AC 2010-859: AN AUTONOMOUS CAMPUS TOUR GUIDE ROBOT AS A PLATFORM FOR COLLABORATIVE ENGINEERING DESIGN

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An Autonomous Campus Tour Guide Robot as a Platform for Collaborative Engineering Design

1. Abstract

The University of South Alabama School of Computer and Information Sciences and the Department of Electrical and Computer Engineering are participating in a collaborative effort, funded by the National Science Foundation (NSF), to design and build an autonomous robotic campus tour guide. The life-size tour guide robot, called JagBot after the University of South Alabama jaguar mascot, is capable of verbal and physical interaction with prospective students and visitors. The robot can answer questions, describe campus landmarks, and can autonomously navigate from location to location on campus using a variety of on-board sensors. The NSF funding for JagBot was leveraged with University undergraduate research funding to provide a wide variety of opportunities for student research. During a two-year period, interdisciplinary research involving the School of Computer and Information Science and the Department of Electrical and Computer Engineering resulted in opportunities for undergraduate research, senior capstone design projects, graduate research, three master's theses and invaluable community exposure for STEM education. In addition to research opportunities, the work with JagBot resulted in the development of a 400-level senior elective engineering class in LabView and provided justification for University funding of a laboratory based on National Instruments data acquisition systems. This paper describes the design process and the contribution of the students to the final JagBot design.

2. Introduction

Robots, as much as any other advance in science, epitomize progress. Robots have starred in motion pictures, are routinely used in industry, and, although they have not become integrated into society as fast as imagined by science fiction writers, they have been making inroads into society in roles such as mowing yards, cleaning houses, assisting the military and providing companionship to the elderly[1-9]. In addition, robots are an excellent way to introduce students at all levels of engineering and computer science education to sophisticated design and research issues.

The University of South Alabama (USA) was fortunate to obtain an NSF grant to develop, build and test an autonomous tour guide robot, named the JagBot, after the university jaguar mascot. In addition to providing funding for a wide variety of research, the NSF is a staunch advocate of quality education in American universities. It is increasingly evident in NSF proposal requirements that the education and preparation of students for careers in the sciences is an integral part of research that is equally as important as the proposed research topic. In recent years, the NSF has placed more emphasis on undergraduate research opportunities, partially in response to criticism of American universities and the performance of American undergraduates in the arena of world education. The JagBot project provided an excellent opportunity to expose undergraduate students to state-of-the-art research problems.

The JagBot project was funded as a Special Grant for Engineering Research (SGER) project with a duration of two years, beginning in September of 2007 and ending in September of 2009. As part of the proposal, funding for a total of four graduate students on full-time assistantships and three undergraduate students on summer research assistantships was requested and approved. In addition, the University of South Alabama University Committee on Undergraduate Research (UCUR) has provided summer research fellowship funding for six undergraduate students.

The objective of the JagBot project was to design, build and test an electromechanical tour guide robot. The robot has the capability to move freely around campus buildings and is able to interact with visitors to the campus by responding to verbal questions and handing out promotional materials. The process of specifying, designing, constructing, debugging and testing the robot has been a valuable educational experience for all students involved in the project. The project is jointly administrated by the School of Computer and Information Sciences (CIS) and the Department of Electrical and Computer Engineering (ECE) in the College of Engineering. Students from both areas are participating in the project.

3. Technical Approach

The design of a humanoid robot is a complex task. The problems of navigation, sensor integration, control, vision and speech processing and autonomous behavior have been addressed by many researchers, sometimes in part, sometimes as a system. The design and construction of JagBot presents a challenging opportunity for the researchers, and, specifically, an opportunity for students to gain exposure to the engineering design process. A series of preliminary design meetings were held to develop a set of functional behaviors that included the following:

- Speech recognition/synthesis capabilities - JagBot, like any tour guide, should be able to greet participants going on a campus tour. A directional microphone and a speaker should provide input/output for the speech synthesis system implemented in software.
- Autonomous navigation - The robot should be able to determine its position at all times. As landmarks and locations are reached and identified, questions might be posed by the human participants that should be answered by JagBot and/or lead to possible detours from the planned route.
- Physical interaction with participants - To physically interact with human participants JagBot should have two arms with hands equipped with grippers. JagBot should be able to perform human-like functions, such as shaking hands, pointing to locations and landmarks, holding objects and picking up items for distribution to the participants.
- Safe operation – Appropriate safety systems and interlocks should be in place to prevent injury to participants, damage to the robot, or damage to property under all reasonable conditions of operation.

