Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (3): 471-479, 2008
ISSN 1812-5654

A Knowledge Based Interactive System for Complex Product Design

Ahmet Gayretli
ANS Campus, Faculty of Technical Education, Afyon Kocatepe University, Afyon, Turkey

Abstract: This research presents a new Artificial Intelligence (AI) based product development approach for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products by avoiding design conflicts in the early stages of the design process. The proposed approach has been implemented in a Delphi based environment integrated with a CAD system. The system assists designers from different disciplines in evaluating complex systems as far as parts relation, potential effects on each other, conflict management, costs, weight and physical constraints are concerned in the early design stages. This helps the designers to avoid design iterations leading to longer lead-time, hence increased cost. The developed system enables to rapidly develop and evaluate new complex products and add new functions to the existing products within given constraints.

Key words: Interdisciplinary product design, expert systems, complex product design, constraints, conflict management

INTRODUCTION

Electromechanical products are becoming increasingly sophisticated and significant in advanced high tech products for the commercial and defense markets. These products such as digital cameras and robots have multi-technological characteristics. An electromechanical product consists of electronics, mechanical components, software and other systems. Designing these products is a complex and time-consuming process due to constraints from different engineering domains. There are obstacles that have to be overcome at the interfaces between each of these domains (Fig. 1).

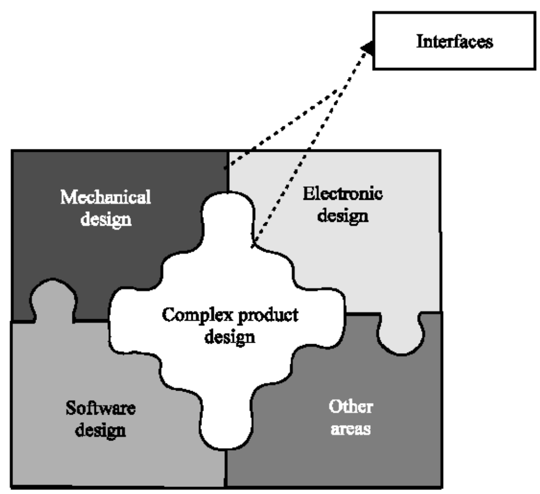

Fig. 1: Different view points in interdisciplinary product design

In complex product design, early design decisions have significant impacts on product cost, time and quality. There is lack of people who completely understand the range of discipline-related technologies to be very likely found within electromechanical systems. Different approaches have been proposed for supporting electromechanical product design. One such approach is that of agent-based systems (D'ambrosio *et al*., 1996; Campbell *et al*., 2000). As an alternative method of presenting product requirements, constraint networks have been implemented to help the designer to improve product designs by preventing conflicts (Bowen, 1997; Hayes and Su, 1995). A large amount of work has been devoted to the development of physical modeling and simulation environments for electromechanical systems (Gupta *et al*., 1998; Diaz-Calderon *et al*., 1998; Porter *et al*., 1998; Gayretli, 2007). Concurrent engineering approach has been successfully implemented in a purely mechanical or purely electronic design domain (Wang *et al*., 1996; Gayretli and Abdalla, 1999), but little progress has been made towards the use of this approach for electromechanical product design (Hsiao, 1999; Farr *et al*., 2002a). A number of issues such as conflict management, information sharing, integration of CAD tools and collaborative decision-making have become critical in advanced electromechanical design (Wang *et al*., 1996; Gayretli and Abdalla, 1999; Farr *et al*., 2002b; Gayretli *et al*., 2001; Gayretli, 2005; Breedveld, 2004). In spite of a speedy growth and extensive use of mechanical and electronic CAD tools, knowledge gaps still exist between the isolated areas of design and manufacture because of the lack of appropriate methods and tools to support the development of electromechanical systems in the early design stages.

It is essential that a cooperative methodology needs to develop a cooperative methodology for capturing customer requirements for translating them into system requirements, module requirements and sub-system and component requirements. Therefore, the focus in this research work is on achieving such support, integration and consistency for complex product design.

