concept14			Fork	Tip-truck	
Concept15			Fork	Ramp	
Concept16			Fork+ Grabber	Tip-truck	
Concept17			Fork+ Grabber	Ramp	
Concept18			Fork+ Grabber	Pusher	
Concept19			Grabber	Pusher	Static Map
Concept20			Fork	Tip-truck	
Concept21			Fork	Ramp	
Concept22			Fork+ Grabber	Tip-truck	
Concept23			Fork+ Grabber	Ramp	
Concept24			Fork+ Grabber	Pusher	

Table 4. Experiments defined from Taguchi method

Experiment	Variable				Variable			
	A	B	C	D	Localization	Obstacle	Tool	Storage
3	1	3	3	3	Beacons	Bumper	Both	Pusher
4	2	1	2	3	Odometry	Static	Forklift	Pusher
5	2	2	3	1	Odometry	Sonar	Both	Ramp
7	1	1	3	2	Beacons	Static	Both	Tip truck
8	2	2	1	3	Odometry	Sonar	Grabber	Pusher
9	1	3	2	1	Beacons	Bumper	Forklift	Ramp

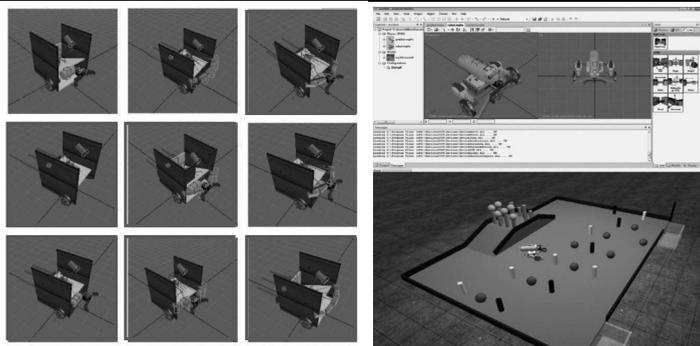


Figure 6. Robot models for virtual experiments and chosen concept

5 CONCLUSIONS

The combination of methods presented helps selecting progressively an optimal concept of solution according to non-subjective criteria. However, when considering several other performance criteria such as cost, energy consumption, development time, results should be mitigated. In fact, these criteria have a strong effect on the rapidity to collect the playing elements. From the results on AHP method

[14], low cost and low energy design choices affect negatively both the development time and the collecting speed criteria. On the other hand, the choice of high-end components does not affect the collecting speed compared to middle price components. This result suggests that the analyses from each of these methods to be combined in order to corroborate the results and guide decision making in a more rational manner.

The modern robot simulation tools can be used to develop virtual laboratories or exercise environments for robotics education. The simulation software can be run on a server which streams the results to the student's computers in real time. However, using the design GUI of, for instance, Marilou software over internet is not feasible, so the robots and their environments should be prebuilt by the virtual laboratory staff. The exercises for students would thus be related to implementing different control schemes and programming the virtual robots. In this kind of environment it is possible to experiment high level robot algorithms such as for navigation.

To use the robot simulation tools over internet some data transfer protocols have to be implemented. Most importantly the students need some interface to upload their code to the virtual robot. On the server side, the results of the simulation have to be streamed to the student's computer.

Future work should assess the benefits of the tools developed in this paper for educational purpose. Also, results from students working as a distributed team should be compared with results from students working physically together.

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