DESIGN AND PROTOTYPING A WIRELESS AUTONOMOUS GUIDED VEHICLE IN UNDERGRADUATE MECHANICAL DESIGN PRACTICE

Jhy-Cherng Tsai[1] *and Guo-Jen Wang*[1]

Abstract *— This paper describes a team of juniors, major in mechanical engineering (ME), to design and prototype a wireless autonomous-guided vehicle (WAGV) in a project-oriented mechanical design and practice course. This course is intended to give students hands-on experience in mechatronics as it plays an important role in modern product design. The WAGV is a typical example of mechatronics device as the vehicle itself is a mechanical device but controlled by electronics through wireless communication. Although it is a highly challenged target for ME-majored juniors to design, fabricate, and integrate such a WAGV in a two-semester course, students are encouraged to study related knowledge and try different design possibilities to complete such a difficult, or impossible, mission through teamwork. A team of five students is requested to complete the process of technical survey, design and analysis, parts fabrication, assembly as well as testing and refinement -- both mechanical and electrical, of a WAGV under limited time and budget. The WAGV is driven by a DC motor, steered by a stepping motor with a set of worm and gear, and controlled by a remote computer with commands sent via radio frequency. Students are not only highly appraised at the semester-end exhibition, but also fill with confidence in mechatronics after completing this course. This achievement suggests that students do have the potential to achieve difficult, or impossible, missions through a well-designed course with teamwork.*

Index Terms — *mechanical design and practice, mechatronics, undergraduates, wireless AGV.*

INTRODUCTION

Manufacturing industries, in particular electronics- and computer-related industries, are the fastest growing and most prosperous industries in Taiwan. One of the reasons is that industrial infrastructure is well implemented and efforts on engineering improvement are encouraged. This situation results in that OEM (original engineering manufacturing) has been one of the most important businesses in this country. While looking ahead, industrial and governmental leaders foresee that manufacturing and fabrication industries, though they are the most profitable industries at this point, will not last long as near-by countries are also promoting similar industries and strategies with better benefits for investors. One of these leaders' conclusions is that product design will be one of the key industries and needs to be stressed on in order to transfer from current industry status to a more competitive position in the next decade.

Product design, however, needs both vertical integration of different phases of product lifecycle, and horizontal integration of related technologies. Industries, though handy in manufacturing and fabrication, are often lacking of creative idea and basic supporting theoretical background. This is one of the critical issues for the transformation from current fabrication-oriented industries to design-oriented industries.

As technologies for product design and manufacturing change and improve very fast in the past decades, product life cycle is thus dramatically reduced. While college graduates are the most important source of higher-level manpower for industry in Taiwan, engineering college students are expected to be sharpened with product design and manufacturing knowledge at school, in addition to theoretical analysis capability. This is an important issue in particular when industry faces the increasing competition in the global marketplace nowadays. It is obvious that college curriculum and courses must be designed to meet this challenge in order to lead students to become productive engineers in their future[1,2].

However, it is still argued that what should an ME-major student should learned at school? In other word, what an institute should provide to students, including theoretical and practical training as well as environment to stimulate students' interests and creativity, during his/her stay at college. This is even a more challenging issue that has been discussed [3,4]. Conventional manufacturing industries ten years ago in Taiwan are still labor-intensive, though their manufacturing and fabrication technologies have been worldwide famous, and insufficient to face the competition in the global manufacturing marketplace. The government has noticed in the early 1980s that automation technology will play an important role in improving this nation's industrial competence. A nine-year three-phase nation-wide program on developing automation technologies has been formed since then to improve the productivity of industry by transferring labor-intensive industries into technology-intensive and capital-intensive industries. Under this program, educational institutes have stressed on training students with automation-related knowledge and technologies. Several curriculums on automation technologies, such as mechatronics, information technology,

