Internet Based Design: e-Design and e-Decision Making

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Abstract

It is inevitable that product design, and the associated engineering analysis to support such design, will be primarily accomplished by multidisciplinary teams, with members that need not be located in the same geographic location. Though some corporations are practicing distributed design, most notably the multi-national automobile manufacturers, a documented procedure for conducting this form of distributed design and product development has yet to be created, tested, and distributed.

This paper documents an innovative method for integrated internet-based distributed product design. A team of Mechanical Engineering seniors, Management majors and high school students from across the U.S. teamed to design and construct a series of three electromechanical devices, using the internet as the primary design communication platform. Effective internet communications using off-the-shelf software have been used to guide the idea generation, concept prototyping and detailed engineering design necessary to manufacture autonomous and remotely controlled robotic devices. The paper details the distributed design (e-design) methodology, examines three case studies which apply the e-design process, and illustrates how distributed decision making methods can be applied to entrepreneurial teams with members located in different locations.

Introduction

The focus of this project was to create a distributed team of high school and college students to solve a design challenge. By communicating over the Internet, this distributed e-team researched, evaluated and applied technologies for remote learning, design and manufacturing. The objective for the college students was to apply their undergraduate education to solve a modern problem, namely working in teams with members in remote locations. The objectives for the high school students were to develop a new set of communication skills, introduce leadership and responsibility in a team scholastic activity, and increase their motivation and ability to pursue higher education.

The project was started in the summer of 2000 when a group of high school youth from across the country was brought to the U.S. Coast Guard Academy for a week long program to introduce minorities to engineering. From this group, a subset of 8 high school students were recruited to participate in the initial stage of the Distributed Design and Decision Making project. Guided by a group of senior cadets majoring in Management, the initial team developed the infrastructure to support distributed teams, established communications protocols using low cost, off-the-shelf technology, and successfully β-tested the distributed team concept in three robot building activities. In December of 2000, the Management Majors provided the Engineering Majors with a “turn key” operation complete with team members and an Internet-based communications platform.

Under the guidance of the Engineering Majors, the distributed team then participated in a third beta test: constructing a robot for the national FIRST Robotics Competition. FIRST is a national robotics competition that partners high school youth with engineers and colleges to design, build and compete sophisticated robots. As an indicator of the sophistication of these devices, they typically weigh 120 pounds, can move at the pace of a human’s jog, have the dexterity to accomplish athletic tasks, and are strong enough to lift themselves off the ground. While over 500 teams from across the U.S. participated in FIRST 2001, this project’s team – known as CGA Team USA, was the only one to do so with teammates located across the U.S. working over the Internet.

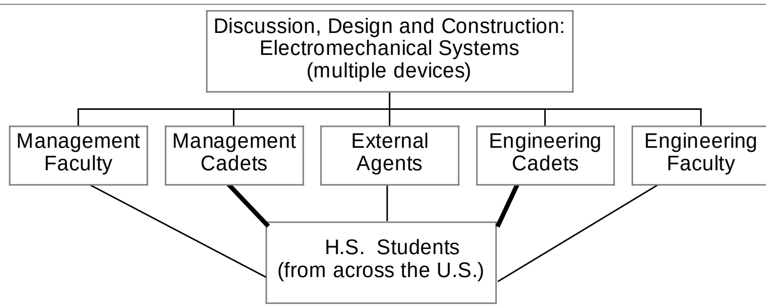


Figure 1: Team Organization

Embedded in the process of designing the communications platform and procedures for distributed design and decision making, all members of the team were immersed in learning about a new medium that will become an increasingly important component of their professional lives.

Learning Community

Three distinct learning communities participated in this project: the high school students from across the U.S., the Academy Cadets, and “external agents” who have joined the project. The final composition of CGA Team USA was 47 members from 9 locations across the U.S.

High school students: Although it was originally envisioned that the Team would have only 8 high school student members, that number grew significantly. The Team was composed of 28 high school students from Connecticut, Massachusetts, Georgia, Tennessee, Arkansas, Michigan, Indiana, California and Washington. This unanticipated growth in the Team’s size was attributable to the tremendous interest of both students and high school educators who learned of the project. Examples of additional members included friends of original team members, a high school teacher who wanted to have her class participate in the FIRST competition but did not have the funds, and a group of students from a vocational high school who assumed responsibility for the Team’s Autocad drawings.

Academy Cadets: As previously noted, the Academy cadets were seniors in either the Management or Mechanical Engineering major, all of whom received academic credit for their involvement. For the five Mechanical Engineering majors, this project represented their capstone design project.

External Agents: The initial external agent was the faculty and staff at the Academy. Other external agents who later assisted the Team included various high school faculty members, Coast Guard field technicians, a professional engineer who heard of the project and volunteered, NASA, and a faculty member from MIT.

