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Development of Mechatronic System Integration Course for Senior Students in Mechatronics Engineering at the University of South Australia

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BACKGROUND

The courses of Mechatronics I (EEET 2044) and Mechatronics II (EEET 4060) have been offered with two separate curricula in School of Advanced Manufacturing and Mechanical Engineering, and the School of Electrical and Information Engineering at the University of South Australia since 1996. In Mechatronics I, students study the fundamentals of mechatronic systems aiming to identify and determine the key components of mechatronic systems. They also are involved in a group project to design and manufacture pseudo intelligent object avoidance and path following mobile robot. In the subsequent course of Mechatronics II, the concepts and skills of mechatronics are further extended with aims at raising the competency level in designing and implementing mechatronics systems involving the mobile robot system. However, within these two courses students would not become adequately familiar with the relevant practical industrial mechatronic systems. Hence, it was decided to introduce a new course; Mechatronic System Integration (EEET 3044) with the aim of developing a sense of systematic approach to solve industrial mechatronic problems for the students.

PURPOSE

The major reason of investigation in this paper is to develop a systematic approach to introduce what an industrial mechatronic system is comprised of and how various electro-mechanical components can be integrated and work together. This is beyond what they have learnt before, since this course offers an opportunity to make a link between class room theory and industrial practice. It is also aimed to facilitate the graduates' transition from university as a student to industry as an engineer with focuses on their communication and technical skills.

DESIGN/METHOD

A new curriculum has been developed in association with replacing the existing mobile robot development projects by the Modular Production Systems (MPS) which was purchased from FESTO including distribution, testing, and storing stations. The MPS system was selected as part of this course after intensive search, visit and discussion on mechatronic laboratories at a number of universities including Queensland University of Technology (QUT) and Curtin University.

RESULTS

By implementing this course, students are expected to be more familiar with real industrial mechatronic systems and equipped with the ability to combine several modular systems into a whole integrated system, in conjunction with being able to incorporate a range of industry standard equipment and components. Also, through a continuous lab logbook practice during the course, students will be able to communicate effectively with others, which is at the core of what will be required as a professional engineer in their future career development.

CONCLUSIONS

The new developed course for senior students in Mechatronics at University of South Australia will allow the students to be versatile with identifying, integrating, and debugging a large scale mechatronic system encompassing three significant tasks frequently used in industry with substantial development of their multi-disciplinary knowledge in mechanics and effective communication skills.

KEYWORDS

Mechatronics, engineering education, system integration, engineering practice.

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Abstract

This paper presents the design and development of a third year level course, “Mechatronic System Integration” in the Mechatronics streams both at the Schools of Advanced Manufacturing and Mechanical Engineering, and the School of Electrical and Information Engineering in the University of South Australia (UniSA), Australia. Currently, most courses in Mechatronics stream in UniSA are mainly focused on comprehensive theoretical fundamentals with some minor hands-on practice with focus on electrical aspects of the Mechatronics. The lack of integration of real industrial equipment and software with practical industrial applications had imposed a significant weakness which resulted in design and development of this new course. This paper describes the detailed contents of this new course with inclusion of real industrial equipment in its teaching methodology, in particular manufacturing simulation stations, provided by FESTO, aiming at practical integration of the whole system using programmable logic controllers (PLCs) and supervisory control and data acquisition (SCADA). The lecture components of this course will provide the fundamental theories on design principles of mechatronic systems, pneumatic systems, large scale system integration, system interface, PLC and SCADA. On the other hand, in a series of hands-on lab sessions, students will develop and implement an industrial manufacturing system consisting of distributing, testing and storing stations provided by FESTO. This will include extensive involvement of design of sequence control, integration of sensors and automated pneumatic, electrical and mechanical mechanism, and demonstration of such system with appropriate software. This course will be delivered for the first time in study period 5 in 2012, therefore, the full comprehensive evaluation and feedback is not available yet. However, the initial feedback from the students indicated that the course is well accepted from the student.

Introduction

According to the statement in Centikunt (2007), Mechatronics consists of the synergistic integration of three distinct traditional engineering fields for the system level design process: Mechanical Engineering (represented by the word ‘mecha’) Electrical or Electronics Engineering (represented by the word ‘tronics’) and Computer Science. This entails horizontal integration of various engineering discipline along with vertical integration between design and manufacturing. Also, Auslander (1996) believes that the exploitation of computers to generate systems makes mechatronics unique with respect to any qualitative disciplines that have come before. He explained how the definition of mechatronics to be broadened due to the advent of the computing as the preferred decision making medium.

