# Documentation of Automation Projects

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This paper describes a method to teach documentation skills as part of automation design projects. At the beginning of the semester, students are given a simple automated system and assigned the task of improving it in some sense. They are guided through the following steps: generate ideas for improving the existing system, prepare a proposal for approval by the instructor explaining the improvements, plan and execute the approved modifications, and prepare technical documentation. Students work in teams of three to four students. The projects are carried over from year to year. At the beginning of a semester, each team receives all the documentation generated the previous semester. The students understand that the documentation they generate will be useful for other students in the future, therefore they are motivated to produce clear and complete reports. Documents generated include: project proposal, project technical report, user manual to operate the project, poster board, and video tape of final presentation. Results from this laboratory are encouraging. The level of motivation in students is very high, and most of them complete the course with a very good understanding of concepts discussed in class.

## Introduction

Being able to document design projects and communicate results is an important skill for practicing engineers. There are reports in the literature [2, 3] that discuss methods to improve teaching these skills to undergraduate engineering students. Audeen Fentiman [2] indicates that students do not learn much by writing final reports poorly and receiving feedback in the form of instructor comments and a grade. Students can benefit the most by doing it properly. Therefore students should be given the opportunity to correct deficiencies, which requires instructors to plan report deadlines a week or two earlier than normal to allow enough time for grading by the instructor and make corrections by the students. The approach presented in this paper requires students to correct deficiencies in their documentation as shown in the Gantt charts in Figure 1 (activities 13, 14 and 15), and in Figure 2 (activities 13, 14, 15 and 16).

From experience in conducting courses with projects in which students are required to design and build something, students often prepare design documents after the project is built only to satisfy the instructor's requirements. For example, I recall an instance in which an electrical engineering student avoided preparing a wiring diagram until the device was completely wired. There were several corrections done to the wiring during construction, and the student argument was that he wanted to avoid redoing the diagram after each change. That argument neglets the likely possibility that by using a wiring diagram as a planning and design tool, the corrections made to the wiring could have been avoided. Another example is the use of a Gantt chart as a project planning and control tool. I have seen many industrial engineering students prepare very poor Gantt charts at the beggining of their projects, and fix them after the project is completed, only to satisfy final report requirements. The student's argument in those cases is that they would not know the steps required to complete the project until it is finished. Hence, they miss the opportunity to learn the proper use of Gantt charts for project planning and control.

The material presented in this paper has been used in conducting laboratory projects of an introductory level manufacturing automation course for industrial engineering students. In its current format, this laboratory incorporates various aspects of engineering practice into a learning experience. This environment can be very effective in developing engineering skills such as problem identification, problem solving, engineering design, teamwork, project planning and control, communication, documentation, and oral presentations. This paper focuses on the documentation skills, other details regarding this laboratory were presented previously [3].

## Basic Course Structure

This laboratory is part of a course oriented to freshman and sophomore level students. The course objective is to introduce students to the fundamentals of computer controlled processes and mechanisms. The only prerequisite is a previous course in computer programming in which the students learn C-language. The book "Robots and Manufacturing Automation" by Ray Asfahl [1] is utilized as the text, and is supplemented with handouts.

The lecture portion of the course includes first a discussion of various types of automated production systems. It is followed by a description of various types of sensors and actuators, control concepts and analytical tools to design switching and continuous type of controllers. Finally, there is a review of some current applications such as numerical control, industrial robots and computer vision. The course has three exams including the final. The grading criteria for the course gives a weight of 20% for each of the three exams, 30% for the laboratory project, and 10% for all of the homework assignments.

The class size has been fairly stable between 25 to 30 students during the last few years. The students are divided into eight teams in order to develop their laboratory projects. The size of each team is three to four students, and each team works in a different project. Each team is free to organize their activities, and there is no fixed time allocated for this laboratory. The students can work at any time or day throughout the semester.