PROPOSED APPROACH TO INTERDISCIPLINARY PRODUCT DESIGN

The proposed approach to address the significant problems of electromechanical proposed design has been

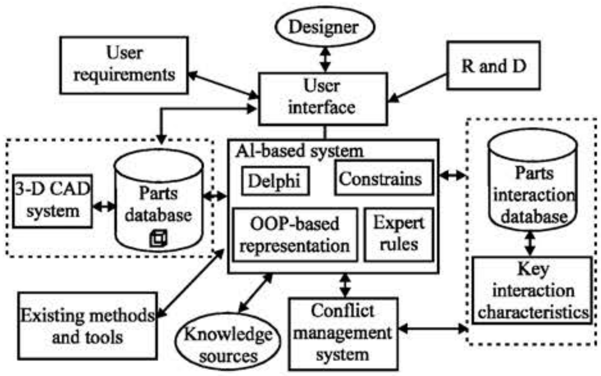

Fig. 2: A new approach to interdisciplinary product design

shown in Fig. 2. It consists of interacting modules with their own functions. It is an object oriented product development approach for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products subject to given requirements.

The proposed approach has been implemented in a Delphi based PC environment integrated with a CAD system. To understand relationships between each component in a complex system some existing products such as an electrical toothbrush and a walking robot (Fig. 3) have been examined and relationships between components are modeled based upon constraints, rules and frames. It embodies a CAD module with a part database, requirement definition module, user interface, conflict management system, parts interaction database, AI-based system incorporating constraints, rules of thumb and object-oriented representation of parts with key-interaction characteristics.

The procedure for designing a complicated product, via this system, requires the designer to interact with the CAD system and parts-database to create the product and its components/sub-systems. Information about the product and its individual components is passed to the knowledge-base system by the user interface.

The designer enters requirements, coupled with target cost, weight, dimensions, resources and capabilities, together with other areas of the design process, into the system as a set of constraints. The

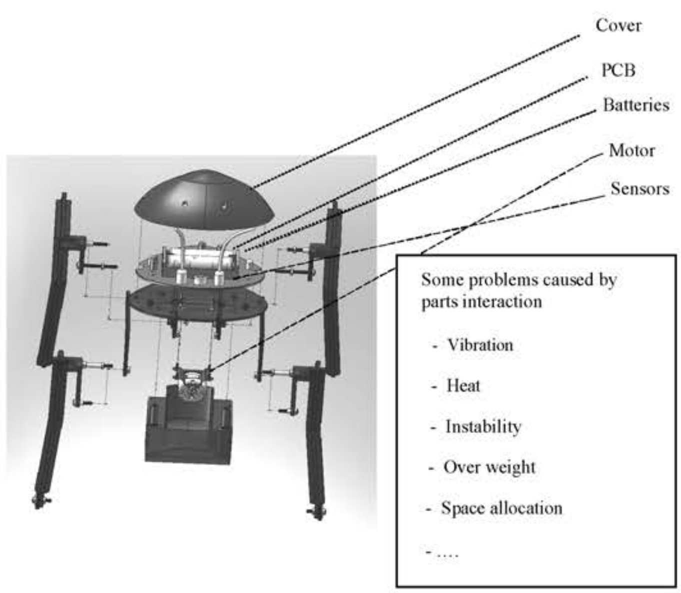

Fig. 3: A 3-D electromechanical walking robot with various interacting parts

system conducts various tasks by satisfying all the constraints. It begins by simultaneously checking the target cost, weight, dimensions and interactions of the proposed system whilst it is designed. The system provides the designer with an evaluation of all the decisions associated with the system, its sub-systems and parts. Recommendations are provided when the proposed design cannot meet all the requirements.

This allows the designer to avoid unexpected consequences leading to longer lead-times, customer dissatisfaction, failures and costs during the product life cycle. Also it allows the effective conflict resolution strategy for inconsistencies and conflicts arising from the different design domains.

Product key characteristics as constraints: Product key characteristics are generally associated with factors affecting the performance of electromechanical products. These can be modeled in terms of constraints.

Electrical/electronic and mechanical systems and components interact one with another when they are designed and worked together. Interactions between individual components can have important impacts on functions, cost, reliability, performance and quality. Therefore, these interactions must be taken into account in order to achieve better product designs without conflicts during the design process. The most common key characteristics of electromechanical products are determined as follows; noise, heat, power, space allocated, vibration, conductivity, velocity, location, gravity, safety, electromagnetism, environment and mass. In our approach a system design process is divided into subsystems, then components and finally features. Conflicts, which may arise at any level, are resolved at that level subject to the key characteristics set out by the multi-disciplinary design team. The design process consists of four downstream levels; system level, subsystem level, component level and feature level. Similarly, factors affecting electromechanical design are formulated in terms of constraints; global constraints, local constraints and feature constraints (Fig. 4).