For the last few decades, the mechatronics education has expanded with evolution into multi-disciplinary courses offerings to specialise mechatronics curricula development (Acar, 1997; Grimheden and Hanson, 2005). From the recent communications with industry, however, it is clear that a course in Mechatronics must include how the mechatronic system design to be implemented into real industrial applications with emphasis on system level understanding and integration reflected on the fundamentals and basic tools across multiple engineering disciplines.

At UniSA, up to 2011, two separate streams of Mechatronics in the bachelor degree level have been offered: Mechanical and Mechatronics Engineering, and Electrical and Mechatronics Engineering. Due to the strategic re-alignment of program in Mechatronics

Engineering, the university has decided to implement a Bachelor of Mechatronics Engineering program from 2012. One of the major changes due to this is the replacement of the current courses Mechatronics I (EEET 3008) and Mechatronics II (MFET 4060) with two more industry related practical courses of Mechatronics System Integration (EEET 3044) and Autonomous Mechatronics System (EEET 4070). According to the students' evaluations, aside from strengths of the current two courses, the students have never gained a proficient insight into integrating various mechanical, electrical, and software components into real industrial applications. The other main issue was a lack of systematic disciplinary educational approach from both teaching and technical staff to help the students to complete their project on time. Basically, the teaching was far too theoretical which is sometime not relevant to the practicals that need to be completed in a short time frame. The new Mechatronics System Integration course was developed to address these main issues by introducing integration of industrial automation systems, an organized and systematic teaching, and practical assistance for the students to efficiently gain the fundamental knowledge and skills to achieve it.

Related works

The multi-disciplinary notion of mechatronics raises some issues in terms of coordinating the three engineering mechanical, electrical and computer science. One of main goals of mechatronic courses should be to broaden the engineering perspective and eliminate the technical barriers between different engineering disciplines by encouraging combined problem-solving approaches with some forms of practical integration of industrial systems (Jenkins & Nagurka, 2004). Stojanovic (2009), described how an existing course in mechatronics curriculum in University of Novi Sad in Serbia was modified to encompass modern equipment by connecting Physics, fundamentals of Electrical Engineering, and Materials in Mechanical Engineering to engineering applications. Introducing a modern approach and advanced educational methods, the teaching methodology was improved through using in-class discussions and audio-visual equipment. It was observed that the developed lab activity was used to quantify only electrical parameters. Hsu (1999), at University of San-Jose, USA developed a curriculum stand in mechatronics system engineering at the undergraduate level. Three significant factors that contributed to establish this program can be categorised as: increasing demand for engineers with multi-disciplinary skills and knowledge by industries, generating a model to develop inter-engineering programs disciplinary based on the emerging technologies, and fulfilling the demand for human resource supply to the Silicon Valley high technology industry. Consequently, through this curriculum development three-pillar concept was evolved: the fundamentals of mechatronic systems engineering, the hands-on laboratory experience and the application of the fundamentals of Mechatronic systems engineering in design and manufacture in specific industries. These three pillars are important aspects of any Mechatronic engineering courses to be equipped. The main objective was to create control laboratory and open-ended project course in which students work on group project to design and implement the smart product. As it was observed, the hands-on projects were more related to control architecture than industrial applications. In a more recent paper (Kulic & Croft, 2006) the authors have implemented a similar structure into a course in the department of Mechanical Engineering at University of British Columbia. The objective of the course is to give students theoretical and practical experience with large-scale mechatronic system integration. In the lab activities, the students design and implement a part-sorting system which is progressively built in complexity. They also, developed the interface for communication between PLC unit and the LabView through DeviceNET network. In order to make the most out of the limited time of one semester, students are provided with the mechanical components of the system. In this way, they would be able to focus on sensor selection and placement, control and process algorithm development, and integration. This is one of a few examples of mechatronics lab activities that covered control architecture. However, the graphical user interfaces (GUI) used in this project is only limited to LabView and DeviceNet which is in contrary to the diverse types of programming languages available in most GUI devices. A similar approach was developed at Philadelphia University of Jordan with emphasis on regional needs (Tutunji, Jomah,Saber & Rabbo, 2007). In the more junior level courses, hands-on practical aspects of mechatronic systems are implemented as an introduction of different disciplines of engineering, where students learn to analyse, design, and build two mechatronics devices, CNC machine and a Tech arm robot. It was noted that their projects were based on lab based control applications rather than industrial one. Castles and Lohani (2010) have acknowledged the introduction of mechatronic module in the first year of engineering program in Virginia Tech. USA. The module includes a two-part hands-on activity involving the assembly of a gearbox and building a motor-driver circuit for a two-wheel robot. These are single-microprocessor based projects rather than control architectures commonly used in industry. Zamani (2009) described an introductory course on mechatronics in Mechanical Engineering department at the University of Windsor, Canada. The lectures concentrate on the microcontroller architecture and programming by PBASIC, and the lab activities were about using experimental kits ranging from process control to the toddler robot kit, in association with microcontroller characteristics covered in the lectures. Their course lacks assigning large scale practical industrial projects to the students.

