University Transportation Research Center - Region 2

Final Report

Using Mobile Computers to Automate the Inspection Process for Highway Construction Projects

Performing Organization: University of Puerto Rico - Mayagüez

December 2013

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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16. Abstract

Highway construction projects are characterized by the large amount of data that needs to be collected, processed, and exchanged among the different project participants. Collection of construction inspection data, in particular, allows field personnel to monitor project performance with the ultimate goal of improving productivity and lowering costs. The accomplishment of these two goals could lead to better construction project management and performance that could in turn reduce the time required for project delivery.

Current practices for recording and filing field inspection data are mainly paper-based. The manual process using paper forms is a time consuming and tedious task. Not only is the clerical expense of this process very high, but also the organization and review of the information commands an inordinate amount of time by a project manager, of which most managers posses very little. Continuous evolvement and improvements of mobile computing such as iPADs and Android Tablets, software technologies including more powerful processors, smaller storage devices, higher quality displays, and wide availability of third party application software, have made it possible for these devices to become stand alone systems with powerful functional capabilities. Because of their high mobility characteristics due to their small size and lightweight, these mobile devices can be used in the highway construction field to perform various tasks including recording of inspection data. The use of such mobile devices in construction processes seems to be the next logical step.

This report communicates the research findings of the development of a mobile computing application for automating the collection process of field inspection data using iPADs or Android Tablets. The use of this application results in a more efficient data collection process, and faster transfer of information between the parties in a highway construction project, therefore improving the current communication process. After the application was developed, the research team tested it in several highway construction projects, and positive feedback was received from the users of the application.

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Executive Summary

Highway construction projects are characterized by the large amount of data that needs to be collected, processed, and exchanged among the different project participants. Collection of construction inspection data, in particular, allows field personnel to monitor project performance with the ultimate goal of improving productivity and lowering costs. The accomplishment of these two goals could lead to better construction project management and performance that could in turn reduce the time required for project delivery.

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1. Introduction

The construction industry is inevitably characterized by generating vast amounts of data. Such data includes inspection data (e.g. quantities installed, project field conditions, project status), work instruction data (e.g. information on how to assemble material), and maintenance data (e.g. items and equipment needing repair and patching), among others. The generation of vast amount of inspection and maintenance data is characteristic of highway systems. The amount of construction operations involved in the creation of transportation systems is immense when compared to a typical housing project. Of particular importance, in our case, is the construction and remodeling of highway systems in Puerto Rico. Inspection and maintenance data is generated on a daily basis, with the frequency of daily data generation being very high. Not only data is generated during the construction phase of a highway system, but also, when the route is being inspected for compliance. In addition, maintenance data is generated when the route is being repaired, and when the equipment is being maintained.

Construction inspection data allows field personnel to monitor project performance with the ultimate goal of improving productivity and lowering costs. Examples of recorded inspection data include such things as weather conditions, quantity and location of materials delivered and stored on site, quantity and quality of work performed, project progress status, accident records, and so on. In addition, inspection allows for quality control and quality assurance, critical aspects for the overall success of the project. Quality control and assurance are vital for compliance not only with owner requirements, but also with federal and state regulations.

2. Justification

Effectively managing such an immense volume of information to ensure its accuracy and availability in a timely manner is crucial to the successful operation of the transportation system and to ensure a safe operation of the overall system. Therefore, the efficient collection of such data and its timely communication should be of critical concern to all members of the industry. Efficient and timely communication of data could result in an improvement of the time required to complete a project or project delivery. For example, if a deficiencies report can be sent electronically, immediately after the inspection data is collected, the contractor will be able to correct deficient work much faster, which, in turn, leads to shorter delivery times for the completion of the project.

Current practices for data collection at the highway construction jobsite rely mainly on paper-based forms to compile information. Recorded data is, therefore, manually sorted and filed. When needed, the user must search, retrieve and distribute the records manually. This collection, filling, and distribution of paper form, in this manual process, is time consuming and prone to error.

Time spent in collecting, filing, and distributing paper forms in a manual process raises many concerns. Not only is the clerical expense of the process very high, but also the organization and review of the information commands an inordinate amount of time by a project manager, of which most project managers possess very little. In response to such concerns, a first attempt to solve this problem is to transfer the information once collected to a computer database where it can be viewed, manipulated, and distributed electronically. Although this method helped save vast amounts of time in terms of the processing and presentation of data, it did very little to eliminate the use of paper forms, and still required double manipulation of data, once to collect on paper in the field, and again to enter into the PC.

The conceptual model for transforming the manual data processing and filing effort into an automated database management system is a relatively easy concept to understand. Essentially, a computer database is nothing more than an automated version of the manual process. For example, like a filing cabinet, a computer database accepts and stores information in a structured format that the user defines. These areas of storage are known as database tables. In addition, as with paper-based forms, the use of a digital form interface in database applications helps facilitate the entry of information into these tables. Specific portions of the stored information can then be retrieved through the use of a query language, and calculations and comparison processing is possible with the support of built-in functions. To conclude the process, graphs, charts, and reports can then be formatted and displayed based upon queried results.

Although this second method helps save vast amounts of time in terms of the processing and presentation of data, it does very little to eliminate the use of paper forms altogether. Specifically, this process still requires double manipulation of data, once in the field as well as re-entry of the data in the office. This issue raises additional concerns, for it increases the possibility for typographical errors, causing inconsistencies in information as well as loss of information in some instances.