- Global constraints are generally derived from customer requirements. They are associated with the performance a system has to achieve. For instance, AThe system (walking robot) must weigh less than 200 g and walk at least 5 sec.
- Local constraints are related to individual items of which the actual system is composed and based on global constraints inherited down the hierarchy. In order to achieve the above performance local constraints can be defined as follows:

- subsystem_1 (motor) must be no more than 75 g
- subsystem_2 (PCB) must have a length of < 100 mm
- subsystem_n (legs) must carry a load of ....

- Feature constraints are imposed on feature attributes such as tolerance and process.

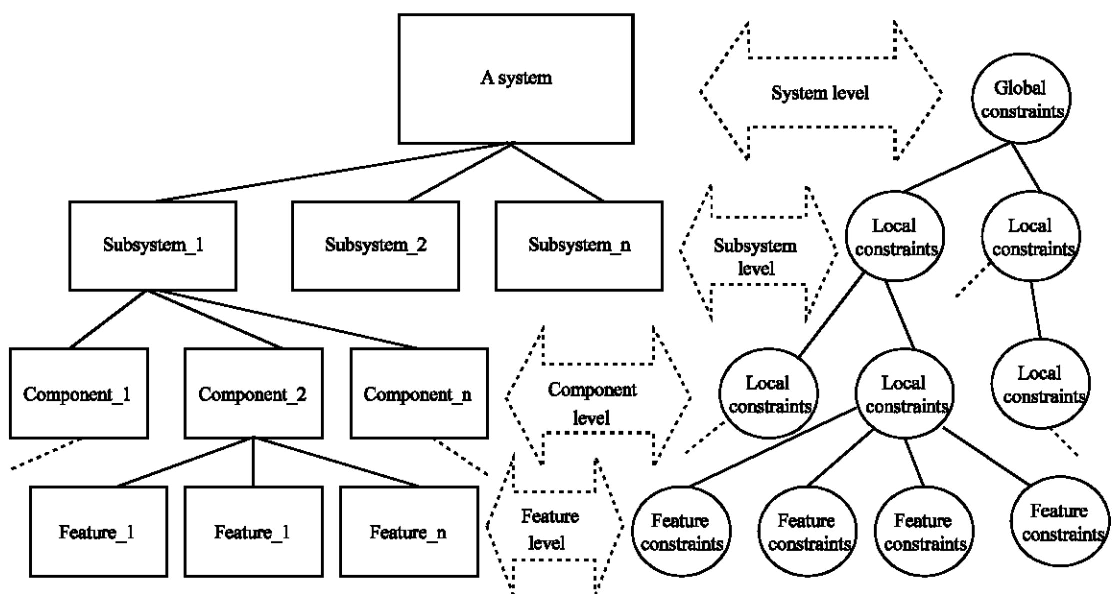

Fig. 4: Constraints representation

Conflict management via Constraint Satisfaction Algorithm (CSA): Since electromechanical system design is a complicated task, many decision-making problems have to be resolved by the participation of various design engineers with local expertise. A complex system design consists of various activities, which often need to be carried out by different departments or subcontractors, located in remote geographical areas. Co-ordination is therefore considered as the lynch pin of managing interactions and knowledge exchange between these as conflicts often arise due to different views on design parameters. Such co-ordination can be achieved by developing a cooperative constraint-based conflict resolution system that can provide an efficient infrastructure for resolving conflicts by satisfying all the requirements.

This problem is then formulated as a Constraint Satisfaction Problem (CSP), that is defined by means of a triple (X, D, C) where, X is a set of n variables (i.e., weight, cost, temperature, force) and for each variable $x_i \in X$ there is a corresponding (finite) set $D_i \in D$ that represent its domain (possible values of each variable).

The set C is a set of constraints (relationships between parts) that are required to hold between the values of the variables. A value $d^*_i \in D_i$ is assigned to each variable x_i in such a way that all constraints are satisfied, $d^* = (d^*_1, ..., d^*_n) \in c_j$ for each $c_j \in C$. The assignment d* is called a feasible assignment, that meets given requirements. Any constraint that is not satisfied, is called constraint violation and it is resolved by either a system user or the system itself through negotiations.

Constraints-based system module: To achieve an effective management of constraints, an efficient and timely communication system has to be developed within engineering areas. This system needs to contain a good conflict management system for avoiding disagreements between various design domains. The proposed system includes two main modules; a constraint-based module and a consistency management module. The constraint-based module is utilized to model and handle design requirements and it is integrated with the consistency management module for managing design decisions and conflicts. The developed constraint-based module uses constraints for modeling information on various life-cycle issues, for their effective use during the design process.