Communication Methods

Five separate communication methods were used to guide the team's design process. These methods were:

- Internet based discussion forum
- Internet file server
- Microsoft Instant Messenger for text and voice
- Microsoft NetMeeting for file sharing and idea exchange
- Broadcast emails

The Internet based discussion forum is illustrated in figure two. This web site consisted of discussion threads for the project organization and for each project activity. In addition to these discussion threads, the site contained background information on the overall project and contact

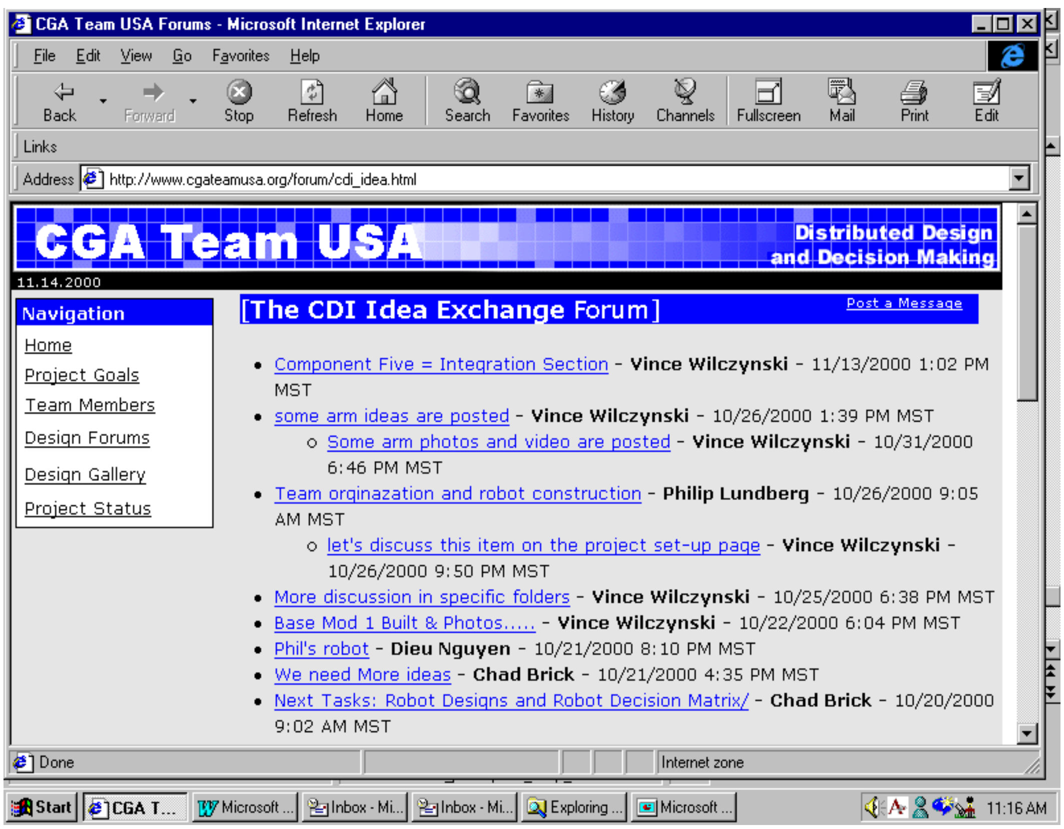


Figure 2: Team Web Communication Platform: www.CGAteamUSA.org

information for the team members. The site also included a location to upload and download project files in any format such as word documents, spread sheets, Autocad drawings, jpeg images or video clips of working components. Each team member could open the site, make posts, and track the progress of the project. The site was open to viewing by the public, but a registration system was used to track who made each post.

The Internet file server was established at a buzzsaw.com site created to serve the design industry. This site was chosen for the project as a file server to retain all the documents related to the project. It was a secure file server and only users that were registered by the project administrators were allowed access to the site. It was primarily used as to store and trade organizational files for the project such as internal planning documents, grant requests, budget worksheets and inventory control. A useful feature of the site was that it was not merely a file server, but rather an interactive file server. Each posted file contained a comment section where project participants could annotate the documents with background information or related comments. When files were posted, the user had the option of automatically emailing all members of the team to alert them to the new information. The site contained tremendous administrative features that allowed read and edit privileges to be assigned to each team member. The site also tracked each team member's use of the site. To avoid a user from having to comb the entire site for new information, the site would highlight the new information that had been posted but not yet read by the user.

The instant messenger service provided real time text and voice communications with each team member. Most team members kept their connections active when they were on the network, so other team members could readily see if a specific team member was available to discuss a topic. Group text discussions were commonly held to discuss major decision items of each project, and the discussions were saved and recorded on the project file server. Voice communications were possible in this system, but conference calls were not possible.

Microsoft NetMeeting was used to share project documents in real time, with the option of marking up a document so that other users could see the markup while the changes were being discussed. This communication platform worked well with small teams, but the limited bandwidth available through modem connections prevented its use with large groups. If a large number of people needed to see a document at the same time, that document was saved on the remote file server, and each team member downloaded that document using their web browser. Though NetMeeting offers that ability to transmit video of the users, that feature was not used in this project.

Broadcast emails were used as announcements made to the entire team, usually on a weekly basis. Via these emails, which were cataloged on the team web site, the schedule was kept current and the team was advised of those tasks that needed to be completed in the next week.