With the introduction of new and improved portable technologies in recent years, such as iPads and Android Tablets, a more complete solution to the problem of duplicate manual entry of data has emerged. With recent advancements in handheld platforms, portable devices can now be taken to the site in a form small enough to fit in the palm of the hand. Data can then be digitally recorded, and collected the first time without the use of paper forms. In addition, by using wireless technologies, recorded data can be transmitted in real time to the jobsite trailer PC or to other remote locations. The ability to transfer data directly from the handheld device, while doing the inspection, accelerates the notification process of any possible problems encountered. Corrective actions could be taken more rapidly than using the current paper forms, because the data is transmitted instantly and electronically to the interested parties. This process is illustrated in Figure 1.

At present, software that allows storing a digital form of the construction drawings has been developed. Incorporating this type of software into the process formerly illustrated could be useful while doing an inspection. With this feature, the inspector could view in the handheld device a graphical representation of the process being inspected, without the need of carrying a bulky amount of plans that could make the inspection process difficult. It could also add features to minimize misinterpretations of the two-dimensional construction plans, like three-dimensional drawings, which facilitate the visualization of the data to be inspected.

Figure 1: Conceptual implementation of Mobile Computer application for automated field data collection

Such applications exhibit considerably increased control over data accuracy and efficiency as well as offering a much improved solution to two of the most vital concerns in construction: saving time and improving communication. Prototype applications of such fully automated data collection efforts have already become evident in today's construction industry.

Paper based data collection in the field has been used in the construction industry for a long period of time. The use of paper-based forms will continue until the construction personnel realize the benefits of automating the field data collection process. One of the advantages of automated field data collection over manual data collection includes the elimination of double entry of records, which minimizes errors while re-entering data for record generating purposes. Other benefits include the reduction of paperwork, automatic generation of reports, faster data distribution due to automatic generation of reports, and increase in efficiency in the overall process, which translate into cost savings due to reduction of labor time.

The compact size of handheld units, such as iPads and Android Tablets, allows them to be easily carried to the construction site, and with the ability to connect to the Internet, all project data can be easily accessed and updated. The ability to transfer data wirelessly is a major advantage since maintenance and inspection data can be transferred to the interested parties as soon as the inspection process is finished. Some advantages of using handheld devices over conventional laptops include:

- Handhelds are extremely portable and could be carried anywhere relatively easily when compared to laptops
- Handhelds are very flexible and allow any kind of application to be programmed and run in their operating system
- Handhelds can be easily used by any person, and does not required expertise knowledge with computers
- Handhelds allow rapid transfer of the data collected to a corporate database

The time savings derived from the use of a handheld device to complete forms, input the data into a computer system, and filing reports could present greater cost savings for the company. Not only there are savings in clerical expenses and management time, but also savings in material, transmittal of reports, storage space and decommissioning of old reports. The cost of handheld technologies has decreased in recent years, at the same time that the capability of the devices has increased, making their implementation in the job more feasible everyday. Furthermore, by changing from typical paper forms to digital format we are addressing an environmental concern. The information that can be stored on a CD represents a big amount of trees that will be saved. Twenty-four trees are required to make one ton of paper. "*Every person in this USA requires an average of 750 pounds of paper per year. The wood fiber equivalent is 3,125 pounds. A family of four uses one-half of a fully loaded logging truck of pulpwood per year. That is a lot of dead trees*!" "*400 billion trees are cut every year to make paper*" (http://www.ecopaperaction.org/). Therefore, the use of handheld devices is not only cost effective for the construction industry, but is also beneficial for the environment.

3. Methodology and Results

The purpose of this research was to develop a mobile computing application to automatize the data collection process of field inspection in highway construction projects. As a final result, two applications were developed, one for Android Tablets and one for iPads. The research team named the application "TAIP", acronym for **T**ransportation **A**utomated **I**nspection **P**rocess.

Both applications work with checklists created for each of the specifications that appear in the *Manual of Standard Specifications for Road and Bridge Construction* of the Puerto Rico Highway and Transportation Authority (PRHTA). These checklists contain the aspects that the field inspectors have to inspect for compliance during the work of the contractor. The aspects were created in a format to be marked as: complies or does not comply.

3.1 Development of the Android Application

The Android application was developed with a simple interface, and added functionalities that are not possible in the regular paper-based inspection form. It was created as a device-based application, which means that the application is associated to a device and not to a specific inspector or project. This characteristic enables the application to be used for multiple projects and by different inspectors.

The application was developed in a way that allows the inspector to easily fill the inspection form, digitally sign it, save it, and convert it to a PDF version for distribution. In addition, the inspector can take photos using the device's built-in camera, and integrate them into the report as evidence of the work inspected. The inspection forms and reports are provided in two languages, English and Spanish. The user has the option of deciding the language of preference. An example of the inspection form is illustrated in Figure 2.

