ECE Undergraduate Research for *Tren Urbano*

Manuel Toledo-Quiñones

Electrical and Computer Engineering Department
University of Puerto Rico, Mayagüez Campus
Mayagüez, Puerto Rico 00681-5000

Introduction

Practical problem solving in correlation with a solid theoretical foundation and a broad background play an increasingly important role in engineering education[1,2]. This article presents a non-traditional undergraduate research and education model in which electrical and computer engineering students participate in a multidisciplinary program focused on promoting careers in mass transport. Participating students from the Electrical and Computer Engineering (ECE) Department of the University of Puerto Rico at Mayagüez (UPRM) improved and acquired skills in areas such as software development, distributed computing, embedded systems, machine vision, image processing, and multimedia. The program complements UPRM's ECE curriculum by combining a year-long development experience with participation in workshops, public presentations and report writing.

As a way of illustration, this article presents two projects being developed by ECE students as part of *UPR/MIT/Tren Urbano Professional Development* (TUPD) program, which is briefly overviewed first. The first project explores a license plate recognition system (LPRS) to monitor the presence of mini-buses at TU stations as a way to automatically maintain a database with records on their quality of service. The database can also be used for other administration or planning purposes. The other project described consists in the development of a prototype for a multi-modal automatic route planner. The route planner will use real-time information from GPS equipped vehicles. In addition historical data and heuristics will help users plan their trips by efficiently combining buses, rapid transit and walking.

Program Description

Tren Urbano (TU) is a heavy rail transit system currently under construction in the San Juan Metropolitan Area of Puerto Rico. The first phase of the project will provide service to approximately 115,000 passengers per day in one of the most densely populated and centrally developed corridors in North America. Because it is the first project of its type in the island of Puerto Rico, the training of local professionals with experience in areas related with mass transport technology, operation, and administration is of crucial importance. The TUPD program was created to satisfy this need. For the past nine years this multidisciplinary program has given undergraduate students the opportunity to perform research in areas related to transportation.

The TUPD program is funded by the government of Puerto Rico through its Transportation and Public Works Department and by the University of Puerto Rico. In brief, the main objectives of the program are to:

1. educate and train local professionals with expertise in high-technology areas related to TU's multi-modal mass transport system,
2. strengthen the university's educational and research in disciplines related to infrastructure development,
3. establish a model for cross-disciplinary collaboration between UPR faculty from engineering, architecture, social sciences and planning, in cooperation with government and industry.

More information about the TUPD program can be obtained from the program's web page[3] and from previous publications[4].

Each year approximately 30 students from the University of Puerto Rico and the Massachusetts Institute of Technology participate in the program. Each student is advised by a participating faculty in the development of a year-long project. Students and faculty advisors participate in a variety of activities that well extend beyond the boundaries of their respective profession and of traditional research. These activities include two ten-day workshops and two public talks where students present their work. The workshops bring together experts in all aspects of the development and operation of large infrastructure projects and expose students to topics ranging from engineering to urban planning and architecture. After completing their participation in the program, students may obtain a summer job working for one of the companies involved in the design and construction of TU and a full-time position upon graduation.

Automatic Detection of License Plates

In this project a LPRS is used to identify vehicles by automatically recognizing their license plates and is an example of the use of machine vision in the development of *Intelligent Transportation Systems*[5]. These systems usually include a video camera that is installed at a proper place to capture front or rear images of vehicles. The image is processed to extract the portion containing the license plate and to identify the vehicle. In each part of this process several techniques can be used. Several ways of implementing LPRS systems have been proposed[6,7,8,9,10]. Specific methods should be selected according to the application requirements.

The algorithm used in LPRS consists of the following steps: 1) capture the car's image, 2) extract the license plate, 3) recognize license plate characters, 4) identify vehicle. This section describes each of these steps.

We have been working with color images captured with a digital camera and transferred to computer memory. Our images consist of a rectangular array of 768x512 pixels. To obtain an 8-bit grayscale image, an algorithm that eliminates the hue and saturation information while retaining the brightness or light intensity information (luminance) is applied.

To determine the portion of the image that contains the license plate, the different objects present in the image are labeled. Those that have the geometrical characteristics similar to license plate characters are selected. If the relative position of the selected objects is consistent with those in a license plate, it is assumed that the plate has been found.

To facilitate the labeling process, the image is segmented according to a threshold level. Segmentation is the separation of an image's background and foreground. There are several segmentation techniques that can be used in order to achieve the proper license plate extraction.

We explored techniques based on edge detection and thresholding, and selected the later because of its superior performance. This technique takes the grayscale image *g* and produces binary image *b*, by applying a threshold to each pixel according to:

$$\text{if } g[m,n] \geq \text{ then } b[m,n]=1$$
$$\text{if } g[m,n] < \text{ then } b[m,n]=0$$

where *m* and *n* represent the pixel's row and column.

In our tests, the threshold level was initially chosen as the image's mean pixel value. This produces a black-and-white image of 1-bit pixels in which most of the background is absent, and facilitates the labeling of the objects. An example of a segmented image is shown in Figure 1.