The communication tools allowed for synchronous and asynchronous communication among the team. Experience demonstrated that large scale synchronous communication should be used sparingly, and with great control. It was very difficult to arrange a time for all team members to be on-line together, and when on-line in a large group, it was hard to maintain a discussion when a delay is built into the system because of the network. For example, if a team member posted a question during a discussion, the short delay in that question reaching the presenter would require the presenter to then pause from the discussion thread they were leading to take on the question. Asynchronous communication was the primary communication technique used in the projects for it allowed the team members to work on their own schedules to make posts and keep current with others' progress.

Distributed Design Process

The following sequential steps define the Design Process used by all Mechanical Engineering Teams at the Coast Guard Academy:

- Problem Definition and Understanding
- Solution Strategy
- Possible Solutions that Follow Strategy
- Analysis and Preliminary Design of Sub-Components
- Refined Analysis and Detailed Design of Sub-Components
- Sub-Component Integration
- System Test

This design sequence is a compilation of many existing design process (ref 1, 2, 3). By no means do we suggest that it is the ultimate design process, but rather one that we have found works for our team based projects. This general method was applied to the distributed team, with specific examples provided in the following case studies. For the distributed team, a detailed daily plan of action was created that provided a framework for each member of the team to participate in each step of the process.

The team's discussion forum web page was used as the principal means of communication for the project. The key for organizing the team is a detailed project activity list posted on the site. This list specifies the steps of the project for each day of the activity and identifies the tasks to be completed, the communication forum to be used.

As a general example of applying the distributed design process, the rules for each design challenge would be posted on the internet and it would be the responsibility of each team member to educate themselves on the "Problem Definition and Understanding." To do so, they could read the design challenge requirements and discuss the requirements with one another on the forum page or in real time using the instant messenger service.

The daily activity plan would specify a time period for individuals to discuss possible solution strategies and then use a decision matrix to decide on the specific strategy to use. A similar period of web based discussion of the possible design solutions would follow. During this period members would post preliminary design solutions as text files, CAD drawings or scanned JPEG images on the team's internet file server. Again, a decision matrix is used, with each team member voting on-line, to select a design to pursue.

The distributed team is then broken into sub-teams for the Preliminary Design and Detailed Design steps. Here, small groups communicate primarily in real-time (instant messenger, web conference calls, and NetMeeting) to transform sketches to working prototypes of the sub-components. For the Detailed Design phase, the sketches and analysis are refined such that the finished product can, to the extent possible, be manufactured in remote locations. During this phase, it is the responsibility for the sub-groups to keep informed on other components of the design. This is achieved by following each others' progress as detailed on the team web page. Integration has been achieved by having all the sub-components sent to a central location, though it is also possible to establish a daisy chain to assemble adjoining pieces and forward that completed part to the next member.

Three case studies are presented to provide insight into how the distributed design process was used to create three robotic devices.

Application 1: Competitive Robots

The distributed design method was first applied in a national robotic competition for 40 teams. In this competition, teams were issued a common set of parts from which they had to construct a robot to accomplish an assigned task. The robots then competed against one another in a round-robin tournament. The goal of the competition was to maneuver around a 40 foot field and deposit 8 inch balls into a goal.

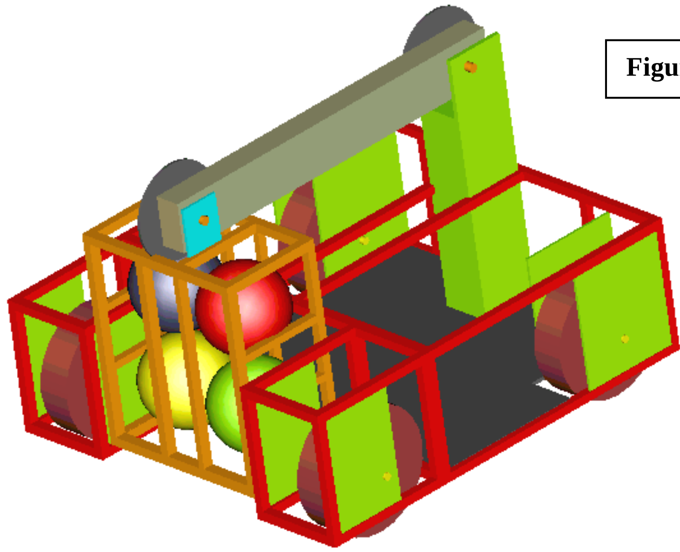


Figure 3: Concept Design

To accomplish this task, the team applied the distributed design techniques detailed in the earlier section. Each team member was required to read the competition rules, which included the kit of parts, from the competition web site. The team's forum based web site was used to talk about the game specifics and identify strategies that could be used to play the game. Figure three illustrates the initial design of the team's robot.