An inspection form is divided into four main parts as depicted in Figure 2. The parts are described as follows:

1. **Project Basic Information.** The first part contains the project basic information, which includes: the name of the inspector filling the form, the name of the project being inspected, city, location, date and time, and the report identification number. This part of the report appears automatically filled when the form is opened, since the information is previously collected in a different window.
2. **Inspection Aspects.** The second part contains the aspects to be inspected for a certain job. After a certain aspect is inspected, the inspector indicates if the aspect complies by marking in the form: Yes (it complies), No (it doesn't comply), or N/A (it doesn't apply). Below every aspect, a space is provided for additional comments.
3. **Pictures.** The third part consists of an area in which the inspector can include pictures. The photos can be taken with the device's built-in camera, and can be erased and retaken as needed. Each photo contains a space for a description and/or comment.
4. **Sign and Distribute.** The fourth part provides the signature and distribution of the report. First the inspector needs to indicate if the job passed the overall inspection by checking the box provided for this matter. Then the user should indicate to whom a copy of the inspection report should be sent, which can be done by selecting from the distribution list provided. Finally, the inspector needs to digitally sign the report for final approval and submittal.

As stated before, the application is capable of creating a PDF file of a completed inspection report. The PDF report structure is similar to the structure of the inspection form. Once the PDF version of the report has been created, the user can easily share the document via e-mail, as well as upload it to a cloud storage service. An example of the PDF report created using the application is shown in Figure 3.

The application stores locally the completed and draft inspection forms, so the user can easily access them. The application also stores the inspector's information and the project's basic information, so the user does not have to repeatedly fill the same information in different specification forms when inspecting different parts of the same project.