Figure 1 Example of a binary image.

In the next step, objects are labeled using a technique known as *connected components labeling*. To recognize objects the algorithm searches every pixel and classifies groups of ones surrounded by zeros as different objects. Each group will be stored as a numbered object. Figure 2 shows an example of a label matrix *L* with three numbered objects.

1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 0 0 0 0 0 0 **2 2 2 2 2**
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 **2 2 2**
0 0 0 0 **3 3 3 3 3 3** 0 0 0 0 0 0 0
0 0 0 0 **3 3 3 3 3 3** 0 0 0 0 0 0 0

Figure 2 Example of a label matrix.

The labeled objects are then analyzed. Those objects that possess geometrical characteristics similar to those previously established for license plate characters, such as width and height, are selected. The distance between the selected objects is calculated to verify that it is compatible with that between plate characters. If so, the region of the image containing the license plate has been

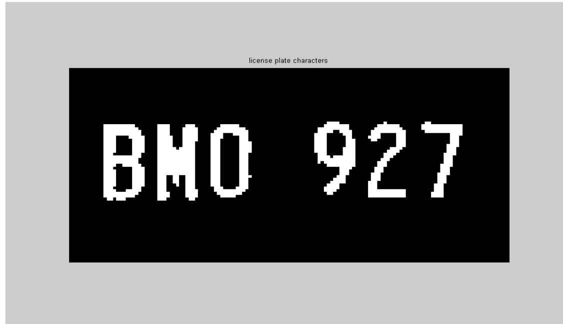

Figure 3 Extracted license.

identified, and the characters can be extracted. The plate characters extracted from the image in Figure 1 are shown in Figure 3.

If attempts to find the region containing the plate fail, the segmentation threshold is modified and the procedure performed again. This process would continue until satisfactory results are obtained or a maximum number of trials are attempted. In our tests, up to about 6 iterations were needed in some images.

Once the plate is localized, the characters are recognized using a template matching algorithm. A predefined character set *A* is compared to the characters found in the plate to select the one with maximum correlation, defined as follows:

$$R = \frac{\sum\sum(A_{mn} - A_{mean})(B_{mn} - B_{mean})}{\sqrt{\sum\sum(A_{mn} - A_{mean})\sum\sum\ (B_{mn} - B_{mean})}}$$

B represents the pixel values for each plate character. The plate number and the time at which the vehicle was detected can then be stored for latter reference in a convenient format or sent to a database server for future use.

Using this procedure it has been possible to locate license plates in several images, like the ones shown in Figures 1 and 3. Figure 4 shows an array of binary images and extracted license plates used in several tests.

The LPRS was developed in a PC using previously captured images. It is now being ported to an embedded platform that integrates an arm processor, a monochrome camera and an Ethernet network link. This new hardware will provide a modular, easy-to-use system of the type that could be deployed in the field. Students will also be characterizing the performance and robustness of the algorithms in order to evaluate the appropriateness of the system for the application.