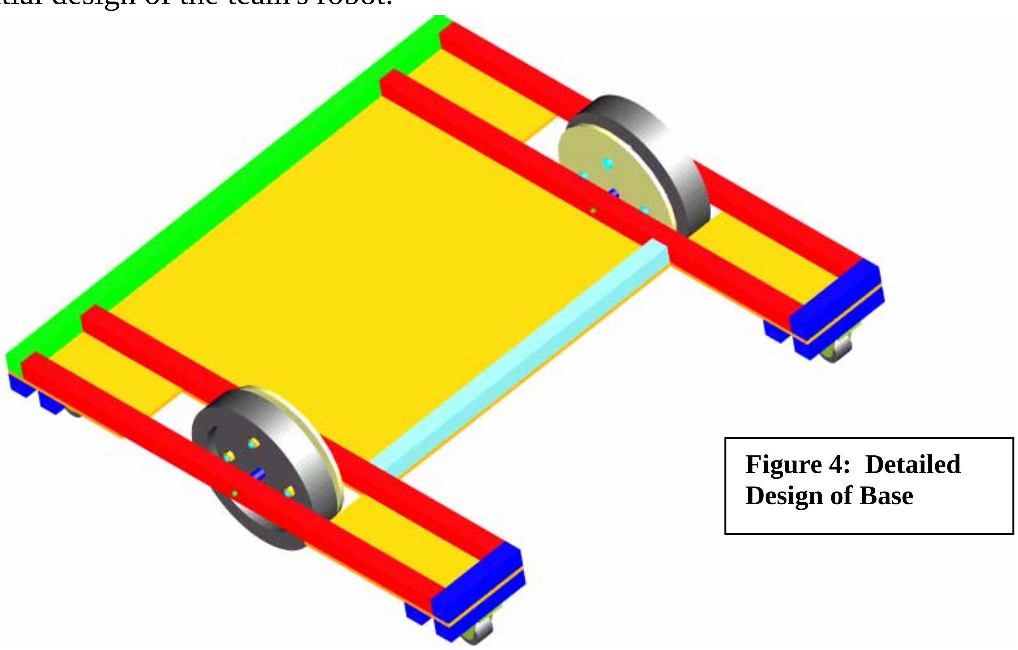


Figure 4: Detailed Design of Base

With this initial design complete, the team broke up into two sub-teams. One sub-team worked on the base of the robot, while the other team worked on the arm design. Each team used the computer resources they were comfortable with to describe their design ideas as. For the base design (figure four) computer aided design software was used to convey design ideas, while another high school student simply used a paint program (figure five) to document design ideas for the arm.

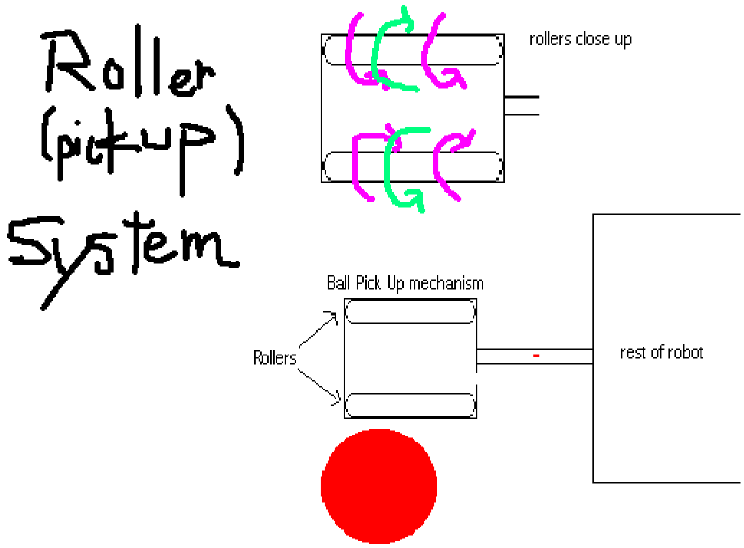


Figure 5: End Effector

The sub-teams then manufactured the sub-components, and shipped their completed sub-component to a third team member to integrate (figure six). By design, the robot was simple but reliable. The integration was not complicated thanks to the fact that the sub-component designs were created knowing how the other sub-components were being created. When completed, the robot was shipped to the competition in Michigan where the team placed 4th out of 30 teams. This high performance demonstrated the first proof of concept