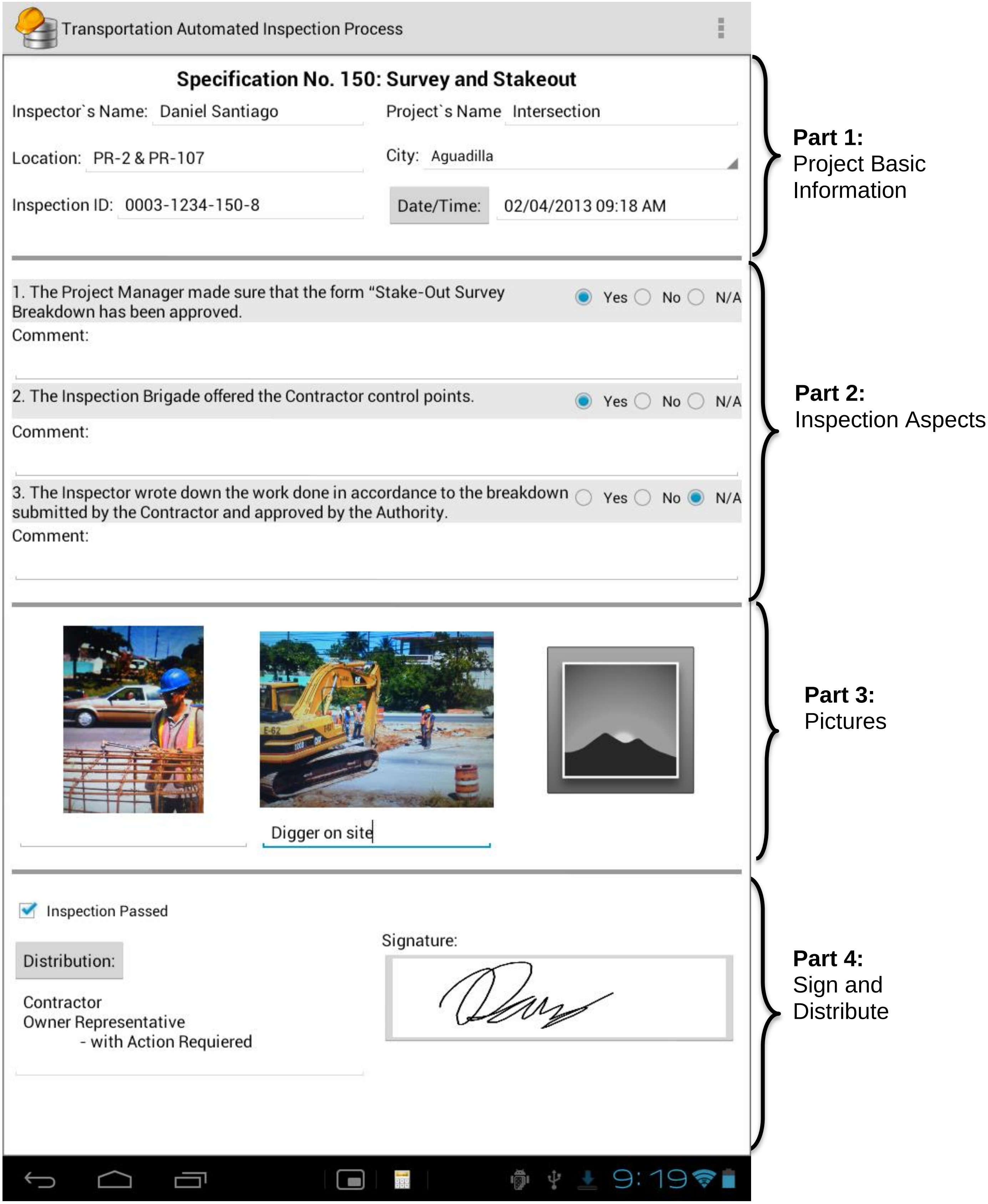
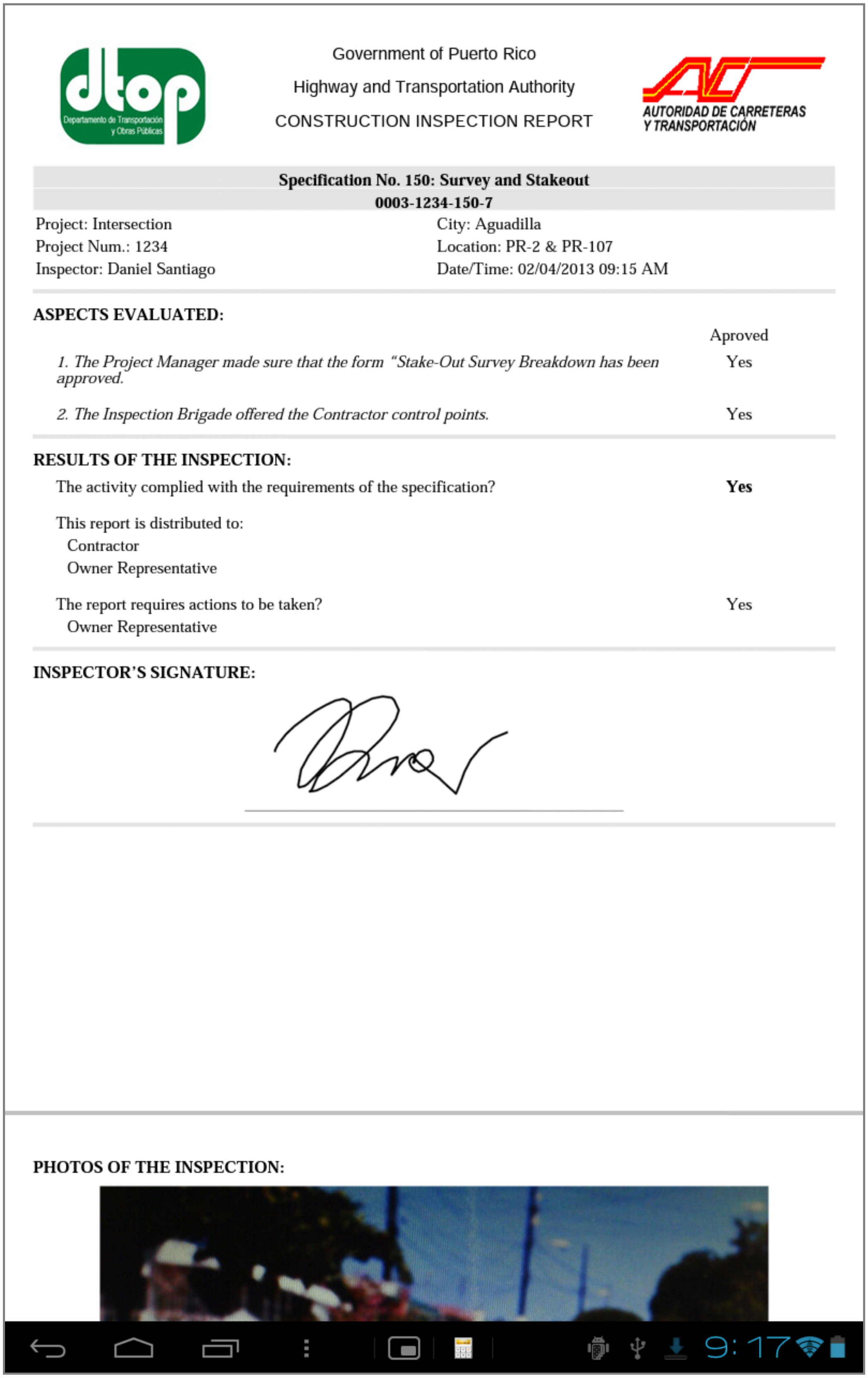


Figure 2: Example of the Inspection Form in the Android Tablet



Government of Puerto Rico

Highway and Transportation Authority

CONSTRUCTION INSPECTION REPORT

AUTORIDAD DE CARRETERAS Y TRANSPORTACIÓN

Specification No. 150: Survey and Stakeout

0003-1234-150-7

Project: Intersection	City: Aguadilla
Project Num.: 1234	Location: PR-2 & PR-107
Inspector: Daniel Santiago	Date/Time: 02/04/2013 09:15 AM

ASPECTS EVALUATED:

	Aproved
1. The Project Manager made sure that the form "Stake-Out Survey Breakdown has been approved.	Yes
2. The Inspection Brigade offered the Contractor control points.	Yes

RESULTS OF THE INSPECTION:

The activity complied with the requirements of the specification? **Yes**

This report is distributed to:
Contractor
Owner Representative

The report requires actions to be taken? Yes
Owner Representative

INSPECTOR'S SIGNATURE:

PHOTOS OF THE INSPECTION:

Figure 3: Example of the PDF Report

Moreover, the application can be used in either portrait or landscape mode. The portrait mode was shown in Figures 2 and 3, and the landscape mode is shown in Figures 4, 5 and 6. While using the application in landscape mode, an additional menu is shown at the right side of the screen, as shown in Figure 4. Also, the application has a tab where all the previously worked forms are available to open as the inspector desires. This feature is shown in figure 5. In addition, the application has the menu of all the inspection forms from which the inspector chooses the desired specification to work on. This is the first step after opening the application and identifying the name of the inspector. The menu is shown in Figure 6.