It includes constraints from different design domains, variables from the design model and a constraint propagation module in order to ensure design consistency (Fig. 5). In the system, design variables are linked to constraints so that values for the variables can be effectively monitored to prevent constraint violations. When a value is assigned to a variable, the constraints propagation starts checking whether the assigned value violates any constraints.

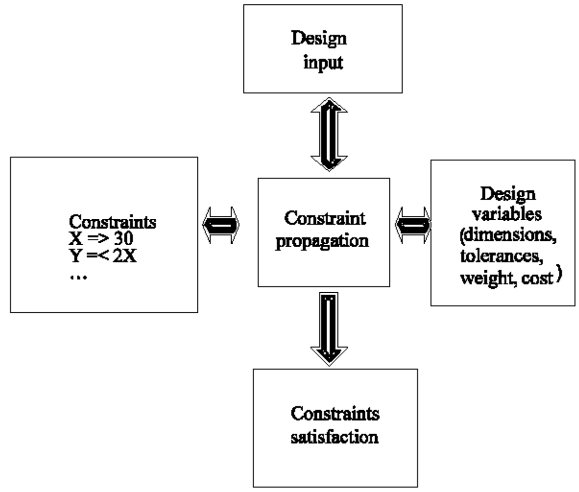

Fig. 5: The constraints-based system module

A valid solution is reached when all constraints are satisfied. When constraint violations occur, warnings are given to the user with some recommendations, which he/she has to take into account.

Constraints obtained from different knowledge sources, such as expert people, are formulated into rules, variables, values and domains. The proposed module covers most of the aspects of design and manufacture constraints including customer constraints, process constraints, machine constraints, part interaction constraints and tolerance and surface finish constraints. The constraint-based system module integrated with the consistency management module, ensures that there are no-violations in the system and that there is constraint satisfaction in the final design.

Consistency management module: The consistency management module manages the decision-making process and deals with conflict situations and justifies decisions made on designs. It includes a mechanism for detecting conflicts and gives warnings and explanations to the designer. This module applies an appropriate strategy for solving conflicts so that design consistency in the constraint network and design output can be achieved. The consistency management module also allows designer to take necessary actions to resolve conflicts and monitor design violations.

For consistency management propose model is presented in Fig. 6. The typical scenario which involved in the resolving the conflicts is presented in Fig. 7.

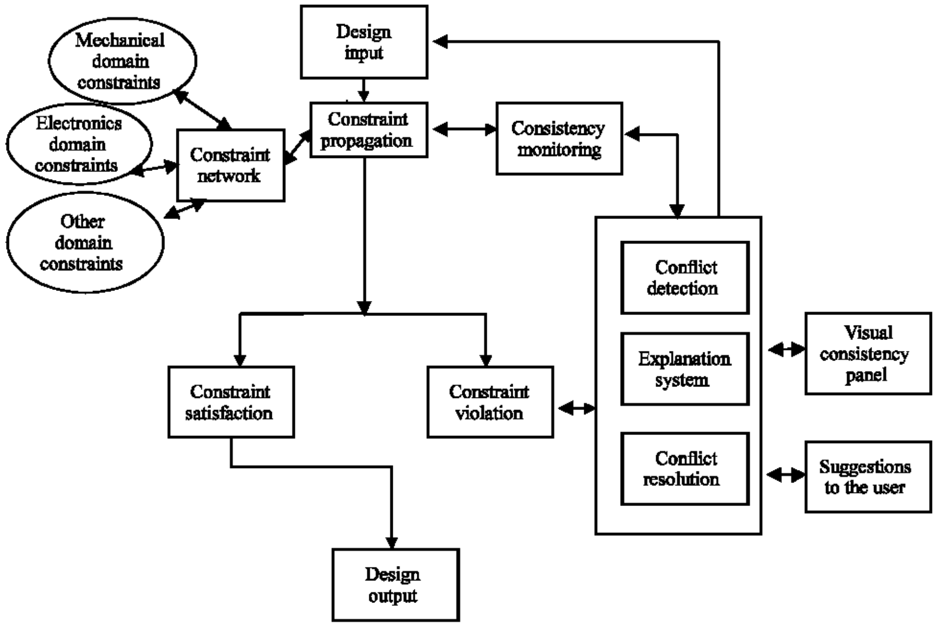

Fig. 6: The proposed model for consistency management

Designer :–

The system: -- Vibration may lead to a failure of that sensor. There have been some problems in the past designs.
I suggest that you should change the location.