[1] Department of Mechanical Engineering, National Chung-Hsing University, Taichung, Taiwan 402, R.O.C.; Tel:(+886)4-22840433; Fax:(+886)4-22877170 jctsai@mail.nchu.edu.tw; gjwang@dragon.nchu.edu.tw

computer-aided engineering, manufacturing process automation and office automation, have been formed and taught at engineering colleges in the past decade. Among these technologies, mechatronics is one of the most difficult technologies as it combines mechanical, electronic, and information technologies. It is a key technology in modern product design as a product often combines both mechanical and electronic functions to make itself intelligent and smart. However, students majoring in electric or electronic engineering often pay less attention on mechatronics partially because that they usually have difficulty to get into the depth of mechanical-related knowledge and technologies. On the contrary, students majoring in mechanical engineering often treat mechatronics as an advanced course as it involves electronics, sensoring and signal processing, as well as control and software or firmware engineering. As a result, very few undergraduates are trained with mechatronics in class that in turn makes them even difficult to try mechatronics-related jobs in their career. This reflects that it is a critical issue for an institute how to efficiently and effectively teach undergraduates mechatronics.

From our point of view, a mechanical engineer should equip himself/herself with the knowledge on how to translate engineering problems and demands into design analysis, and prototyping. Students at school are supposed to learn the process and methodology related to integrating and to testifying the entire process. This is part of the training to let students understand how to apply the knowledge and techniques learned in class to practical problems. A curriculum based on this concept has been implemented in the Department of Mechanical Engineering at the National Chung-Hsing University such that a series of "Mechanical Design and Prototyping Projects" (MDPP) were organized to offer students to explode project-oriented practical problems. These courses emphasize on hands-on practical training of mechanical design and prototyping processes in addition to theoretical analysis training [5]. These hands-on training processes are expected to stimulate students' creativity and cumulate related knowledge in the learned process. It is also one of the goals of the MDPP courses that experience interchange through industry-supported projects will provide students with more practical experience besides theoretical training in the college. Students are also expected to learn the methodology and attitude of teamwork through these processes.

This paper describes a mechatronics project completed by undergraduate juniors major in mechanical engineering. It is one of the projects developed in the class "Design and Prototyping of Automated Systems" (DPAS) in the MDPP program. While students enrolled in this class are clustered into different teams for different projects, a five-students team is formed to design and to prototype a wireless autonomous guided vehicle (WAGV), an unmanned vehicle commonly used in manufacturing and office automation. They have to combine their knowledge in mechanical design, analysis, machine shop, electronics, sensoring and control, information technology, and, of the most importance, their creativities to complete a prototype of the WAGV. In the following sections, the MDPP program and the design of the DPAS course is then introduced as the project-oriented class is conducted in a different way from regular class. Methods applied to the class to bring teamwork, creativity and to achieve the prototype are then discussed. Implementation and progress of the AGV project is then reported. The paper then gets into more detail of the design and prototyping process of the AGV followed by the conclusion and discussions.

COURSE DESIGN

As it has been reported, such as in [6] and [7], that project-oriented hands-on class often gives students more solid training and better understanding. The MDPP courses are organized in such a way that project-oriented classes are offered to ME-major juniors as they have completed basic required courses and certain advanced design and supporting courses. The courses are designed in such a way that students learn the process and related methodologies in mechanical design with hands-on experience and get an idea how to apply what learned at school to engineering problems. The MDPP series of projects were first offered at the department in 1995. The DPAS class has been designed as one of the series of MDPP with emphasis on mechatronics since then [8].