The laboratory projects follow the plan shown in Figures 1 and 2 below. There are fourteen weeks in a regular semester, and the activities are divided in two stages: project planning which terminates in an approved proposal (see Figure 1), and project development which executes the plan or proposal (see Figure 2). The students receive copies of these Gantt charts as examples, and they are free to modify them to fit their individual projects.

| ID | Name | Duration | Predecessors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project Planning & Proposal | 19d | | | | | | | | | | | | | | | |
| 2 | Learn about the existing system | 5d | | | | | | | | | | | | | | | |
| 3 | Video tape | 1d | | | | | | | | | | | | | | | |
| 4 | Run existing system | 2d | 3 | | | | | | | | | | | | | | |
| 5 | Review reports | 2d | 4 | | | | | | | | | | | | | | |
| 6 | Find opportunities to improve existing system | 4d | 5 | | | | | | | | | | | | | | |
| 7 | Select and prioritize improvements | 2d | 6 | | | | | | | | | | | | | | |
| 8 | Draw diagram of the improved system | 1d | 7 | | | | | | | | | | | | | | |
| 9 | Write description of improved system | 1d | 8 | | | | | | | | | | | | | | |
| 10 | Write description of automated operation | 1d | 9 | | | | | | | | | | | | | | |
| 11 | Calculate expected performance improvements | 2d | 10 | | | | | | | | | | | | | | |
| 12 | Prepare proposal report | 3d | 11 | | | | | | | | | | | | | | |
| 13 | Submit Proposal Report | 0d | 12 | | | | | | | | | | | | | | |
| 14 | Grade reports (by faculty) | 3d | 13 | | | | | | | | | | | | | | |
| 15 | Correct proposal | 4d | 14 | | | | | | | | | | | | | | |

**Figure 1. Gantt Chart for Project Planning and Proposal**

| ID | Name | Duration | Predecessors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project Development | 37d | | | | | | | | | | | | | | | |
| 2 | Mechanical modifications (construction) | 14d | | | | | | | | | | | | | | | |
| 3 | Table of input and outputs | 3d | | | | | | | | | | | | | | | |
| 4 | Draw wiring diagram | 3d | 3 | | | | | | | | | | | | | | |
| 5 | Electrical modifications (wiring) | 4d | 4,2 | | | | | | | | | | | | | | |
| 6 | Test electrical connections & operation of sensors | 3d | 5 | | | | | | | | | | | | | | |
| 7 | Draw state-transition diagram | 8d | | | | | | | | | | | | | | | |
| 8 | Software modifications | 8d | 7 | | | | | | | | | | | | | | |
| 9 | Test & debug software (by modules) | 4d | 8,6 | | | | | | | | | | | | | | |
| 10 | Test & debug software (integrated) | 5d | 9 | | | | | | | | | | | | | | |
| 11 | Write final report and user's manual | 5d | 10 | | | | | | | | | | | | | | |
| 12 | Prepare final presentation | 2d | 11 | | | | | | | | | | | | | | |
| 13 | Submit Final report | 0d | 12 | | | | | | | | | | | | | | |
| 14 | Grade final report (by faculty) | 2d | 13 | | | | | | | | | | | | | | |
| 15 | Corrections to final report | 5d | 14 | | | | | | | | | | | | | | |
| 16 | Submit complete documentation | 0d | 15 | | | | | | | | | | | | | | |

**Figure 2. Gantt Chart for Project Development**

The laboratory portion of this course also includes a set of demonstrations. The demonstrations are used to illustrate the programming, operation, capabilities and limitations of industrial grade equipment such as robots, computer vision, programmable logic controllers, and numerically controlled milling machine.

## Documentation Methodology

The innovation in this laboratory consists of giving the students an existing operational automated system including all existing documentation, and asking them to find ways to improve it. The students brainstorm and propose improvements in a written plan or proposal. After instructor approval, the students implement the plan, measure and compare the improvements achieved with those proposed, and document their work.

Since students understand that the documentation they generate will be useful for other students in the future, they are motivated to produce clear and complete reports. They are asked to critique and record problems in the documentation they receive, and use this information to avoid similar problems in the documents they generate. The documents generated include: project proposal, project final report, user's manual, poster board, and video tape of final presentation. Relevant features in each of these documents are as follows:

A. Project proposal.
The students prepare a written project plan with the proposed improvements, and submit it for approval to the instructor. This is similar to technical and economic justification required from engineers in industry when they seek approval of improvement projects and their corresponding budgets. Many important design decisions are made during the planning stage and these projects are no different. The students are asked to prepare diagrams that explain the operation of the proposed system, and capture many design decisions. These diagrams, if properly done, become part of the final report. Some examples of these diagrams are given below in Figures 3 through 6.