Designer: -- Yes. Vibration might be big enough to cause the failure. Further analysis is necessary.

The system: – The motor you have selected is increasing the total weight of the system and it violates a weight constraint that should be no more than 250 g. There are some light weight standard motors. I suggest that you should choose one of them.

Designer: – OK. I think about that. How about dimensions of the printed circuit board (PCB)?

The system: -- The board dimensions are too big to fit the space allocated. You either make the space bigger or make the board dimensions smaller. But, you should not forget that the total weight of the system might change and it should be no more than 250 g.

Designer: –

Fig. 7: A typical conflict resolution scenario

Problems affecting electromechanical product design process: Electromechanical systems consist of moving parts and their size, weight and volume are important. They are also fundamentally 3-dimensional, which increases complexity and number of functions to be carried out. There are strong relationships between 3-D shape and functions, which are difficult to be described. In order to achieve the functions physical prototypes and various analyses should be utilized. Limited space allocated for them needs all items to be designed together in order to avoid side effects on their performance. Electromechanical design requires the combination of functions in complex parts to deal with space, weight and energy/power constraints. Therefore, electromechanical

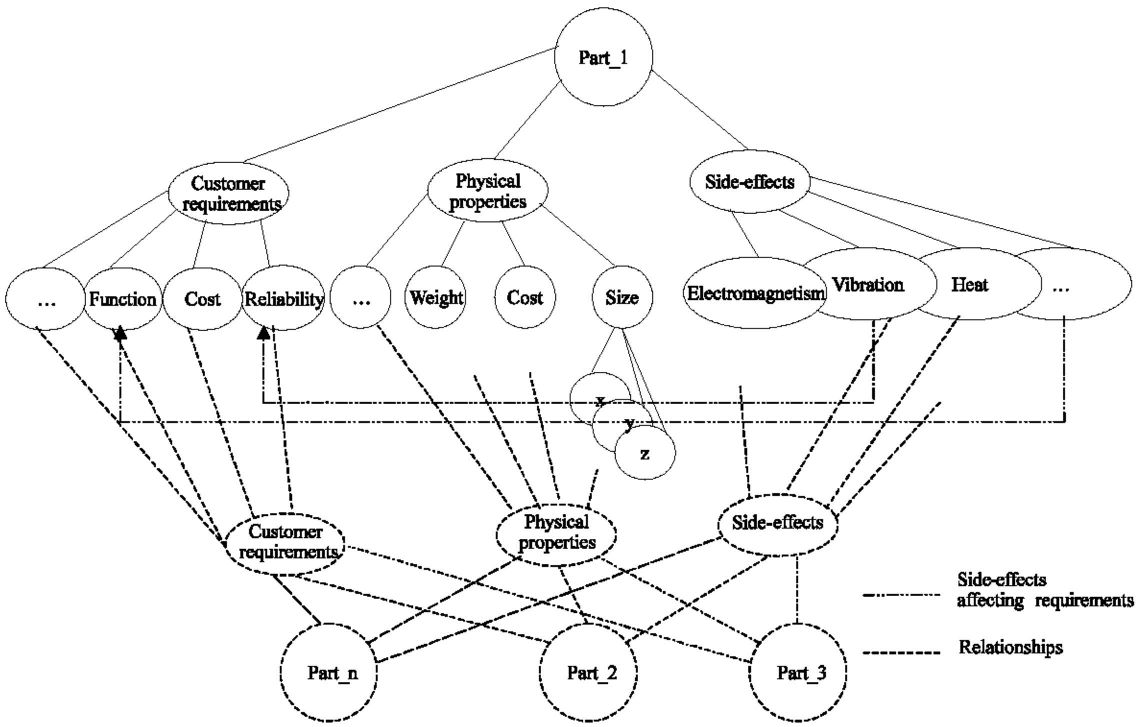

Fig. 8: Parts interaction and constraints network

systems design must be considered together with the design of individual components. Modeling of parts/sub-systems and their interaction which may affect the performance of a proposed system are shown in Fig. 8.

Knowledge elicitation: Several knowledge sources have been used to capture the knowledge necessary for the development of the system. The necessary expertise has been gathered through meetings and discussions with industry and academics. Expert knowledge has been modeled in terms of constraints, frames and production rules.