The graduate and undergraduate students associated with the project were actively involved from the inception.

3.1 Hardware and software task definition

Since the robot was required to specifically exhibit certain behaviors, one of the first challenges was to define which portions of the design task should be handled by CIS personnel and which portions should be handled by ECE personnel. The tasks were first separated as follows:

- CIS Responsibilities: Speech recognition, speech synthesis, tour routes, recognition of landmarks, interaction with visitors and general behaviors.
- ECE Responsibilities: Mechanical assembly, control of motion, selection of sensors and actuators, design of hands, arms, chassis, body, and head.

The overall design was generally based on a human neuroanatomical model, where computers, actuators, motors, and sensors have analogous roles to their biological counterparts.[10]

3.2 Hardware design

The robot was divided into six subassemblies: The body, which provides support for other subassemblies; the chassis, which provides mobility and motion control; the arms, which grasp objects, point at landmarks, and shake hands with people; the positioning and tracking system, which enables the robot to navigate; the vision and speech recognition system, which enables the robot to interact with people in real time; and the sensors and control system, which provides control of all mechanical aspects of the robot.

A design team was formed for each subassembly with a design team leader responsible for coordinating the tasks assigned to the group. The design team leaders were either graduate students or undergraduate research assistants with two to five students working in a particular group. In some cases, students worked in more than one group. The individual members ranged in academic level and experience from freshman volunteers to seniors working for class credit on capstone design projects. Some students were volunteers solicited by posting notices on the bulletin boards in the electrical and computer engineering department.

At the beginning of the project, each group was encouraged to do a literature search to see how similar design problems were solved by other researchers. As a result, the students did not initially focus on the first solution that occurred to them. The groups were encouraged to do software simulations where possible. Each group was given a budget that it was required to adhere to during the design process. The groups were also encouraged to find cost-effective off-the-shelf solutions to problems where possible.

The design team organization was similar to the organization of an industrial engineering group. The team leaders reported to the project managers (the faculty project investigators) and were responsible for tasks within each subsystem. Initial meetings were held to determine the requirements for each subassembly, then the team leaders assigned subtasks to the workers in each group and were responsible for documentation, meeting schedules, keeping work areas clean, and observing laboratory rules. The experience has been good exposure to industry practices in engineering design.

3.3 Software design

The software design portion of the project was divided into four tasks: speech, tours, sensor fusion/blending and human-robotic interaction. The speech system was developed to provide both speech recognition and synthesis in a potentially noisy environment with untrained speakers. The tour system was created to manage the possible tour routes that JagBot would be required to travel. The sensor fusion/blending system focused on the acquisition and conditioning of the data gathered by the various sensor systems. The final human-robotic

interaction software was developed to provide a feeling of natural human behaviors by JagBot in a variety of planned settings. The initial tasks of speech and tours were done in parallel with the hardware development.

All of the work was performed by CIS graduate and undergraduate students, which were organized into project teams. The teams were directed by two Master's students who were doing research for their theses under the guidance of the principle investigators. The members of the teams consisted of undergraduate summer research students funded by the University. The project teams held regular weekly meetings to report progress, develop solutions, test and evaluate results and plan future directions. As with any research experience, a search of the literature was undertaken and a significant portion of the weekly meetings were devoted to the discussion of existing literature. When appropriate, existing software was used to accomplish a task or provide a starting basis of the implementation of a particular task.