B. Project final report.
The final report includes all technical documents generated, specifically diagrams and tables for the mechanical, electrical, software, and automated operation aspects of the project. In addition to those the students need to explain the changes made and the results obtained. They are expected to measure performance and compare the effects of improvements made with those proposed The students receive blank forms for many of the required diagrams or tables. The advantages of using blank forms are: modularity, cleaner reports that are easier to read, completeness since missing data is easier to detect, and they facilitate interaction among various groups.

C. User's manual.
This is a manual that anybody unfamiliar with the project should be able to follow to operate the project without any assistance by the group members. This report represents a different challenge to students than a traditional engineering report, because they are used to writing reports for the instructor who is familiar the topic. It forces them to think about engineering reports in a new way. The utility of the user's manual to the instructor is that the next semester, new students unfamiliar with the projects can operate the projects with minimum assistance from the instructor.
D. Poster board.

Students are also asked to prepare a poster board which is due by the end of the semester. This board should describe their project, its automated operation, and the improvements they made to it. This also represents a challenge because there is very limited space, and text and figures have to be large enough to make them readable from a reasonable distance. This forces the students to think about what is important, and about how to explain it clearly, simply and concisely. The utility of the poster boards to the instructor is that they can be useful when having open houses or visitors touring the laboratories.

E. Video tape of final presentation.
At the end of the semester all groups make a 15 min. oral presentation of their project, including demonstrating the operation of their project and an explanations of their improvements. The time limit is strongly enforced, except for allowing questions at the end. The presentations are video taped, and copies are made available to any student that wants one. These video tapes are also provided to new students the next semester the class is offered to help them understand the operation of the project.

The next section is an example to illustrate some of the diagrams used in documenting automation projects in this course. It should be noted that the automated system shown in these examples is a very a simple one, and the projects built by students in this course are more sophisticated.

## Example

This example is used to illustrate some of the documents generated and their more relevant features. In this course, students need to include diagrams, tables, and descriptions similar to the ones shown in this section in both: the project proposal and the final report.

A. English description of the automated operation.
Figure 3 below shows a magazine and mechanism to release cylindrical components one at a time. An operator can start the mechanism by pressing a START push-button. After that, a computer controller will repeat the (automated) release cycle until the operator presses the STOP push button. Proximity sensor S1 detects the presence of a cylinder at the bottom of the magazine. Actuators A1 and A2 are solenoid plungers that retract when its solenoid is energized. The release cycle is as follows: If the position at sensor S1 is empty, actuator A1 should retract until sensor S1 detects the presence of a cylinder.  If sensor S1 does not detect the presence of a cylinder in the next five seconds, the controller should sound an alarm and turn on a red light. All alarms are reset when the operator presses the STOP push-button. If sensor S1 detects a cylinder, then at the same time that actuator A1 returns to its extended position, actuator A2 should retract. This condition should be sustained for three seconds to allow enough time for the cylinders to roll and fill the position between actuators A1 and A2. After that time actuator A2 should return to its extended position.