After a brief literature survey, a clever design of course contents with combination of three important aspects was found as the most essential part of mechatronic course development. They include a comprehensive coverage of theoretical fundamentals to equip the graduate with the necessary knowledge and skills needed for the industry, systematic lab hands-on activities for in-depth knowledge in analytical experimental and computational hands-on skills for different engineering disciplines, and the integration of systems for skills and knowledge to analyse, design, implement and maintain fully integrated practical industrial system. Keeping these three aspects in mind, the new Mechatronic System Integration course is developed, especially with a systematic integration, efficient network communication and effective control using PLC and SCADA. It is intended for the students to have ultimate experiences in various control architectures, modelled on large-scale industrial mechatronics systems.

Course development process

The current Mechatronics I and Mechatronics II courses offered in UniSA are focused on the development of a mobile robot platform to achieve a designated task including target search, and trajectory design with obstacle avoidance. These two courses are developed as project-based learning approaches with student oriented learning. Over the last 10 years, these two courses have been compulsory for a bachelor degree of Electrical and Mechatronic Engineering. Since 2008, they became compulsory for the Mechanical and Mechatronic Engineering degree. Since then, the courses are delivered to a cohort of students from electrical and mechanical engineering. Due to this, an urgent need for the modification of Mechatronic education stream has emerged with two major issues: systematic educational supports for two different engineering background students, and design and implementation of integrated system with industrial practical applications. In addition, the survey indicated how Mechatronic courses in Mechanical Engineering tend to focus on modelling, controls and electronics specifically micro-controllers; while, those in Electrical Engineering inclined to concentrate on the development of mobile robot platform with object oriented programming. Many courses are run in lecture format with modelling and controls illustrated through simulations; while others have lab components based on a particular microcontroller or PC-based hardware and software. As another survey outcome, it was found that Australia needs to invest more on mechatronics education to remain competitive in a global marketplace. Furthermore, two important skills gap for graduates were identified, lack of training in integration of industrial systems with PLC and SCADA, and unsatisfactory verbal or written communication skills. These facts clearly reveal a mismatch between university education and industry needs. This issue has resulted in efforts made by two Australian universities, Curtin University and QUT, to be resolved through development of new approaches with balancing theoretical and practical aspects of mechatronic courses.

At UniSA, as a natural step forward, two academic staff from the School of Advanced Manufacturing and Mechanical Engineering have visited the Queensland University of Technology (QUT) and Curtin University to find more about their experience. At the same time, an external consultation on the necessary facilities and equipment was conducted with a rigorous selection process involved. As a consequence, the Mechatronic System Integration course is developed in association with an integrated industrial manufacturing system called Modular Production Systems (MPS) provided by FESTO. The contents of courses and the new assessment methods based on continuous monitoring of the progress using various tools will also be implemented as a part of the development process.

Course contents

This course was designed as a part of a new mechatronic curriculum in the third year level course at the University of South Australia in 2012. The main aim of the course is to introduce the fundamental design principles of mechatronic systems and to enable the students to identify key components and integrate such a component into real industrial systems. As the main part of course, in a series of lab activities, students will analyse, design, and implement MPS consisting of three stations: distribution, testing, and storing stations. Students will be grouped and expected to integrate three stations together using PLC and SCADA and demonstrate the operation of the whole system at the end of semester. The PLC adopted in the course is Allen Bradley MicroLogix 1500 with RSLogix 500 ladder logic software and the SCADA software is Wonderware-In-Touch.