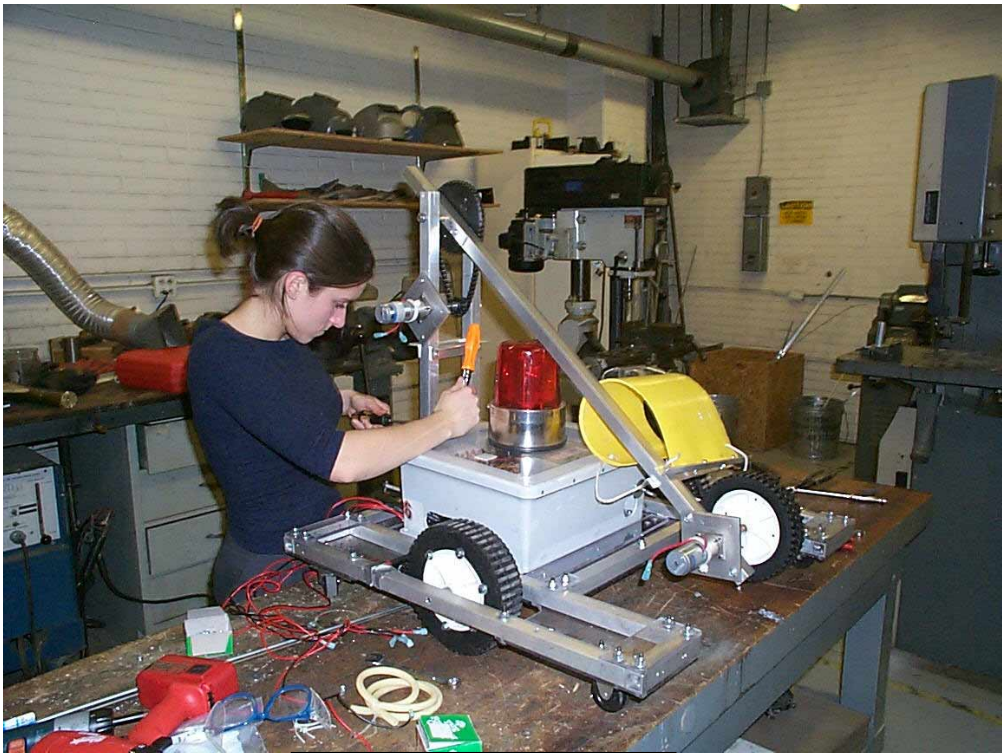


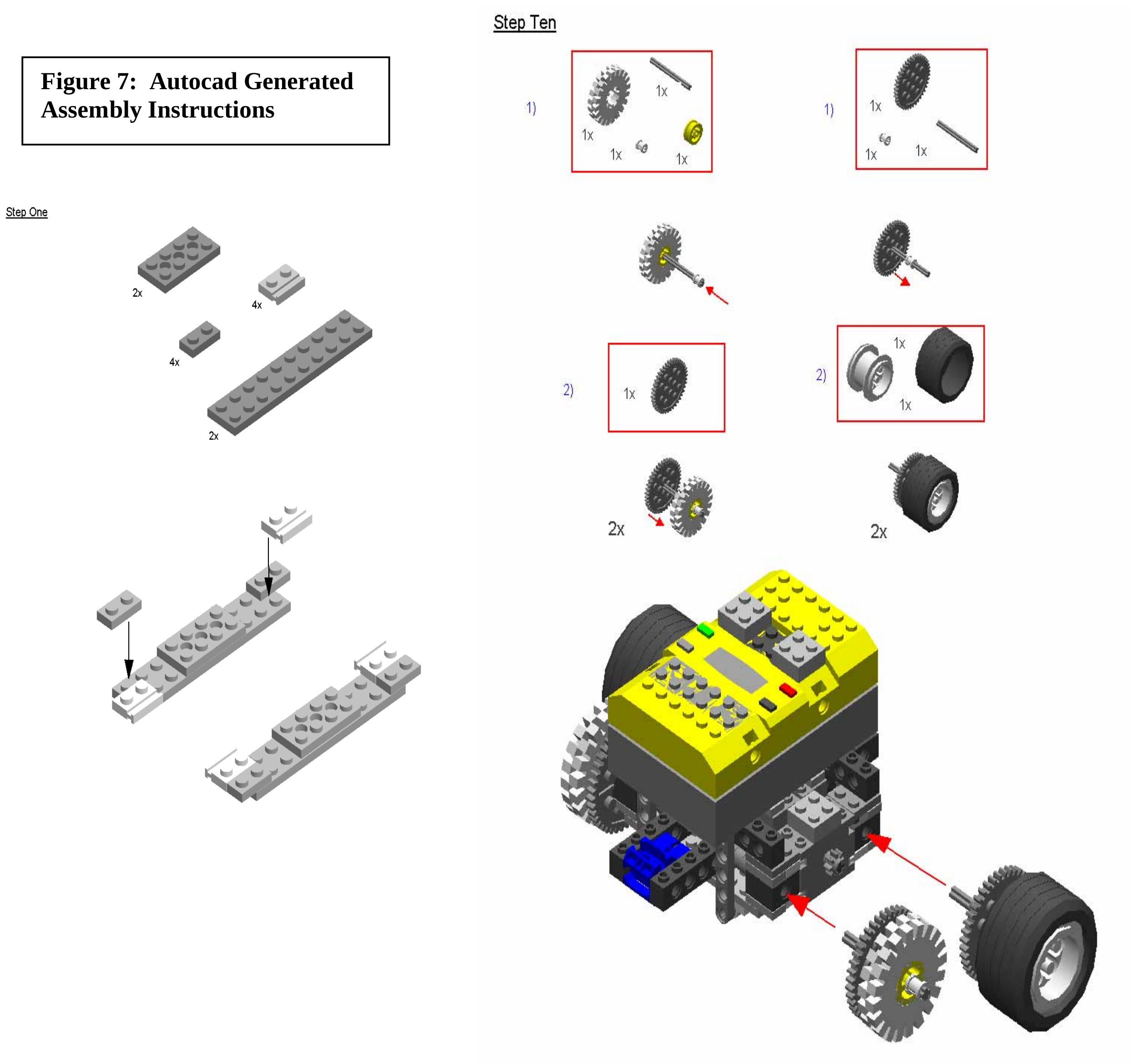
Figure 6: Design Integration

that a distributed team could successfully conceive, design, and construct electromechanical devices using the internet.