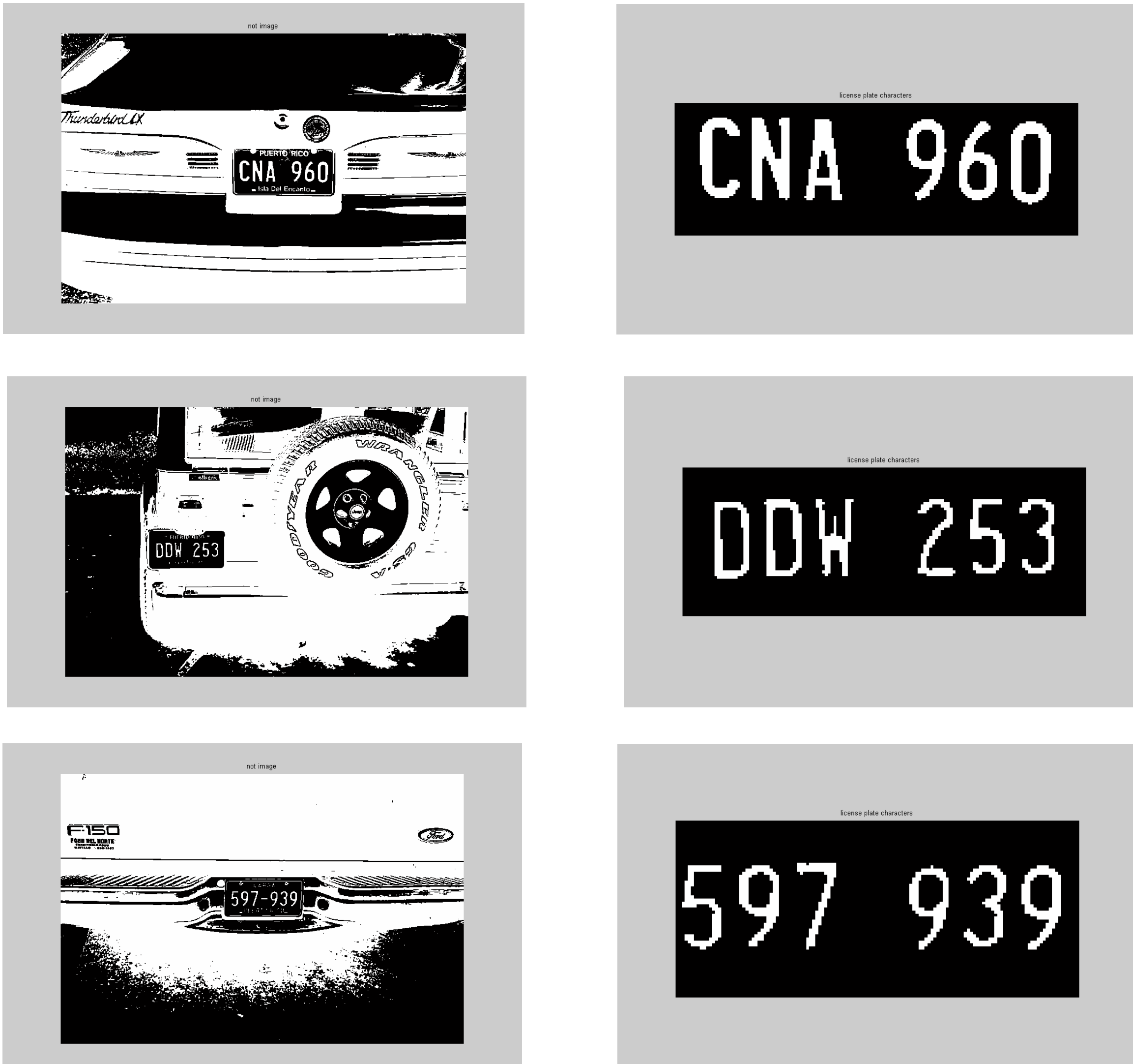

Figure 4 Examples of test pictures.

Multimodal Dynamic Route Scheduling

Many modern rapid-transport systems provide users with the benefits of an automatic route planner but include only one mode of transportation and do not take into account real-time data. This project aims at developing a prototype for an automatic route planner that will assist users when planning a trip. The objective is to include all the different modes of transportation (namely buses, heavy rail, walking) and to use GPS, historical and heuristic data when available. The user shall be able to specify origin and destination, and obtain suggestions on how to perform the trip using a combination of modes.

Early in the project we decided that a modular approach that permit easy migration to a client-server implementation make most sense because it lends itself to expansion into a computer cluster, shall the computational load so requires. This approach also facilitates development, since dummy modules can be used to replace missing functionality and to isolate specific parts of the program for easier testing. Thus the automatic router program was divided into the following modules:

- User interface front-end
- Route planner
- Generalized cost estimator
- GPS-based vehicle locator
- Database

We visualize the multimodal system as a two-dimensional set of *stops* linked by one or more connections. Each connection has an associated *cost* that measures the expected time that it would consume, but that can include other factors such as uncertainty in the estimate and other user specified preferences. The route planner determines subsets of connections that provide feasible ways to go from origin to destination, requests the connection costs for each, determines the route with the lowest cost and send it back to the user interface. The generalized cost estimator is responsible for calculating these costs based on information from the database and providing them to the route planner. The database stores live GPS data about the location of buses and other information associated to each connection. The user interface allows communication with the user.

Since the project is still in progress, only preliminary versions of these modules have been implemented. A route planner has been implemented using the *A** algorithm[11]. A public-domain distributed database is being used. Fixed connection costs have been used so far, and a generalized cost estimator is under development. The user interface front-end consists right now of simple text queries because they are convenient for the development and testing of the other modules, but will be implemented as a web page soon. Other forms of communication with the user, such as by telephone and voice, are also possible and straightforward to implement.

Conclusions

A successful model for non-traditional electrical and computer engineering education has been illustrated by describing two projects performed under the auspices of the TUPD program. They show that the TUPD program provides an excellent complement to UPRM's ECE curriculum. It provides students with the opportunity to "learn-by-doing" about important areas of increasing technological importance, such as machine vision, embedded systems, and multimedia. The program also provides students with skills of high professional value and prepares them for graduate education by complementing an undergraduate year-long project development experience with participation in workshops, public presentations and report writing.

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Biographical Information

Manuel Toledo-Quiñones finished his BS the Electrical Engineering Department at UPRM in 1979, his MS in Applied Physics at the University of Massachusetts in 1989, and his Ph.D. in the Electrical, Computer and Systems Engineering Department at Boston University in 1995. He joined the University of Puerto Rico in 1998, where he has been an assistant professor at the Electrical and Computer Engineering Department. He is currently involved in projects in the areas of wireless micro-sensors, watermarking of medical digital images, automatic detection of vehicle license plates, modeling and simulation of Chemical Vapor Deposition, and vehicle tracking using GPS.