3.4 System integration

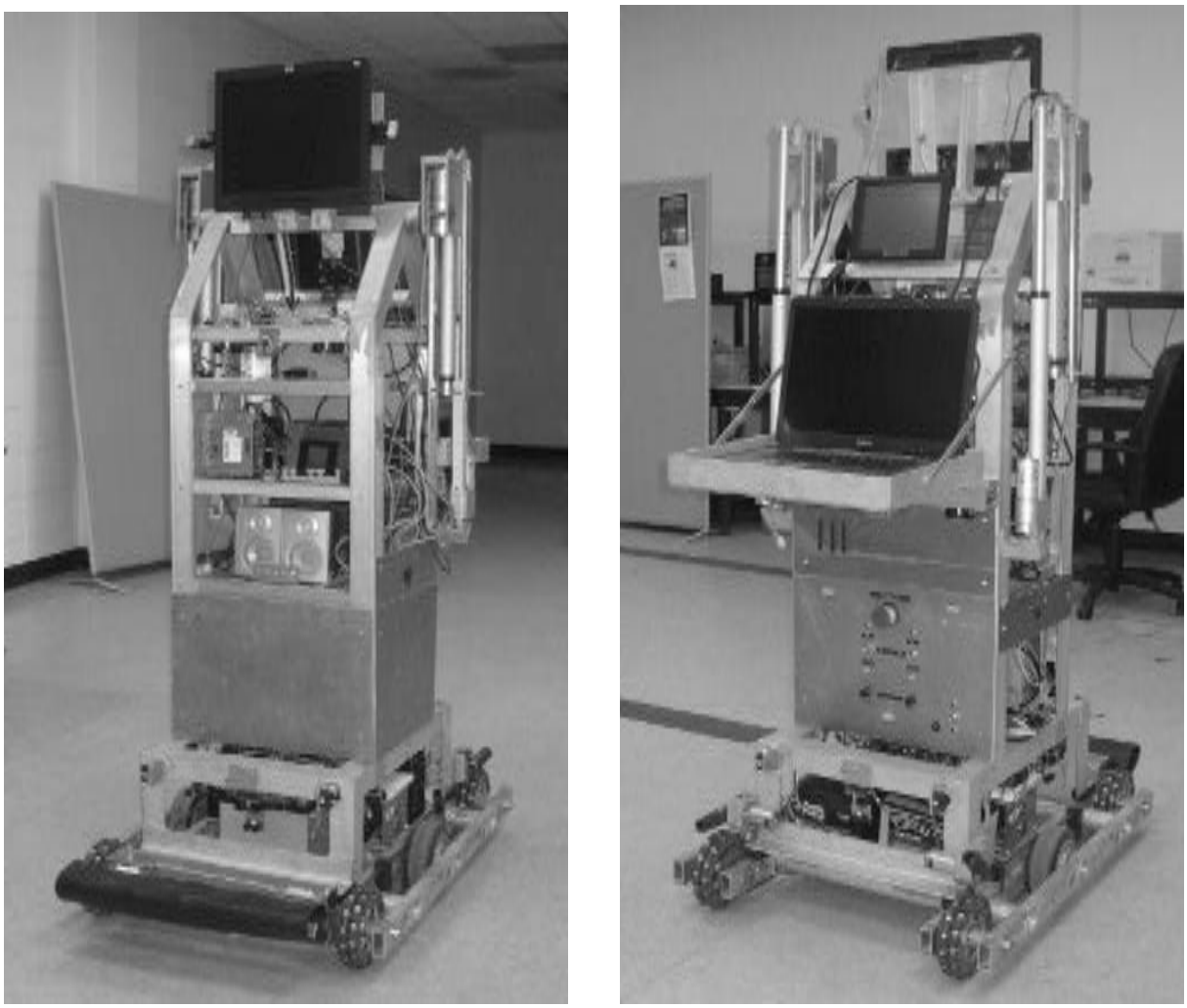
Communication between the hardware and software teams was facilitated by weekly meetings that included all project personnel. Integration issues were discussed, goals were set, and responsibilities were assigned. The faculty principle investigators and team leaders encouraged all team members to freely contribute to the discussions. Everyone's ideas and suggestions were given equal consideration. The hardware and software integration process resulted in several significant design changes, in many cases in response to suggestions by team members. Thus, the students learned that personnel outside their particular field of expertise often look at problems in novel ways.

4. Results

The scheduled project completion date was September 2009, but a 90-day no-cost extension was requested to finalize documentation and to complete two in-progress master's theses. The principle results of the JagBot project were as follows:

4.1 Hardware

The mechanical assembly of the robot chassis, body, motor controls, arms, hands, head, and sensors were completed. The real-time control system was integrated into the system and algorithms for navigation were written and tested. Virtually all of the design decisions and implementation of the subassemblies were done by ECE students. All wiring, troubleshooting, mechanical assembly, and documentation was handled by students. The students were encouraged to specify and order their own parts, a real-life engineering task that is often neglected in undergraduate engineering education. The students also were encouraged to seek outside help and consultation on the design of mechanical assemblies from the College of Engineering machine shop foreman, mechanical engineering students, and mechanical engineering faculty. This process provided invaluable experience to the ECE students in the iterative design process that they will encounter after graduation. They learned how to communicate complex information to individuals with different technical backgrounds than their own. Figure 1 shows a front view and a rear view of the JagBot with the outer skin removed.