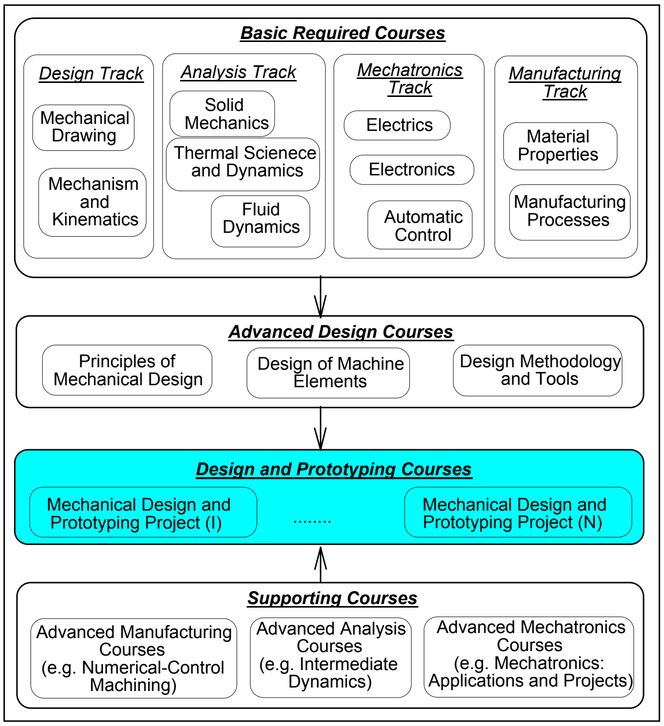

FIGURE. 1
COURSE DESIGN OF THE MDPP PROJECTS[11].

As it has been noticed that project integration and teamwork can stimulate students' creativity and achieve a better result [9,10], students enrolled in the MDPP project are required to join a team, usually 3-5 students. As the projects are offered to juniors, students have completed basic required courses, as shown in figure 1, and some advanced design courses. It is therefore not too difficult to ask students to apply what they have leaned in their freshmen and sophomores to the project [11].

The DPAS is one of the MDPP courses to offer students projects on design and prototyping mechanical systems or sub-systems based on automation technologies. Typical knowledge and technologies include computer-aided design, mechanism design, sensoring and control, system integration, and information technologies. Students in the class are required not only to develop the mechanical and electronic sub-systems, but also to use their creativity to think about possible applications of the developed systems. Students are teamed up and required to design and to prototype automatic systems based on their own designs, but not just paper work. They are required to define their target and then taught how to search related information and to do analysis in order to complete design and to implement their goal. Each student from each team is required to deliver a weekly progress report and/or demonstration of their project. This has shown a great success in tracking each project.

Projects completed in the DAPS class include prototypes of a computer controlled Automatic Storage/Retrieval System (AS/RS), a rotary type storage system, an electric elevator, an anonymous guided vehicle, and an electricity-powered motor vehicle. In this paper, we use a wireless AGV project completed in 2001 as an example for discussion.

METHODOLOGIES

As students have limited hands-on experience on implementing their design that often needs to be modified again and again until it becomes practical. The MDPP course provides a one-year long step-by-step process. To have students learn related knowledge and technologies efficiently, approaches employed in this series of courses include learning by doing, teamworking, brainstorming, and divide and conquer [11]. It has been reported that this approach is quite successful for training undergraduates with hand-on experience. The series of courses are also highly praised by students as they do learn how to apply knowledge in class to prototyping a device and/or methods for stimulating creativity and teamworking together.

- **Teamworking**: As a yearlong project consists of many working items to be completed by team members, students are required to share the load among the team. It is often suggested that students form their own team with a team leader. Working items are shared by sub-teams using matrix organization, such as mechanical, electronic, control, and integration sub-teams. It was observed that this is a key to a successful project.

- **Brainstorming**: Brainstorming is one of the most often used methods in the class as it is usually a plus that brings together team members' crazy idea and discussion for more practical. This method is applied at the first five weeks as students are encouraged to discuss what their project goal is and how to achieve it. Students conducted extensive literature survey as well as brain storming to bring their idea firm. With the experience, they learned how to take the advantages of brain storming whenever they face problems in the yearlong project period. It was observed that this is one of the most powerful tools, together with teamworking, students leaned in the course.

- **Divide and conquer**: While students have very limited practical experience in conducting a project, the course asked them to divide and conquer problems/goals in the process. For example, each team is required to write a proposal at the fifth week with solid specifications of their project, detailed working items, working sub-teams, time schedule, resources required and financial plan. The proposals are returned to students with comments and suggestions from advisors/lecturers. A refined proposal must be handed in after three weeks. With the process, students learned how to divide a project into different phases and how to plan resources to achieve the goal at each stage. Each team member has to make a formal weekly report and presentation in turn so ensure each member keeps itself on the track. Once the schedule was delayed, team members must make it up to keep up the schedule. This method, again, demonstrated itself a very effective way for project management.