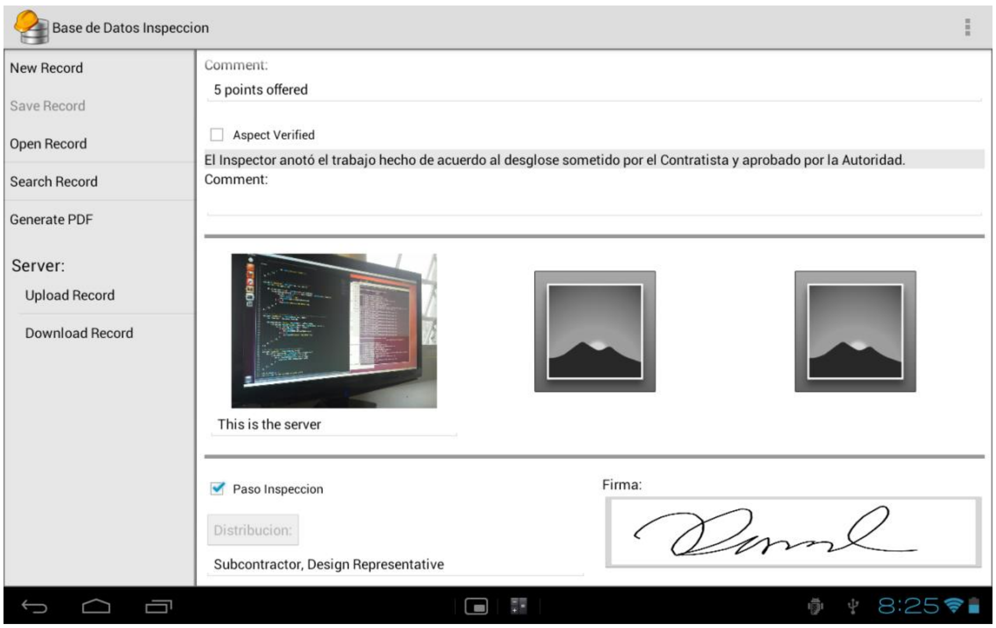


Figure 4: Form View in Landscape Mode

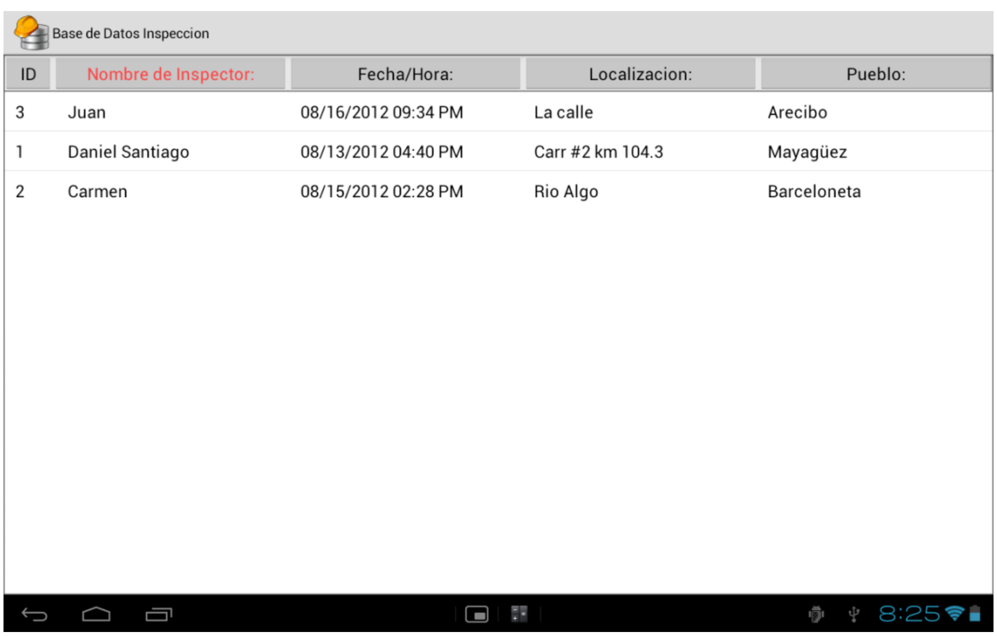


Figure 5: Search view of local records

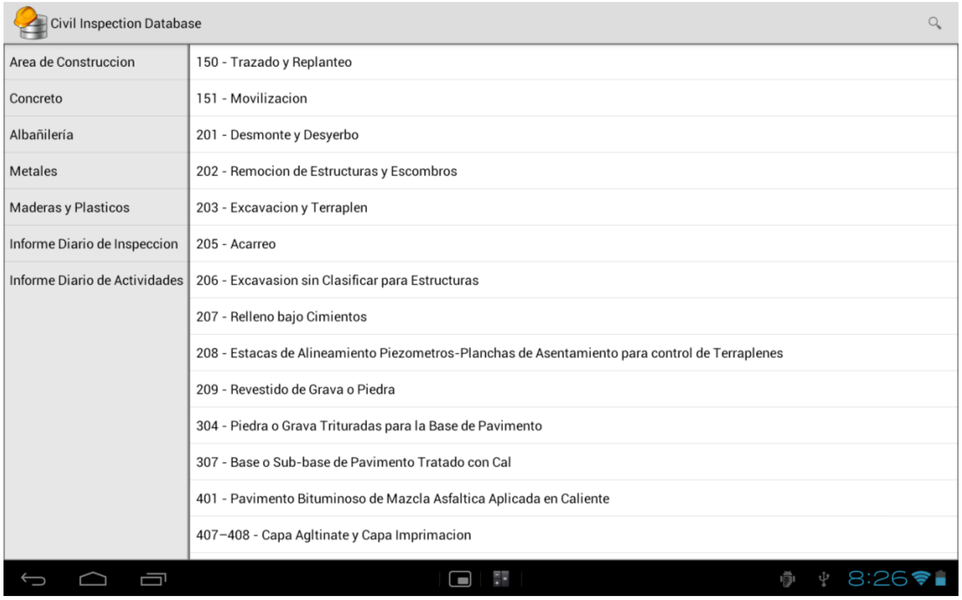


Figure 6: Specifications form menu

The application also contains other features to make it user-friendlier. One of these features is the availability of the complete PRHTA Specifications Manual, which can be used as reference in the field, in case there are conflicts or doubts with any aspect of the inspection form. For convenience, the Specifications Manual is separated into chapters, which makes it easier for searching through the documents. Another feature is the search engine, located at the top-right corner of the screen (where the magnifier icon is located), which allows for an easier and faster search through all the inspection forms in the application. In addition, the application has the capability to switch languages. This can be achieved easily by going to the “options screen” and choosing between English and Spanish. After the language is chosen the application restarts automatically in the new language.

3.2 Development of the iPad application

The iPad application contains the same features and characteristics than the Android application, but in a somewhat different format and aesthetic. For this reason, this report does not go into a detailed description of the iPad application to avoid repetition. The report only shows a few pictures of the application with a general description.

The first screen that appears when the user launches the application is the “Basic Project Information Selection”, which is shown in Figure 7. At this screen the user is required to enter his/her name and the name of the project. This information is stored in the database, so it only needs to be entered once into the application. Returning users select from the list available the name of the inspector and the name of the project that is going to be inspected at the time.

Following the selection of the basic project information, the user proceeds to the “new” tab, which is located in the bottom part of the screen. From this tab the specification to be inspected is selected, and then the inspection form appears in blank, as depicted in Figure 8.