Knowledge representation and dynamic knowledgebase: The dynamic knowledgebase includes 3D CAD models of mechanical and electrical/electronic components in order to create and configure models of electromechanical systems easily. The knowledge-base consists of separate groups of data: CAD models, key characteristics of the items, attributes, part interactions and constraints imposed on variables. The CAD models represent real electromechanical components such as electric motors, PCBs and springs. The knowledge-base is dynamic and multi-functional, allowing the designers to enter newly designed components to the database and update them whenever necessary (Fig. 9). Advanced knowledge representation techniques such as constraints, production rules (if-then), object-oriented programming and frames have been utilized to model the expert knowledge necessary to develop the knowledge-base of the actual system. As an example, object-oriented representation of an electrical motor is shown as follows:

(electrical motor
with
(brand_name :Bosh) (power :6 W)(weight: 150 g) (cost: 3$)
(width: 30 mm) (length: 50 mm)(vibration: ... ...)
(electromagnetism: ... ...)
(heat_generated: ... ...) (.........................))

The developed prototype expert system: The integrated prototype system with its sub-modules has been developed and it is shown in Fig. 10. It consists of a number of interacting modules; a CAD window, a part record window, a database entry window and an evaluation window. The interfaces of the prototype software system has been originally developed in Turkish Language, however English translations are given whenever it is needed throughout the study.

In the developed system, systems and subsystem concepts are designed together and analyzed within the modeling environment to identify potential failures which