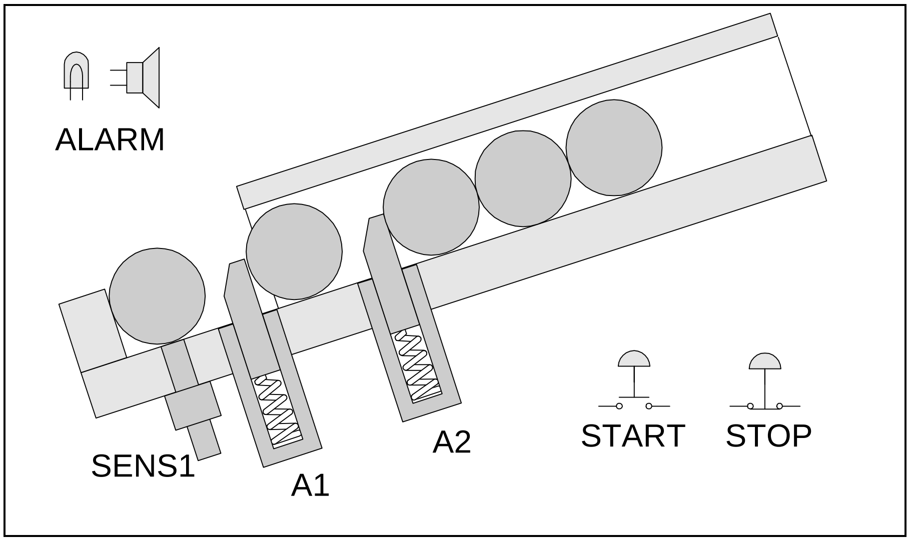


**Figure 3: Sample System Schematic (side view)**

B. Diagram of Controller and Inputs/Outputs.
Figure 4 shows a simple input/output diagram. This type of diagram is used to help the students clarify their understanding about the sensors and actuators and their interface with the controller.

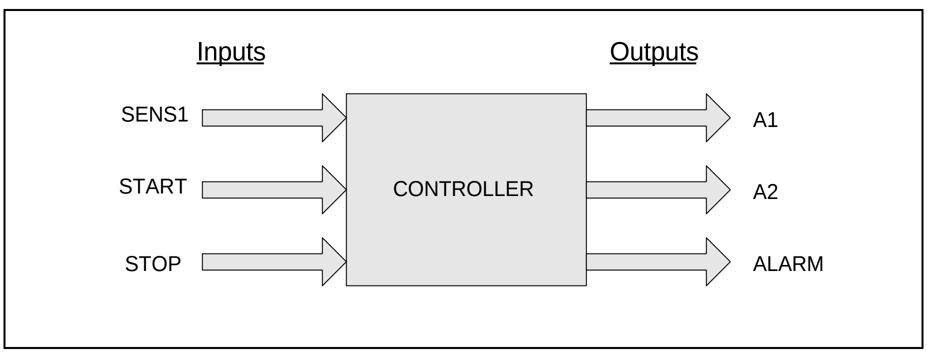


**Figure 4: Sample Diagram of Controller and Inputs/Outputs**

C. State-Transition Diagram.
Figure 5 shows a state-transition diagram, also known as a state-machine diagram. This type of diagram is used to help the students design the logic in a switching sequential controller. More information about use of this diagram for design can be found in Auslander [4], and in Bollinger [5].