It has been observed that the above mentioned methods did bring a team to a successful project. Students also leaned these methods, implicitly, through leaning by doing. In the following section, the detailed process and contents of the WAVG project is demonstrated and discussed.

DESIGN AND PROTOTYPING A WAGV

The WAGV project is a continuous project with wireless communication and improvement on the hardware of a previous AGV project. While an AGV needs a local processor to control the vehicle, it bothers us in previous project that a portable PC is required in the AGV to serve as the processor. A WAGV differs from common vehicles in the guidance system as it is autonomously guided though the sensoring and control system with control signals communicated wirelessly. It consists of both hardware and software that involves in mechanical, electric, electronic, information technologies. The hardware includes the mechanical structure of the vehicle and the power transmission system as well as electronic hardware for sensoring, control, and communication. These two parts are integrated by the control system driven by control schemes, coded in software. Communication between the WAGV and computer at control station is wireless so that it can monitor and control the AGV.

The design process includes the following steps: survey and define functional specifications, conceptual and functional design, detailed engineering design, manufacturing and assembly planning, material preparation, parts machining and components purchase, system assembly, sensing and control assembly, system integration, adjustment and refinement. For readers who are interested in the detailed process of an AGV, please refer to [12] for detailed design and prototyping process. We briefly discuss some of these steps in the following subsections with emphasis on wireless communication.

Survey and Define Specifications

As the first step in product design is to form the problem, we started this project by some introduction material including the function and applications of AGVs in automated systems. Some functional specifications, hardware and key characteristics are also hinted and suggested. While we keep the approach "learning by doing" in mind, several literatures, references, magazines, and videos are suggested or requested for students to read or watch as a survey. Although this is the first project these students ever experienced, they showed no fear to face the challenge.

Conceptual and Detailed Designs

Based on the functional specifications, different possible structures and mechanisms that satisfy functional requirements are brought to class for discussions. The structure of the AGV was first sketched and brought to discuss in the class. It was then revised based on comments and suggestions from project advisors and other classmates. This is intended to let students understand the design loop from functional specification to concept sketch, to functional check, to design for manufacturability and assembly check, and design revision. The structure of the first draft is not determined until functional specifications and evaluations are checked. This stage, from our experience, usually requires four to six weeks as students' concept is solidified during this stage.

The team, together with project advisors, then specified the primary function, mechanical structure, the driving system, the sensing and control system, and communication schema step by step. A draft design, based on the above specifications, is then decided after brainstorming several times. Figure 1 is a conceptual draft of the structure that is composed of steel frames and two guidance sensors are located in the front of the frame. The vehicle is driven by an DC motor and steering with a set of worm and gear, driven by a stepping motor, in order to provide sufficient torque.

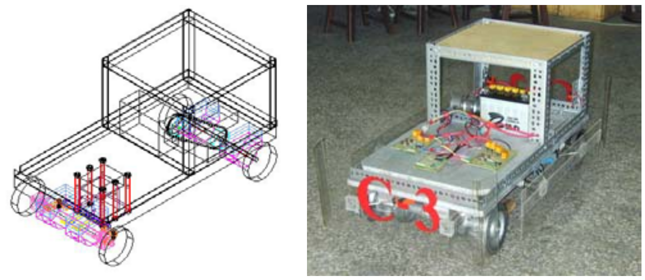

FIGURE. 2
CONCEPTUAL DESIGN (LEFT) AND FINAL PROTOTYPE (RIGHT) OF THE WIRELESS AGV.

Detailed design analyses are then conducted that includes structure strength analysis, friction and transmission system analysis, efficiency and power analysis, manufacturing and assembly analysis, resource planning, time and cost estimation. This is the standard training for engineering students so students feel comfortable and learned how to apply knowledge learned in class to this project. Engineering drawings, including parts, sub-assemblies and assemblies, are then prepared using CAD system as design changes are expected in the following phases.

Although control schema and sensing system of this vehicle are designed, the difficult part for ME-major students is the wireless communication between the control computer at the control station and the vehicle. Infra Red (IR) is relatively simple and economical and was first considered. However, IR is easily blocked if there exists barrier between the emitter and the receiver. We consider another option to use radio frequency (RF) as the signal carrier because of it provides good diffraction and bandwidth, though it is even more difficult to design and to implement.