Application 2: Engineering Design Drawings

While the first application reinforced the sequence of the distributed design process, the second application was used to detail a method for sharing engineering drawings. For this application, each team member was assigned a table-top robotics kit (the popular LEGO *Mindstorms* kit) with the goal of trading designs and software over the internet to make a robot capable of running on a table without falling off.

Figure 7: Autocad Generated Assembly Instructions



Autocad 2000 was selected as the drafting tool for the project. For this project, a group of high school students from a vocational school created Autocad drawings of the major parts of the MINDSTORMS kit. These pieces were then rendered as three-dimensional objects and the individual parts were then combined to model a composite design, as illustrated in figures six and seven. The robot design was then documented as an instruction book that illustrated how to build the robot from the kit of parts. Because the typical Autocad drawing was greater than 5MB, and that every team member did not have the Autocad software, the finished files were created as JPEG images. These images were imported into a word processing document that was posted on the team web site. The distributed team downloaded the word document and built the system.

Application 3: Competitive Robots II

Using the infrastructure developed during the fall semester, the distributed team participated in a third beta test: constructing a robot for the national FIRST Robotics Competition. FIRST (For Inspiration and Recognition Science and Technology) is a foundation that, among other programs, sponsors a national robotics competition that partners high school youth with engineers and colleges to design, build and compete sophisticated robots.

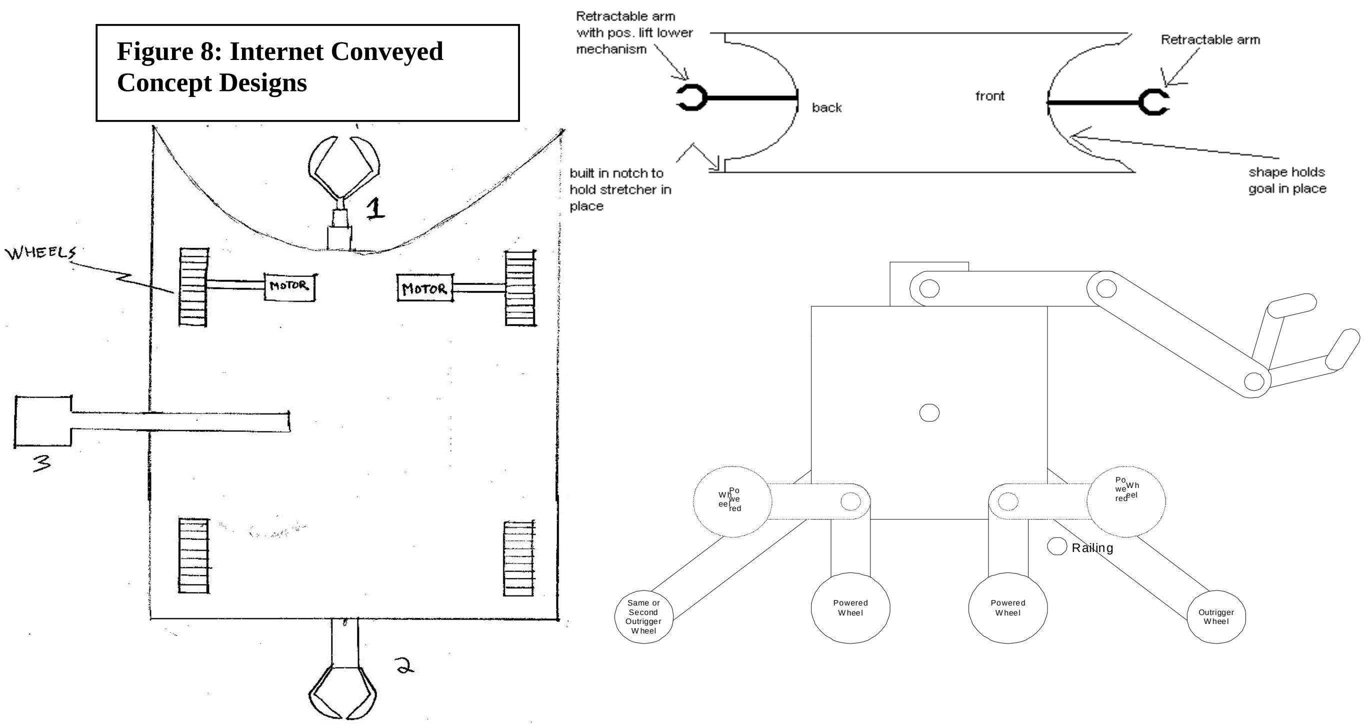


Figure 8: Internet Conveyed Concept Designs

The purpose of the FIRST Robotics Competition is to enhance technical literacy of youth. By teaming engineers and universities with high school students, the project shows students that engineering is fun and exciting, and that they have the capacity to be successful as engineers. The competition has been widely reported on in the popular press, and additional information can be found at the sponsoring organization's web site www.usfirst.org.