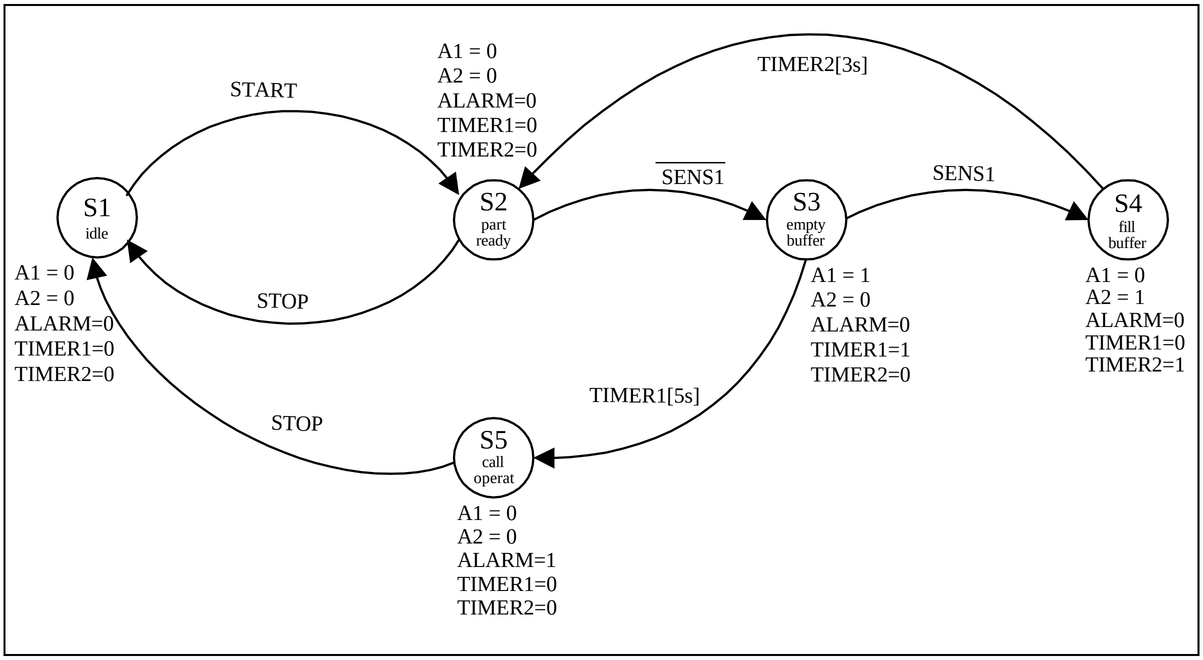


**Figure 5: State -Transition Diagram**

D. Table of Inputs and Outputs.

Table 1 shows a format used to document the interface between sensors/actuators and the controller. The students receive a blank format as well as the filled form documenting the existing project. They fill the blank form to reflect the design changes they are planning to make to improve the project. Working with blank forms provides modularity, is standard practice in engineering, helps the students concentrate on the content and not on the form, and is easier to review for the instructor.

**Input Port 1 (on-off switches)**

| bit # | sensor label | description | wire color | terminal block # |
|---|---|---|---|---|
| 0 | SENS1 | Sensor to detect part present at pick location. | red | In1-0 |
| 1 | START | Push button to start the automated cycle. | blue | In1-1 |
| 2 | STOP | Push button to stop the automated cycle & alarm | yellow | In1-2 |
| 3 | | | white | In1-3 |
| … | … | | … | … |
| 7 | | | black | In1-7 |

**Output Port 1 (on-off actuators)**

| bit # | actuator label | description | wire color | terminal block # |
|---|---|---|---|---|
| 0 | A1 | Solenoid plunger lower end, retracts energized. | red | Out1-0 |
| 1 | A2 | Solenoid plunger upper end, retracts energized. | blue | Out1-1 |
| 2 | ALARM | Alarm sound and red light. | yellow | Out1-2 |
| 3 | | | white | Out1-3 |
| … | … | | … | … |
| 7 | | | black | Out1-7 |

**Table 1: Sample Table of Inputs / Outputs**

E. Wiring Diagram.
Figure 6 shows a wiring diagram between sensors and actuators and a connection terminal available in every project. The labels in the connection terminal are standardized in all projects and they match the inputs/outputs available in the computer interface.