By providing all necessary mechanical components of the system, students will be directly engaged in hands-on large-scale mechatronic system integration. In particular, the students will be involved in the development of an efficient way to identify and use a given sensor input, an effective process control strategy with safety considerations, and integration. In addition, RSLogix 500 ladder logic programming environment will be used to demonstrate students how to program the PLC units, and easily interface to the hardware and gain experience with a large variety of mechanical equipment. The course consists of 10 hours of lectures, and 30 hours of formal laboratory time over thirteen week semester. The lecture material and lab manuals are available through the course website. Students also have access to the lab throughout the week as required. This extended availability time provides students with the opportunity to practice more in the lab particularly at the end of the semester when may face more complicated procedures in integration of the entire system when they normally need more time to finalize their final project. For the debugging process as well as safety reasons, the system simulation package called EasyPort with CIROS software is also available. This is a virtual environment where FESTO stations are accessible and the students can debug the PLC program as well as conduct a simulation for the operation of each station at the final stage right before the real hardware implementation. Moreover, students have open access to a computer lab containing all the software used in the course. Figures 1, 2 and 3 show three stations of the MPS system purchased by UniSA. Figure 4 illustrates a combination of them connected together in the lab. They have specific functions of their own, while working collaboratively in a sequence. Each station is mounted on a trolley which carries a Control Panel, Allen Bradley ML1500 PLC Unit, and the Control Console. The PLC units are supplied by a 24V power intake. Using RSLogix 500 software, a PLC program can be uploaded to or downloaded from each PLC unit.

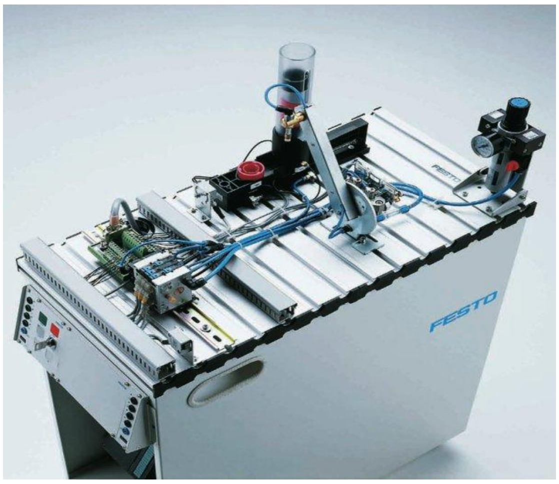

Figure 1: Distribution Station of FESTO system

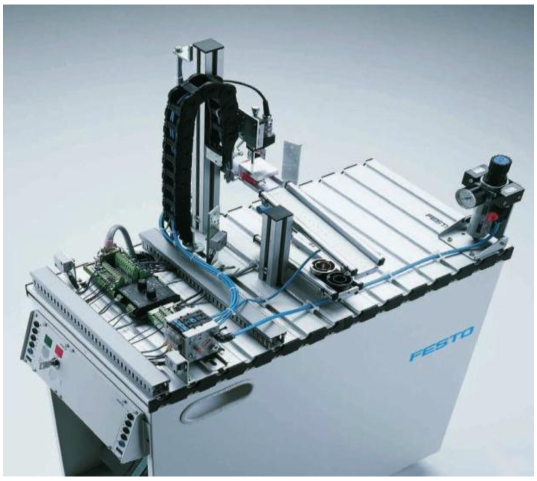

Figure 2: Testing Station of FESTO system

Figure 3: Storing Station of FESTO system

Figure 4: Three FESTO stations purchased by UniSA

There also exist three types of workpieces in silver, black and red colour made of two different materials: metal and plastic which are illustrated in Fig. 5. Besides, the red and silver workpieces are 2.5 mm higher than black workpieces. The different types of sensors can be used to distinguish the workpieces from one another.