Front view Rear View

Figure 1 : JagBot with outer skin removed

4.2 Software

Two laptop computers were used to host the high-level software. One computer was dedicated to the task of speech recognition and synthesis. The other computer was used to map tour routes, interpret sensor inputs, and provide high-level control of robot motion. The decision was jointly made by the CIS and ECE students to use ETHERNET and a dedicated hub to communicate between the real-time control system and the laptop computers. Two of the graduate students, one from CIS and one from ECE, developed a hardware control protocol that allowed communication between the mechanical systems and the laptop computers dedicated to high-level behaviors such as speech and navigation. A CIS graduate student implemented the speech recognition and synthesis system as a Master's thesis. As it turned out, the development of control algorithms was an open-ended task and, although satisfactory performance was obtained, there exists room for much refinement in navigation and situational awareness. For example, vision processing is a potentially rich navigation tool that was investigated in a cursory manner.

The only vision processing algorithm that was developed to a significant extent was edge detection to enable the robot to navigate sidewalks.

4.3 Educational

In the opinion of the researchers, the most significant end product of the JagBot project was education. There was not a single problem in robotics pertaining to the project, either hardware or software, that had not been investigated to some extent in the literature. The thing that made this research novel was that virtually all of the design work and implementation was done by students. The students gained invaluable exposure to the design process, including interacting with individuals with diverse backgrounds. They learned how to specify and order parts, how to converse with individuals outside of their specific disciplines and how to improvise in the face of unexpected problems. Engineering education in the United States does an excellent job of technical preparation, but an on-going problem is that real engineering design requires interpersonal skills and an ability to focus on non-technical problems. The JagBot project provided an opportunity for the ECE and CIS students to experience this first hand.

4.3.1 Undergraduate research

According to a report prepared by the Carnegie Foundation for the Advancement of Teaching entitled "Reinventing Undergraduate Education: A Blueprint for America's Research Universities," undergraduate research opportunities increase retention and enhance understanding in technical education.[11] The University of South Alabama provides several methods for students to become involved in undergraduate research and design. The JagBot project took advantage of this situation by involving ECE and CIS undergraduate students in the design process, assigning real responsibility for design tasks and their implementation, a situation all too rare in undergraduate education.

4.3.1.1 UCUR

The University of South Alabama introduced the University Committee on Undergraduate Research (UCUR) program in 1998 in response to a need to promote scholarly and creative activity in all disciplines at the undergraduate level, enhancing critical thinking, problem solving skills, creativity and written communication. The UCUR program emphasizes hands-on experience through summer programs in many disciplines in the university. The summer programs run for 12 weeks, during which students work with a faculty mentor and are paid a stipend. The students jointly apply for the UCUR stipend with a faculty mentor and must be at the junior or senior level in a specific program.

UCUR funding is jointly provided by the University of South Alabama Academic Affairs, individual Colleges and Departments, and the Alabama Space Grant Consortium. Students are expected to work a minimum of 20 hours per week during the 12-week summer period and are expected to formally present the results of their research at the annual University Research Forum held in the Fall semester of every year. Projects are all presented as posters accompanied by written reports, some of which are competitively selected for oral presentation.

The JagBot project included five UCUR students, two from CIS and three from ECE, who all made significant contributions to the project. In summer of 2008, one student from ECE focused on the mechanical design of the robot and one student from CIS focused on the creation of routes for the guided tour. In summer of 2009, two students from ECE focused on vision processing and navigation based on sensor input, while one student from CIS focused on integrating speech, navigation, and situational awareness. The students presented their research each year in October at the Research Forum, which provided valuable publicity for the JagBot project. Both of the CIS poster presentations were selected for oral presentation at the forum, one in October of 2008 and the other in October of 2009.

4.3.1.2 CSEM

The University of South Alabama received a grant from the NSF for a Computer Science, Engineering and Math (CSEM) Research Scholars Program, which provides scholarship funds for students with financial need and academic excellence. The CSEM scholarships give students the opportunity to gain practical experience and enhanced professional development by working on a specific project with a faculty mentor. The students are expected to work a minimum of 15 hours per week during and academic semester and are expected to present the results of their research at the annual Research Forum.

The JagBot project included four CSEM students, two from CIS and two from ECE. Topics included route planning, the creation of a sensor database (CIS), robot safety systems, and the creation of navigation algorithms based on image processing (ECE).