The FIRST Robotics Competition, founded by inventor Dean Kamen and derived from MIT Professor Woodie Flowers' famous MIT 2.70 Design Course presents an annual design challenge that must be solved using material from a standard kit of parts. Teams receive the game description and their kit of parts the first week of January, and then have six weeks to develop a team strategy, design, build, and test their robot. Teams then assemble at any of 13 Regional Robotics Competitions where they celebrate technology. The competitions have been described as part rock concert, part technology festival and all around fun. A National Championship is held at Epcot center in Orlando, where in 2001 over 20,000 participants assembled to test their inventions and celebrate their success. In 2001, over 520 teams participated in the FIRST Robotics Competition.

At the U.S. Coast Guard Academy, five senior Mechanical Engineering students led this activity with the distributed team as their capstone design project. Using the internet platform and communication protocols developed by the Management cadets the previous semester, the Mechanical Engineering students led the distributed teams through the strategy, concept design, and preliminary design phases of the project using the internet as the principal communications medium. The detailed design phase of the project, which included most manufacturing and integration, was conducted by primarily by the cadet team at the U.S. Coast Guard Academy.

The time table for their activities is presented in table one. Examples of internet delivered content for the concept, preliminary and detailed design phases of this project are presented in figures 8, 9 and 10.

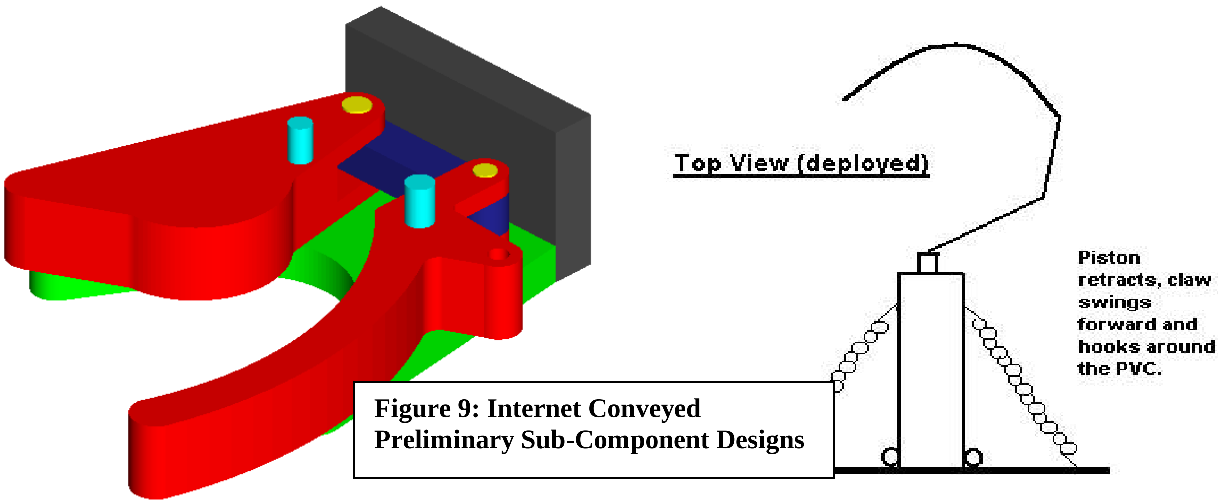


Figure 9: Internet Conveyed Preliminary Sub-Component Designs

The team's robot competed in Regional and National FIRST Robotics Competitions, where it performed as designed. The designed simplicity of the device, a criteria for the distributed team to ensure success of the project, proved to be a key factor that provided value as a robust and reliable device during the competitions. Especially noteworthy for the team was the acknowledgement of a special award for the creativity and uniqueness of the distributed team, and its success of completing a competitive design using input from team members across the U.S.

Table One: *CGA Team USA Project Time Table*

Phase One:	Jan. 7-9:	Game Requirements and Team Strategy
Phase One:	Jan. 10-13	Conceptual Design of TEAM USA robot
Phase Two:	Jan. 14-20:	Preliminary Design: Prototype Sub-Components
Phase Three:	Jan. 21-27	Detailed Design of Sub-Components
Phase Four:	Jan 28-Feb 12	Fabrication of Sub-Components & Integration
Phase Five:	Feb 13 -19	System Test
Phase Five:	Feb 20	Package and Ship
Phase Six:	Mar 1-3	New England FIRST Regional
Phase Six	Mar 22-25	Silicon Valley (CA) FIRST Regional
Phase Seven	Apr. 5-7	FIRST National Championships

From the Cadets' Perspective: Educational Value and Lessons Learned

For the Academy Cadets, this project provided an opportunity to gain practical skills with project management and product development. The Management Majors were not only able to apply the management techniques learned in the classroom, but were also able to participate in the engineering design process; something they would not have been able to do had they not enrolled in this directed study. The Mechanical Engineering Majors not only designed and constructed a complex device, but gained tremendous experience with project management and the use of the Internet.