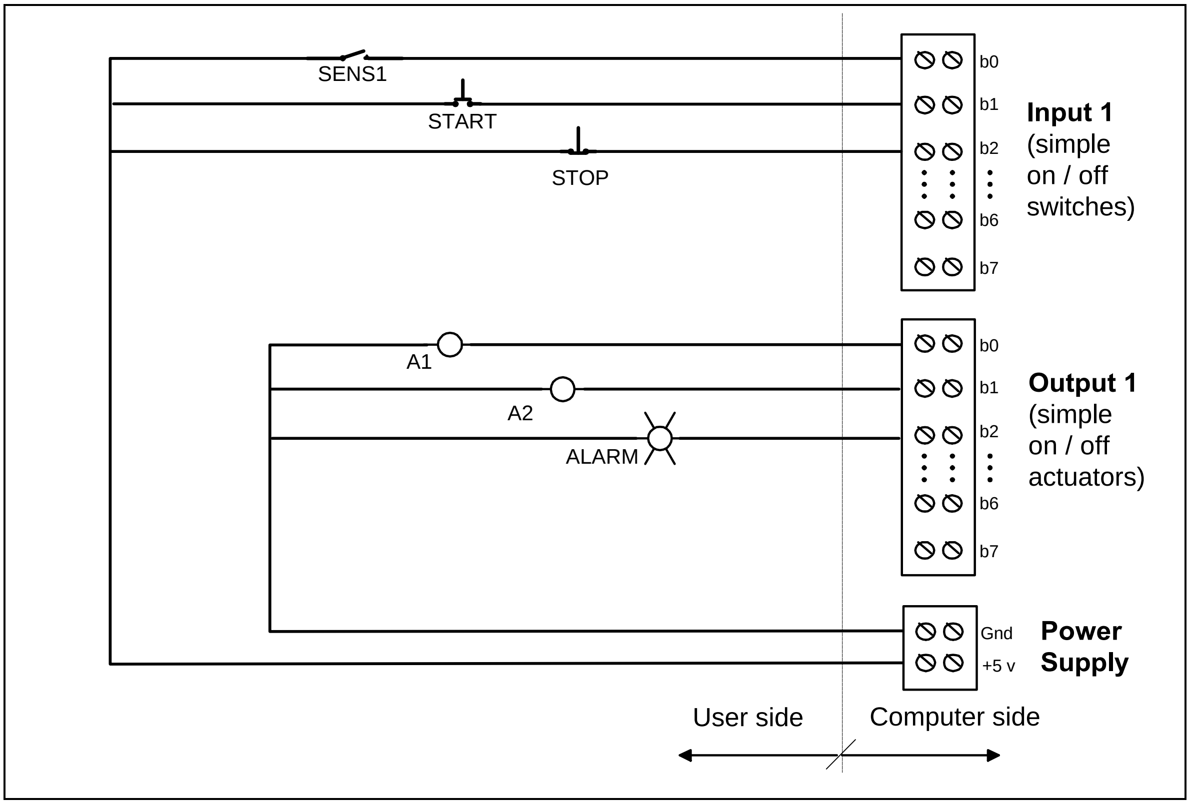


**Figure 6: Sample Wiring Diagram**

F. Project Schedule.
The project is scheduled using a project planning Gantt chart similar to the one shown in Figure 2. The project management software Microsoft Project is made available to students.

Once all the previous forms have been filled, the design phase of the project is over. All the important decisions have been made. The students are expected to reach this level of design during the planning stage of the project, and their proposal is expected to have these documents properly filled. These documents, prepared as part of the proposal, will also become an important part of the final report (perhaps with minor changes) because they contain all important decision made during the design stage. It should also be noted that this level of design does not require any knowledge of programming or controller hardware. After the instructor reviews and approves the proposal, the construction phase can begin. During construction there are several activities that often can be executed simultaneously. For example, see the Gantt chart in Figure 2. Activities 2 through 8, which are related to mechanical, electrical and software modifications, begin in week 5 and progress can be made simultaneously in these three areas for about 4 weeks.

## Results and Conclusions

Results from conducting this laboratory are very encouraging. The level of motivation in students is high, and most students complete the course with a good understanding of concepts discussed in class. In addition, the students benefit from practicing various engineering skills such as:

1) Teamwork. Students are assigned to groups for the duration of the project. They are expected to organize their teams and assign responsibilities on their own. They are encouraged to collaborate with other teams in the execution of their projects.

2) Problem identification skills. At the beginning of the project, students are asked to brainstorm and find opportunities to improve the existing system. Most sophomore students are perfectly capable of doing this, but some suffer a kind of mental block because they are used to receiving clear and complete problem statements in exams and homework.

3) Problem solving skills and engineering design. There are usually many possibilities to implement the planned improvements. The various alternatives usually have advantages and disadvantages, as well as tradeoffs between simplicity and reliability. Sometimes the selected approach does not work as expected and often engineers find that they need to "go back to the drawing board" to find better solutions.

4) The laboratory project provides an opportunity to introduce concepts on project planning and control. Several of the activities required to complete the project can be accomplished simultaneously, if there is proper coordination and communication between team members.

5) Students are required to think about design specifications and performance evaluation. Each team has to include in the proposal a description of the increases in performance they expect to achieve by implementing the planned improvements to the existing system. At the end of the project they are required to measure and report the changes in performance achieved.

6) The project is also used to develop communication, documentation and oral presentation skills. Students understand that the documentation they generate will be used by other students in the future, therefore they perceive the need for preparing clear documentation.

## References

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