4.3.1.3 Senior design projects

The students in the ECE department are expected to complete a senior capstone design project as a required part of their educational experience. The projects address design issues that the students are likely to encounter on their jobs, so they are required to specify multiple design approaches, select a particular approach based on design principles, and implement that approach. The JagBot project was an excellent opportunity for senior design projects.

Three ECE students completed senior design projects in 2008 and 2009, one project involving the electromechanical design of the hands and arms, one project involving the specification of the data acquisition system and sensors, and one project involving the use of global positioning for robot navigation. The results of the senior projects were presented to the ECE faculty and formally defended by taking questions from faculty members, students, and representatives of the ECE department Industrial Advisory Board.

4.3.1.4 Assessment

UCUR and CSEM students are required to present the results of their research in the Annual Research Forum held in March every year. They prepare and display a poster, participate in discussions, and give invited presentations of their research to an audience of faculty, students, and other interested parties. Two UCUR students from the JagBot project were invited to present the results of their research on robot navigation and on robot control system design.

Although not a formal assessment procedure, the results of undergraduate research is disseminated to the entire campus, thus increasing the visibility of undergraduate research as a whole and encouraging future student participation. This is very much in accordance with NSF requirements for funding educational projects such as JagBot.

In order to maintain ABET accreditation, USA must show that senior design projects meet certain criteria. To do so, there is a formal assessment procedure.

- All senior projects in the College of Engineering are presented in a public forum during the Spring semester of each year.
- The students prepare and present the results of their projects.
- The audience consists of students (peers), faculty, members of the College and Departmental industrial advisory boards, and any other interested parties.
- After the formal presentation and question and answer period, the attendees are requested to complete an assessment form for each project. The form includes questions on content, visual aids, the presenter's delivery, the presentation mechanism, responses to questions, quality of English in the written report, and the technical writing content of the final report. Each question is rated on a 1-5 scale, the student must receive a minimum aggregate score of 3.5 to pass.
- The results of all presentations are averaged to obtain an overall senior project assessment number that is reported at the yearly ECE Faculty Retreat. An average below 3.5 is considered to be the threshold at which action is taken. The specific action is agreed upon by the constituents at the Faculty Retreat. This is in keeping with ABET's requirement that assessment drive continual program improvement.
- The three students who presented senior projects from JagBot all received satisfactory scores.

4.3.2 Graduate research

The University of South Alabama has master's programs in both CIS and ECE. Three master's theses specifically addressed aspects of the JagBot's design and implementation, one in ECE and two in CIS. One thesis in CIS, completed in 2008, specifically focused on speech interpretation and synthesis.[12] The other CIS thesis, still in progress, is focusing on situational awareness based on intelligent processing of sensor data. The ECE thesis, still in progress, is focusing on navigation of the robot using neural networks and fuzzy systems. All three Master's students have already co-authored conference papers on their thesis topics and have made presentations at international conferences.

4.3.3 Curriculum development

Early in the project, the decision was made to utilize the LabView graphical programming language developed by National Instruments. The students were inspired by the versatility and ease of use and were motivated to learn LabView on their own. Their enthusiasm resulted in funding from the College of Engineering and the Student Government Association to obtain data acquisition hardware and a College-wide license for LabView. As a result, a dedicated course in LabView and virtual instrumentation has been developed and added to the ECE curriculum as a

dually-listed senior/graduate technical elective. Since more and more industries are adopting LabView as a standard programming environment, the students with a background in LabView programming will have an advantage when interviewing for positions in industry.

In addition to providing an opportunity to obtain funding for data acquisition hardware and the LabView software, the JagBot project provided an opportunity to lay the groundwork for a data acquisition laboratory. It is expected that this laboratory will be utilized by all departments in the University of South Alabama College of Engineering and will provide an opportunity for interdisciplinary collaboration for undergraduate students, graduate students and faculty.

4.3.4 Publications and presentations

The investigators and students have been very active in publishing and presenting the results of the JagBot research. Presentations were made at the 7th International Conference on Computing, Communications and Control Technologies (CCCT 2009)[13] and the 7th International Conference on Education and Information Systems, Technologies and Applications (EISTA 2009)[14] both held in Orlando, Florida. Papers were also presented at the WorldComp08, 2008 International Conference on Artificial Intelligence (ICIA 2009)[15] and WorldComp09, 2009 International Conference on Embedded Systems and Applications (ESA 2009)[11] in Las Vegas, Nevada. Additional publications are currently under review. In the papers mentioned above, graduate students affiliated with the JagBot project actually made the oral presentations at the conferences and were listed as co-authors, which not only provided experience in attending and presenting at a professional conference, but also resulted in publications as part of their professional development.