The detail design phase is a time-consuming process. As design is a trade-off among different aspects thus design change is common after design analyses and evaluations. It is common that students spend two months in the detail design and analysis process because they are not familiar with the problems they faced, nor are they handy to apply knowledge in the engineering problem. Figure 3 is an example of the control circuit for the steering system. The circuit consists of four sets of amplifiers that amplify exciting current to control the forward and reversed rotation of the stepping motor. The current is driven by the control signal that comes from the control computer via an 8255 interface, encoding schema, RF transmitter, RF receiver, and then decoded at the vehicle.

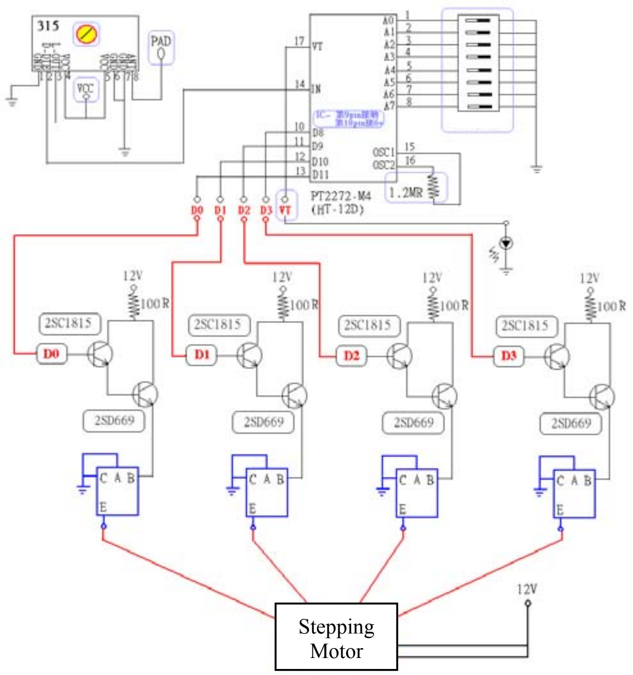

FIGURE. 3
CONTROL CIRCUIT OF THE STEERING SYSTEM.

Parts Preparation and Assembly

As each project has limited budget students themselves machine most parts, unless the precision are too high to reach for machine tools in the departmental machine shop. Students are requested to prepare material in this case. Some commercially available components are directly purchased, often from used parts market to save money. This is another training for students to understand how to achieve their goal under limited resources.

The WAGV system is then assembled at the same time when parts and components are prepared. This is also part of the training for students to get some feelings on the "concurrent engineering" technique. Figure 4 is a snapshot in the assembly process that two students are testing the driving system, another was working on the wiring of circuits. The RF transmitter and receiver, located in right front, are designed and made by students themselves.

System Integration

The sensing and control systems are designed and assembled after the design and assembly of the mechanical structure. As this WAGV is remotely controlled, it does not consist of trivial guidance system in the first version. System integration to bring both hardware, including mechanical, electrical and electronic devices, and software together is conducted when subsystems are completed. The most difficult part in the integration is the mechatronics interface between those devices and firmware. Students, however, did a good job to conquer problems based on their knowledge as well as on help from other experts.

FIGURE. 4
STUDENTS WORKING ON THE ASSEMBLY OF THE VEHICLE.

System Testing and Refinement

The assembled system must be testified against the specifications. This is often in the final stage close to the end of the one-year project-oriented class. However, this process is always required though students are sometimes kind of frustrated after the whole-year long project. Therefore a semester-end exhibition is designed in the MDPP classes that all projects must show their work at the end of the class. Students are forced to do the test and adjustment otherwise they are unable to demo their yearlong achievement.

FIGURE. 5
TEAM MEMBERS AND THE COMPLETED WAGV.

Figure 5 shows the team member and the completed prototype of the vehicle. The WAGV project won one of the three best achievement awards at the exhibition. We observed that students usually did more work efficiently during the week before end-semester. It is very common that students modified their designs in the final stage. This is partially because that they are now very familiar with their project and feel comfortable to make a quick change. This is part of the goals of the MDPP classes as students are more confident after completing their project by the end of academic year.