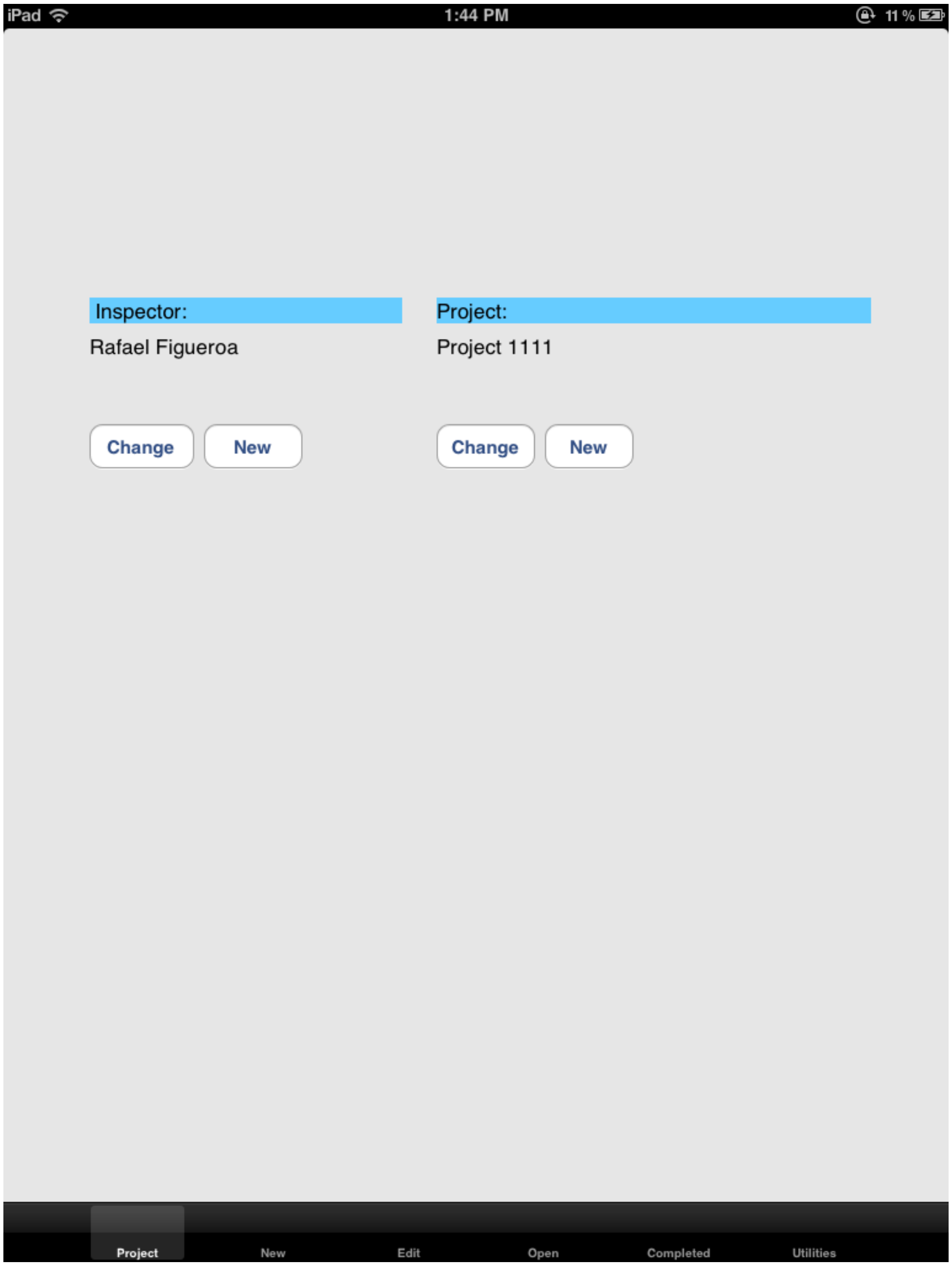


Figure 7: Basic Project Information Selection

The inspection form contains the same four parts previously described: project basic information, inspection aspects, pictures, and sign and distribute. Once the form is finished and signed, the PDF report is generated for distribution among desired stakeholders. Incomplete forms saved can be later edited and finished by entering the "edit" tab. Completed forms can be opened within the application only to review them but not to edit or change them. Finally, the "utilities" tab contains the option for selecting the language (English or Spanish), and the complete manual of standard specifications as a reference tool.