In addition, the JagBot has received publicity from the Mobile Press Register and the University of South Alabama campus newspaper. Presentations and demonstrations have been made to professional societies, such as the Mobile section of the IEEE, and JagBot is a regular participant in recruitment of incoming students, continuing education classes, engineering open house, and prospective student recruitment from area high schools and middle schools.

5. Conclusion

In conclusion, it is difficult to imagine a project that has benefited both graduate and undergraduate research education to the extent that the JagBot project has. Opportunities for state-of-the-art hardware development, multidisciplinary experience, working with mentors, solving real-world problems, and presenting results to peers were unprecedented. It should also be mentioned that both the ECE and CIS programs are ABET accredited and a compelling case can be made that the JagBot project directly addresses all of the ABET outcomes a-k, which is unusual.

5.1 Summary of Results

- Five undergraduate students were funded through the UCUR program for summer research.

- Four undergraduate students received CSEM scholarships to help complete their undergraduate degrees.
- A dually-listed graduate/ undergraduate course in LabView was developed as a direct result of the JagBot project.
- Three Master's students either completed or will soon complete theses directly related to JagBot. Two of the three students have been accepted into Ph.D. programs, one at the University of Utah, one at the Georgia Institute of Technology.
- Three senior design projects were completed and successfully defended.
- The University as a whole has received favorable publicity from the JagBot project.
- The JagBot has been featured in Engineering Open House presentations, Computer and Information Sciences recruitment presentations, and student recruitment visits.
- Six papers directly related to JagBot have been presented at conferences in robotics, embedded systems, engineering education, and artificial intelligence.

5.2 Lessons Learned

It was the hope of the researchers that the JagBot project be an opportunity for even broader multidisciplinary interaction, particularly in the context of undergraduate capstone design. An effort was made to engage mechanical, civil and chemical engineers, but the senior projects for mechanical engineering students in particular span an entire year rather than a single academic semester. The project would have greatly benefited from mechanical engineering expertise in the areas of drive train design and mechatronics. At USA, Chemical engineers are required to take courses in instrumentation, controls, and real-time data acquisition, all of which were integral parts of the JagBot project. Civil engineering is a harder sell, but USA's Costal Engineering program has approved senior projects in wave height measurement, autonomous underwater vehicles, environmental monitoring, and embedded instrumentation, all areas that require the same skills used in robotics.

Undergraduate engineering education at USA is still parochial in the sense that some students and faculty look at the disciplines as being "separate but equal" with their own ways of doing things. In this sense, education doesn't reflect present industrial practice, in which it is very common for engineers of various disciplines to participate in project teams. This is gradually changing at the University of South Alabama with the introduction of younger faculty, which are encouraged by the College of Engineering leadership to actively seek partnerships with other engineers and researchers outside of the College of Engineering. These efforts are beginning to bear fruit with recent proposals submitted to NSF involving teams from Electrical Engineering, Chemical Engineering, and the College of Medicine; funded research in composite materials for NASA involving the Mechanical and Electrical Engineering Departments; and proposals submitted to the NIH teaming the School of Computer and Information Sciences, the Department of Electrical Engineering, the Department of Sociology, and the Department of Geriatric Medicine.

5.3 Future Work

Many problems still remain to be solved and, although the JagBot project was successful in the sense in that all technical goals were either met or exceeded, many questions and issues were

uncovered that will keep researchers busy for years. Additional NSF funding is also being sought; for example, a recent proposal was submitted to design and build a robot that can ride on a Mardi Gras float and participate in a Mardi Gras parade as a member of a mystic society. This project will require situational awareness, response to speech, recognition of landmarks and individuals, and the ability to throw trinkets to a crowd. Even though the funding for JagBot has expired, the robot can still be used as a development platform for additional senior projects, UCUR projects, and Master's theses.

The JagBot is also expected to act as recruitment tool for prospective high school, middle school, and transfer students. JagBot is tangible proof that robotics is a major part of engineering education at USA and plans are being made for JagBot to participate in the USA graduation ceremony either in Spring 2010 or Fall 2010.

To summarize, the students that worked on the JagBot project were enthusiastic and consistently surprised the principal investigators with their dedication, innovation, and problem solving skills. Although the goal of the SGER JagBot project was to design and build a tour guide robot, the main result was enhancement of engineering and computer science education at the University of South Alabama.

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