CONCLUSION AND DISCUSSIONS

While ME-major undergraduate students are not familiar with mechatronics, this paper described the design and prototyping of a wireless AGV that requires intensive knowledge in mechanical, electric and electronic, and information technologies. This two-semester project is conducted by a team of five juniors major in mechanical engineering. The philosophy and methods employed in the course including "learning-by-doing," "teamworking," "brainstorming," and "divide and conquer." It was observed that these are among the key issues to a successful project, in particular collaboration in a team. This project-oriented class has been proven a great success that students are trained not only to complete semi-industrial projects with their own design but also to learn the methods and skill for teamwork and brainstorming. We also find this is an economic way to train students as the total material cost for such a project is less than NT$10,000, corresponding to US$300.

As mentioned previously that this project is a continuous efforts. The ongoing project currently offered is trying to implement a self-positioning system via a 2-D camera. Students are asked to plan working items and schedule when the first draft design is completed. This is to remind them how many work in the following process and how much resource, including budget, manpower, and time they have. As these items often become critical issues when they face industrial projects. We also learned from queries that students did appreciate this kind of training. We would like to share our experience in this paper as many institute and universities in Taiwan now noticed that students need hands-on experience in undergraduate.

ACKNOWLEDGEMENT

The authors wants to give credit to the five-student team that completed the WAGV and was recognized as one of the best achievement projects at the final project exhibition. They are Mr. Jen-In Chen, the team leader, Mr. Jen-I Chi, Mr. Zhen-Mou Chen, Mr. Chin-Shun Chen, and Mr. Hen-Chung Pao. The authors also want to express our gratefulness to colleagues at the Department for their support on the DPAS class. Funding for this project has been supported by the department and partially by the Precision Machine Tool Industry-Academic Alliance, funded by the Ministry of Education of Taiwan, R.O.C.

REFERENCES

[1] Gordon, B. M., "Engineering education – a start towards making it right," *Proceedings of Electro/86 and Mini/Micro Northeast Conference*, 1986, pp.5.2.1-5.2.5.

[2] Atherton, D., "Engineering education and future industrial needs," *Measurement and Control*, Vol. 23, No.6, 19990, pp.164-173.

[3] Inelmen, E., "Refections on enhancing the quality of engineering education, " *Proceedings of the ICEE2001*, 2001, paper No. 247

[4] Smerdon, E. T., "New roles for engineering faculty," " *Proceedings of the ICEE2001*, 2001, paper No. 458.

[5] Tsai J.-C. and Chein, R., "Curriculum improvements on mechanical design practice for college mechanical engineering education," *Proceedings of ICEE1995*, 1995, pp.315-322.

[6] Hoole, S. S. H., "Engineering education, design, and senior projects," *IEEE Transactions on Education*, Vol. 34, No.2, 1991, pp.193-198.

[7] Bianchi, R. A. C. and La Neve, A., "The influence of final course projects on the early engineer's professional life," *Proceedings of the ICEE2001*, 2001, paper No. 252.

[8] Tsai, J.-C., Wang, G,-J. and Chiou, S.-J., "Teaching undergraduate mechatronics in mechanical design," *Proceedings of ICEE1999*, 1999, paper No. 242.

[9] Bordogna, J., Fromm, E. and Ernst, E. W., "Engineering education: Innovation through integration," *Journal of Engineering Education*, Vol. 82, No.1, 1993, pp.3-8.

[10] Koehn, E., "Engineering education utilizing collaborative learning," *Proceedings of the ICEE2000*, 2000, paper No. WB8-3.

[11] Tsai, J.-C., Chein, R., Chen, T.-Y. and Wang, G.-J., "Trail of a college curriculum in mechanical design and prototyping," *Proceedings of the 1st UICEE Annual Conference on Engineering Education*, 1998, pp.73-77.

[12] Tsai, J.-C. and Wang, G.-J., "Prototyping an autonomous guided vehicle in undergraduate mechanical design," *Proceedings of ICEE2000*, paper number WD1-5.