Figure 5: Three different types of workpieces used in MPS

The first station, Distribution station (as shown in Figure 1), consists of Stack Magazine Module, Changer Module, and Profile Plate. Up to eight workpieces can be held by magazine barrel of the stack magazine. A through-beam sensor is used to monitor the filling level of the stack magazine. A double acting cylinder pushes out the workpieces individually. The Changer module grips the separated-out workpiece using a suction cup. A vacuum switch checks whether a workpiece has been picked up. The arm of the transfer unit, which is driven by a rotary drive, conveys the workpiece to the next station, Testing station.

Testing station is equipped with Recognition Module, Lifting Module, Measuring Module, Air Cushioned Slide Module, Slide Module, and Profile. This station determines the characteristics of inserted workpieces. The Sensing Module identifies the colour of a workpiece and the capacitive sensor detects each workpiece irrespective of colour. The optical diffuse sensor identifies metallic and red workpieces but not black colour workpieces. A retro-reflective sensor monitors whether the working area above the workpiece retainer is free before the workpiece is lifted by the Lifting module. The analogue sensor of the measuring module determines the height of the workpiece. A combination of these various sensors can provide students a way to find the most efficient way to differentiate the workpieces. The rodless lifting cylinder and ejecting cylinder (actuators) collaborate to lift the workpieces from the Sensing Module to the Measuring Module. The end position sensing of the cylinders is done by inductive proximity sensors. A linear cylinder guides the correct workpieces to the final station, Storing station, via the upper air cushioned slide. Wrong workpiece are sorted on the lower slide.

The last station is for storing. It detects the colour of incoming workpieces and deposits them into one of three levels of the rack module depending on the colour (black, red, silver). The colour sensor equipped in the pneumatic gripper detects colour of workpieces. The detected workpieces picked-up by the pneumatic gripper will be transported to the next free shelf of the corresponding rack level via Storage Module. Each rack level can accommodate six workpieces. Depending on the operating conditions, once one level of rack is filled or reaches the operation limits, the whole system will stop. The reset button of the control panel in this station should be pressed in order to reset and restart the whole system.

The main objective of the students involving in MPS system is to design, integrate and implement the most efficient mechatronic systems to accomplish designated tasks. To systematically support the student activities during the whole course, the lecture and hands-on computer applications are tightly coupled together with a specific plan. Students will learn the relevant fundamental knowledge in the lecture which is immediately followed by the corresponding lab practicals for the application of such classroom knowledge. Each lab will provide the students to complete their pre-lab works and continuously develop and implement algorithms to control the whole process. These lab activities are progressively monitored and marked using Milestone-based marking coined by E. Lindsay (2011) rather than assessing the students at a specific date. A list of tasks according to the milestones of the given tasks is provided to the students in the early stage. This is mainly to help the students clearly identify the list of tasks to be accomplished. Depending on the difficulty levels the allocated mark in each task varies. For any progress they made, they will obtain the allocated marks at any time before the final demonstration date. This way, they could receive incremental feedback on their progress and have time to make any necessary amendments by the deadline. On top of it, all of these assessments are entirely based on their lab logbook. Like a professional engineer, the students should record their activities correctly and efficiently ensuring effective communication skills required for their future career.

The whole course is divided into four major modules as follows.

Module 1. Mechatronics System Integration: Overview

Lecture Content

In this section students will go through a overview of the fundamental knowledge on mechatronic components and systems, and their architecture and integration issues. They also become familiar with the MPS system to be used in their lab activities. Also a working demonstration of the entire system is introduced.

Laboratory Content

In the first laboratory session, after having a tour of the Mechatronic Lab which is located in the school of Electrical Engineering, students will be divided into a group of four students. They learn about how to draw and interpret function charts in correspondence to each station of MPS system, along with a brainstorming activity to figure out viable solution for the integration of mechatronic systems. They have to analyse and relate the real operations of the each station with consideration of sensor inputs/outputs and pneumatic components into their corresponding function charts.

Module 2. Understanding of Pneumatic Systems

Lecture Content

One of the major components in any mechatronic systems is pneumatic systems. Hence in this lecture, an introduction to the characteristics and applications of pneumatic system is covered. The contents include fundamental theories, pneumatic components, their symbols, and standards. Students also, learn about the role of actuator, output devices, directional control valves non-return, flow and pressure valves, timers, and valve combinations and symbols in pneumatic circuits.