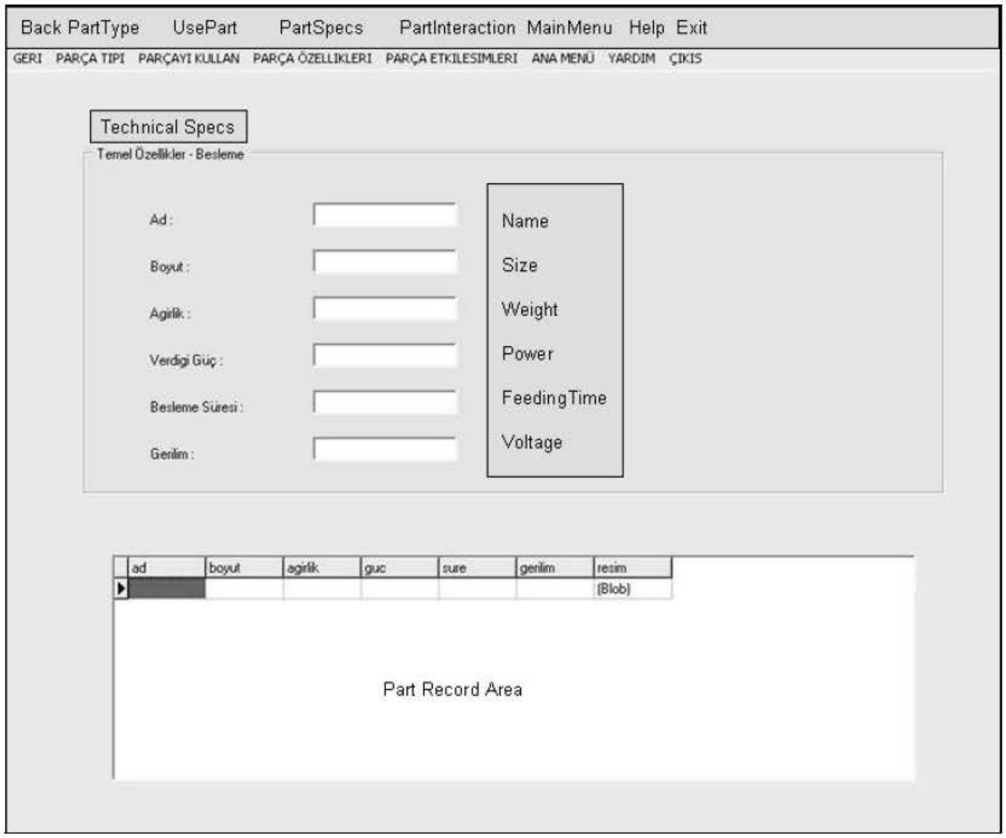

Fig. 9: A database entry for parts

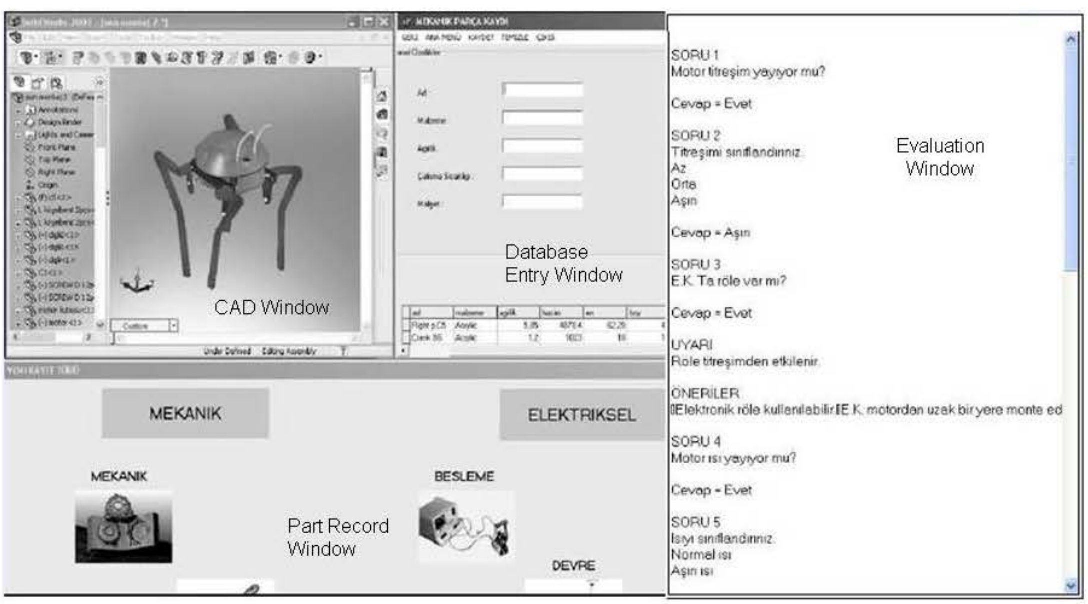

Fig. 10: The print screen of the developed prototype system and its sub-modules

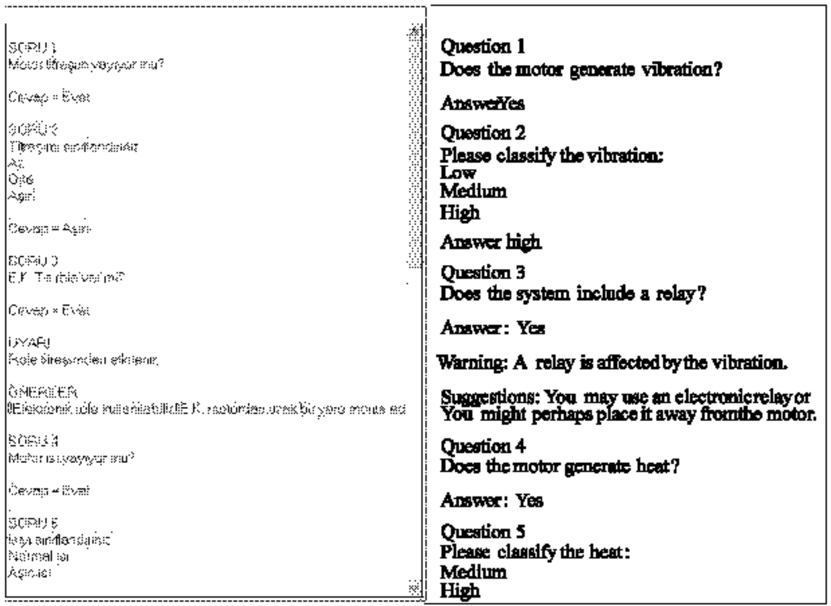

Fig. 11: A sample of the conflict resolution obtained from the system (English translation on the right)

may be caused by parts interactions such as overheating, electromagnetism or vibration to increase the quality of the design (Fig. 11). These interactions may lead to failure of nearby components or sub-systems. The system then generates some suggestions to the designers to improve the design from different points of view such as electronics. Subject to these suggestions the system user can make changes on the design if they are really necessary.

In the system, all components are defined in terms of their outputs, which are normally undesired and their failure conditions, measured in the same terms. For instance, an electric motor not only increases cost and weight of the product but also generates heat, has a magnetic field and causes vibration and these have to be taken into account by the designer.