Figure 10: CGA Team USA Detailed Design

The Management Majors: It was anticipated that the greatest educational value to be derived by these Cadets would be the opportunity to apply and integrate the business knowledge gained in the classroom. Specifically, the formation of an effective team, the development of project plans, use of information systems, and the implementation of management controls (e.g. budget planning and execution). The final report submitted by these students clearly indicated that they had gained tremendous experience in all these areas. It was however, somewhat surprising to learn that the greatest lesson they learned from this experience was the importance – and difficulty – of building an effective team.

By their senior year, all Academy Cadets have completed courses in organizational behavior and leadership. Most have held "senior management" positions in the Corps of Cadets, which is comprised of more than 800 students. Despite their academic knowledge and the "management experience" in the Corps, the greatest challenge for these students was to organize themselves effectively and create a sense of project ownership amongst themselves. "Team building is an integral part of the cohesiveness and success of any team despite the geographic location of the team members. Prior to establishing accountability and ownership, we discovered that motivation was rather low. During the beginning of the project, everyone assumed that 'everyone else' would take care of tasks and consequently, nothing was completed."

The lack of leadership was apparent as high school students initially received conflicting guidance from the Cadets. Once the Cadets "internalized" their ownership of the project, planning and coordination improved significantly. By the end of the Fall 2000 Semester, the Management Majors, along with their high school teammates, had defined an effective communications platform ready for the Mechanical Engineering Majors' use. Although this lesson came with "sweat and tears", it should serve these students quite well in their future careers.

The Mechanical Engineering Majors: This student team realized the unique aspect of a distributed team, namely that working in a distributed team required two levels of organization and management. As the leaders of the distributed team, the ME cadets were responsible for both the traditional aspects of team based design (i.e. working as a team to progress from objective to concepts to prototype to detailed design and manufacturing) and for the "back of the house" activities that enabled the team to be productive.

As an example of the "back of the house" activities that are needed for a distributed team to work effectively, the cadets assembled and posted a very detailed "Daily Plan of Activities" for each phase of the design process in table one. This plan described the goals for each day's activities and in essence was the team's "to do list" for completing the project. While traditional teams can be successful with less well defined task lists, the distributed team requires explicit and detailed instructions. As another example of the additional planning needed to make the distributed team successful, the cadets developed a decision making process, using decision matrices, to allow each team member to have a role in the team's design process. Again, while a traditional team must also develop a decision making process, more care, thought and concern is required for this tool to be used by a distributed team.

The pace of the project, given only six weeks from the game unveiling to the completion of the competition ready device, is exhausting for all participants, and especially so for the cadet members of the distributed team. Given that they were completing this course as one of their academic requirements, they could not devote 100% of their time to the project for fear of not keeping up with other courses. Added to the magnitude of the task was the real time learning needed for communicating design ideas over the internet and becoming leaders of a distributed team. As only Coast Guard Academy cadets can do, this group surprised the authors with their energy, devotion, creativity, and ability to survive on very short sleep.

Project Observations

Multiple levels of planning are needed to enable distributed teams to be effective. More so than teams with members in the same geographic location, the activities of the distributed team must be highly structured and choreographed such that each member can update themselves on the team's progress and their responsibilities. Because of this need for self direction, the members of a distributed team must be self starters with initiative and personal drive. It is nearly impossible to motivate members of a distributed team that are not totally devoted to the program's success.

The documentation needs of the distributed team are more stringent than those of a traditional team. For example, the distributed team found the need for, and developed the following written documentation (that was conveyed electronically to team members):

- Operations Manual to detail team leader functions

- Log-In Manual to guide team members though the process of setting up their computers with the necessary software load-ins and web sites to communicate with each other

- Daily Plan of Activities to alert each member to the progress and immediate requirements for the each phase of the project.

As opposed to most student formed teams, by design, the distributed team used a prescribed decision making process and kept detailed public records of their design process. The availability of all aspects of the design were always available to all members of the team and if the detail was not posted, it did not exist.

Throughout the process, the cadets developed a long term personal relationship with the high school students. This benefit of the project was intended, and it is hoped that this initial work can be used to form the basis of an awareness program between college and high school students to increase their desire for, and assist with their transition, to college.

Results & Conclusions

The four most significant results of this project were:

- The students succeeded in completing a very complex design challenge. Through this process the participants realized the importance of team work and have developed a unique set of skills for distributed team projects.

- The Academy Cadets had an opportunity to experience working on a geographically-distributed multidisciplinary team, which they'll do frequently throughout their Coast Guard careers and beyond.

- The high school students received mentoring from both college students and professional engineers. This experience has hopefully provided them with the interest and confidence to pursue advanced education in math, science and engineering. In addition, these students were exposed to Internet based learning techniques that will benefit them in their further education.

- The team documented a low cost, exportable version of a communications platform that can be used for distributed design and decision making.

As noted in the abstract, it is inevitable that small multidisciplinary teams will increasingly use the Internet to meet, work, and solve problems. In the past, reliable low cost platforms have not been readily available nor reliable. The methods described in this paper can easily be adapted and adopted for other educational team activities where the members are not geographically co-located. Examples of such collaborative activities include multi-university capstone design projects, industry-university joint ventures, distance learning projects, student-industry consulting projects, and other service learning activities.

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