Laboratory Content

In the lab, students learn how to identify, interpret and understand pneumatic diagrams and practice assembling various pneumatic components into pneumatic circuits. Using FluidSIM software, the students design simple pneumatic circuits for real industrial applications. This is an essential part of study for the students to integrate the FESTO systems together in later lab sessions.

Module 3. PLC programming and implementation

Lecture Content

PLC programming has been identified as one of the areas that the mechatronic students should be fully covered in their discipline. Hence this session is designed for the students to understand the overview and components of PLC, Input/output devices working with PLC, various programming methods including ladder logic, and data-types and useful commands in PLC with examples of Allen Bradely MicroLogix 1500 PLC within FESTO system.

Laboratory Content

As part of their group project, students will be expected to get familiar with PLC Allen-Bradley ML 1500 and RSLogix 500 software to integrate FESTO MPS stations. They will be provided with a full description of components, I/O configuration, pneumatic circuit and function chart for the first station (Distribution station) with step by step guidance ensuring their learning experience with good examples as a starting point. In addition, the detailed PLC programming for each sub-module and full integrated PLC program for Distribution station are also provided. This enables the students to shorten the initial learning stage of PLC programming keeping in mind that the integration of the whole system can be done more easily. Full descriptions, I/O configuration charts, pneumatic circuit and function charts for the remaining two modules are also supplied. The basic level of the student task is to achieve the specifications described in those documents. The students are encouraged to further extend the integrated system operations with their own creative initiatives to achieve higher grades. For debugging and safety checking of the PLC programs, the operation of each station can be simulated with the full simulation package provided by FESTO (called CIROS software via EasyPort). This could provide the students an easier and more confident opportunity on their initial programming skill development without any potential problems caused by inattentive PLC programs.

Module 4. Integration using SCADA

Lecture Content

The supervisory control and data acquisition (SCADA) is the core part of mechatronic system integration in the real industrial practice. The students should be familiar with fundamental knowledge of SCADA in junction with the practical industrial applications. This session will cover this in detail with a demonstration of FESTO system integration.

Laboratory Content

In the final stage of the project, students will integrate all three stations of FESTO incorporating workpiece feeding, detection, classification, and storing using SCADA. The objective of the final lab exercise is to allow students to gain experience integrating mechatronic subsystems and performing system level debugging and optimisation like what the real industrial application does.

Note that as a key component of the course, during all lab activities, each group has to record their lab activities in their lab logbook which needs to be checked by instructor in a continuous manner. All tasks that they should complete at the end of the course have been provided at the beginning of the course and if any of tasks listed is completed at any lab session, they can ask for the assessment for that specific task. There are a certain tasks that they should follow the order while other tasks can be completed in any point of time for example, the occupation, health and safety issues and detailed description of each station. The students should complete certain milestones before a designated date. If not, there would be a certain penalty imposed as in the actual industrial environment. In the last week of lecture, as a part of assessment of communication skills, the students are required to present their final result with the project report in junction with demonstration of the hardware implementation. The report should contain a top-level algorithm for sequencing and interfacing the various subsystems with efficient integration method in mind. To ensure the participation of individual student in various tasks, each student needs to submit peer assessment report specifying each member's contribution towards the completion of the project with agreed consent from all other group members.

Since this course is implemented first time in study period 5 in 2012, the full comprehensive evaluation and feedback is not available yet. However, the initial feedback from the students indicated that the course is well accepted from the student. By the time this paper is presented in the conference, more detailed student feedback data could be collected, analysed and reported in the due time.

Conclusion

This paper describes the design and development of Mechatronic System Integration course for third year level students of Mechatronics program at the University of South Australia. The main objective of the course is to introduce the fundamental design principles of mechatronic systems and to enable the students to select key components and integrate such a system with industrial applications in mind. To achieve this aim, the lecture and the lab hands-on practicals are tightly coupled together to ensure the structured and systematic assistant for the students to implement an industrial manufacturing simulation system in the most efficient way.

By implementing this course, it is expected that the students will be more familiar with industrial mechatronic systems and have the ability to integrate various components into a system, in conjunction with being able to incorporate a range of industry standard equipment and computer software. Also, students become more confident on analysing industrial mechatronic system, evaluating the necessary requirements, generating solutions and integrating components together.

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