CONCLUSIONS

In this research, a new intelligent cooperative product development approach has been proposed for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products subject to given requirements. The proposed approach has been implemented in a Delphi based environment integrated with a CAD system. The integrated prototype design system is composed of various interacting modules and assists designers from different disciplines in evaluating complex systems as far as parts relation, costs, weight and physical constraints are concerned in the early design process.

This helps the designers to avoid design iterations and conflicts leading to longer lead-time, hence increased cost. This system enables to rapidly develop new complex products within given critical constraints by preventing design conflicts. It has a very good capability for supporting the design of complex products during the conceptual design as it is a co-operative product development tool. Also, it has been developed in a way that the key characteristics affecting the system design during the conceptual design have impact on the downstream issues of the design process such as detail design and assembly. It could be used by the designers, who are located in different geographical areas, to create successful product design alternatives by taking the key characteristics into account in the early design stages. Conflicts arising between members of the design team at any level, are resolved by a negotiation based conflict resolution system based upon a key characteristics-driven process. This work is an ongoing research project, which aims to address all crucial issues of electromechanical product design, involving process design, reliability and assembly.

ACKNOWLEDGMENTS

This research is funded by the Scientific and Technological Research Council of Turkey (Tübitak) (Grant Reference No. 106M226). The author wishes to acknowledge the Tübitak and our partner organizations for their support.

REFERENCES

Bowen, J., 1997. Using dependency records to generate design co-ordination advice in a constraint-based approach to concurrent engineering. Comput. Ind., 33: 191-199.

Breedveld, P.C., 2004. Port-based modeling of mechatronic systems. Math. Comput. Simulation, 66: 99-127.

Campbell, M., J. Cagan and K. Kotovsky, 2000. Agent-based synthesis of electromechanical design configurations. ASME J. Mech. Des., 22: 61-69.

D'ambrosio, J., T. Darr and W. Birmingham, 1996. Hierarchical concurrent engineering in a multiagent framework. Concurrent Engineering: Res. Appl. (CERA), 4 (1): 47-57.

Diaz-Calderon, A., C.J.J. Paredis and P.K. Khosla, 1998. A modular composable software architecture for the simulation of mechatronic system. In: Proceedings of DETC, ASME 18th Computers in Engineering Conference, Atlanta, Georgia, USA.

Farr, R., A. Gayretli, H. Speller and N. Gindy, 2002a. A software tool for integrated electromechanical system design. In: Proceedings of 2nd International Conference on Responsive Manufacturing, Turkey, pp: 574-580.

Farr, R., A. Gayretli, H. Speller and N. Gindy, 2002b. Collaborative development using EMProDS: The electromechanical product design system. J. Eng. Manuf. Part B, 216: 453-457.

Gayretli, A. and H. Abdalla, 1999. A prototype constraint-based system for the automation and optimisation of machining processes. J. Manuf. Part B, 213: 655-676.

Gayretli, A., R. Farr, H. Speller and N. Gindy, 2001. A product development tool for integrated electromechanical product design. In: Proceedings of 7th International Conference on Concurrent Enterprising BICE 2001, Bremen, Germany, pp: 37-44.

Gayretli, A., 2005. Constraint-based conflict management in a cooperative design environment. Technol. Res. EJMT., 3: 1-9.

Gayretli, A., 2007. 2ODE-IPD: An object-oriented design environment for robust and reliable interdisciplinary product design. Key Engineering Materials (KEM), 348-349: 457-460.

Gupta, S.K., C.J.J. Paredis, R. Sinha, C.H. Wang and P.F. Brown, 1998. An intelligent environment for simulating mechanical assembly operation. In: Proceedings of DETC, ASME Design Engineering Technical Conferences, Atlanta, Georgia, USA.

Hayes, C.C. and C.S. Su, 1995. Using a manufacturing constraint network to identify cost-critical areas of designs. Artificial intelligence for engineering design. Anal. Manuf. (AI EDAM J.), 9: 73-87.

Hsiao, S.W., 1999. Integrated concurrent engineering based approach for electric-fan design. J. Integrated Comput. Aided Eng., 6 (3): 171-187.

Porter, I., J. Counsell and J. Shao, 1998. Schemebuilder mechatronics modelling and simulation. Technical Report, Engineering Design Centre. Lancaster University, Lancaster, UK.

Wang, F.C., P.K. Wright and B.C. Richards, 1996. A multidisciplinary concurrent design environment for consumer electronic product design. Concurrent Engineering: Res. Appl. (CERA)., 4: 347-359.