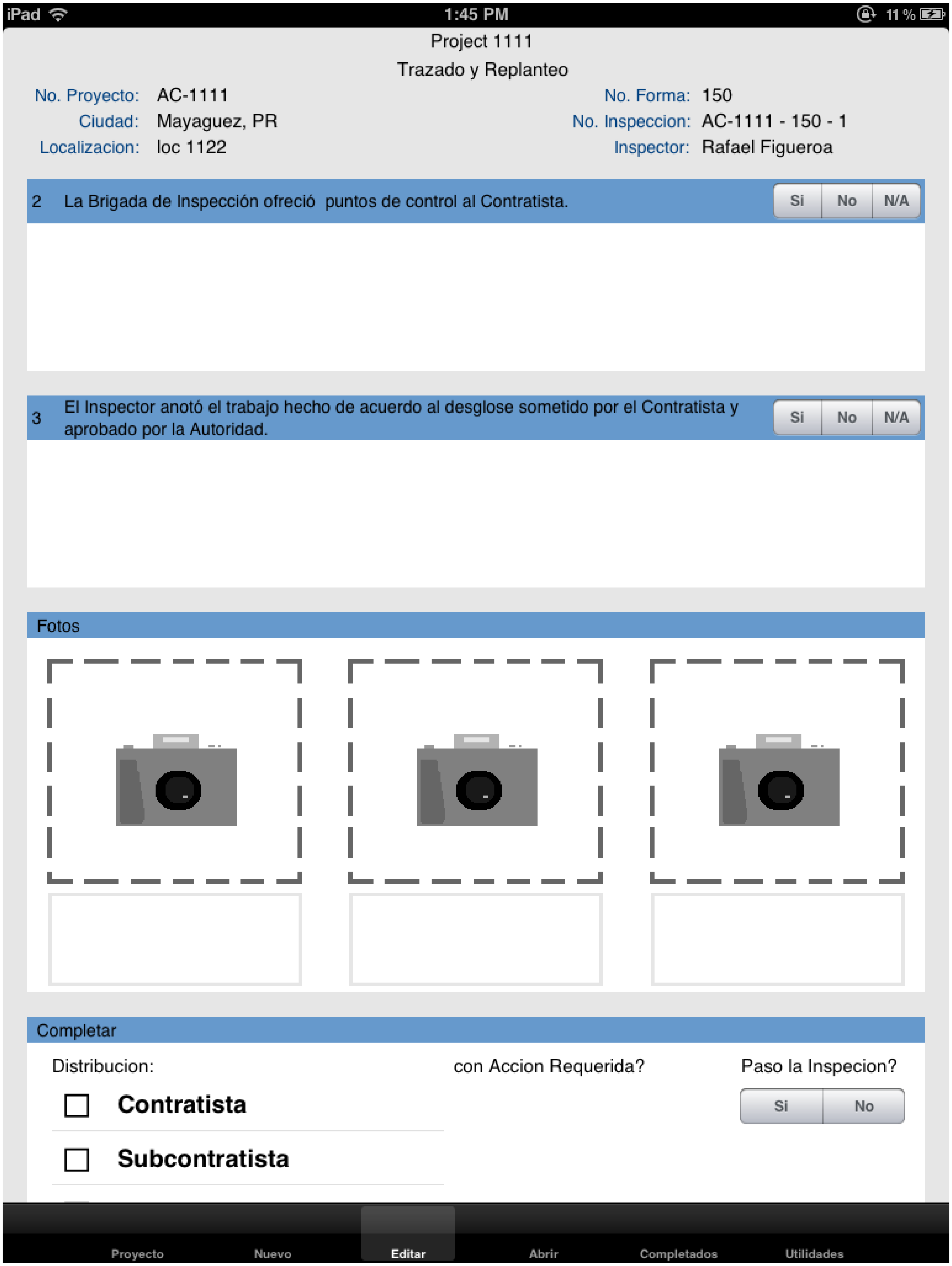


Figure 4: Inspection Form

3.3 Development of the Server

The application has the capability of communicating with a dedicated server that acts as a backup and post-processing of the completed forms. Once a form has been completed the form is uploaded to the server. This allows the information to be accessed by authorized personnel for review and more in depth analysis. This analysis could be performed by statistical and analytical software applications running in the server, which could provide additional useful information, and enhance the control of the project. For communication with the server, each device that runs the application is identified by its MAC Address and requires a one time, initial setup to register the device with the server.

The server was created for the purpose of globally storing completed inspection forms, which can then be viewed and analyzed at any moment. In addition, the server is in charge of keeping track of the devices that use the application, giving complete uniqueness to every completed inspection form. The server has an Application Programming Interface (API) from which the Android and iOS applications communicate.

The main functionalities of the server include: querying the server database, receiving uploaded forms, receiving uploaded photos, generating PDF formats of uploaded forms, downloading the saved reports in PDF format, and calculating and displaying analytical reports of the database (e.g. amounts of reports saved). This server is usually live, and could be accessed at any time by entering the following URL: http://taip.uprm.edu:1337. This provides a webpage for the project, which contains general information, data available, and other information. A screenshot of the homepage is shown in Figure 9.

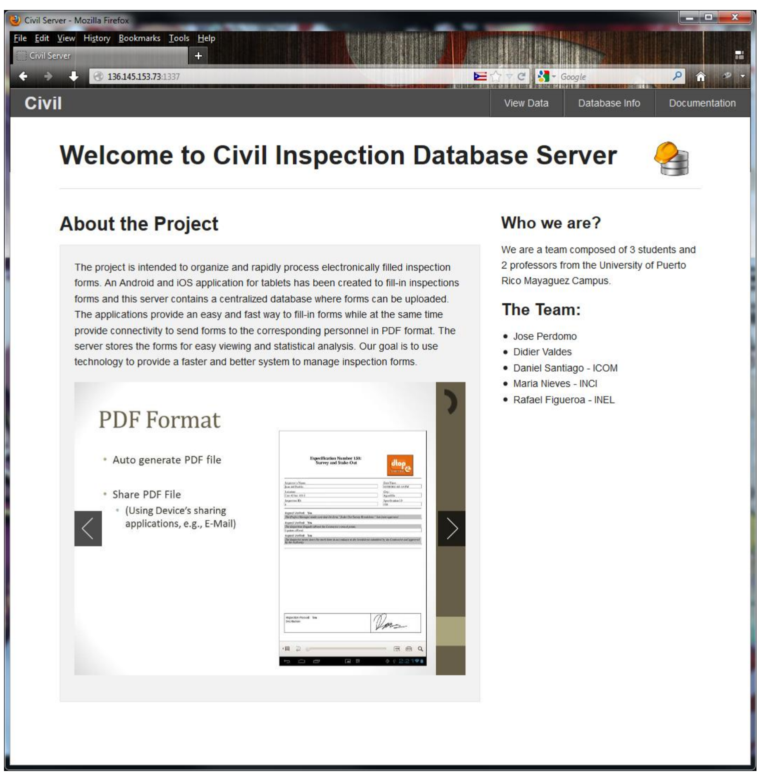


Figure 9: Server's homepage

4. Application in the field

After the first prototype of the application was developed, several tests where conducted to check the efficiency of the application on the field. This exercise was conducted with the collaboration of the personnel from the Puerto Rico Highway and Transportation Authority (PRHTA). For this purpose, a meeting was held at the headquarters of the PRHTA, where project administrators from different regions of the island received a training seminar on the use of the application. At the conclusion of the meeting, the prototype of the application was distributed amongst the participants present, who had a few weeks to test the application on their respective projects. Once the testing period ended, another meeting was held with each of the participants to receive their feedback about the application.

Overall, all the participants of the test said that they considered the application good and useful to their job. They also pointed out that the application was user-friendly, and that no mayor difficulties were confronted in the use of the program. Suggestions to enhance the application include: adding information to make the reports closer to the Daily Activities Report currently used by the PRHTA, and providing a space to address safety issues in the field.

5. Conclusions

Current practices for recording and filing field inspection data are mainly paper-based, which results in a tedious and time consuming process. Continuous evolvement and improvements of software technologies in mobile computing, such as iPADs and Android Tablets, have made it possible for these devices to become stand alone systems with powerful functional capabilities. Because of their high mobility characteristics, these devices can be used in the construction field to perform various tasks including recording of inspection data. Considering these advantages, the research team at the University of Puerto Rico at Mayagüez developed an application for performing daily field inspections, with the purpose of collecting data and verifying compliance with the project specifications.

The result of the research was the successful development of two applications, one for Android Tablets and one for iPads. Both applications have the capability of collecting data, generating reports, filing and saving reports, and sending the reports via e-mail to the desired stakeholders. This process has several benefits, which are listed below:

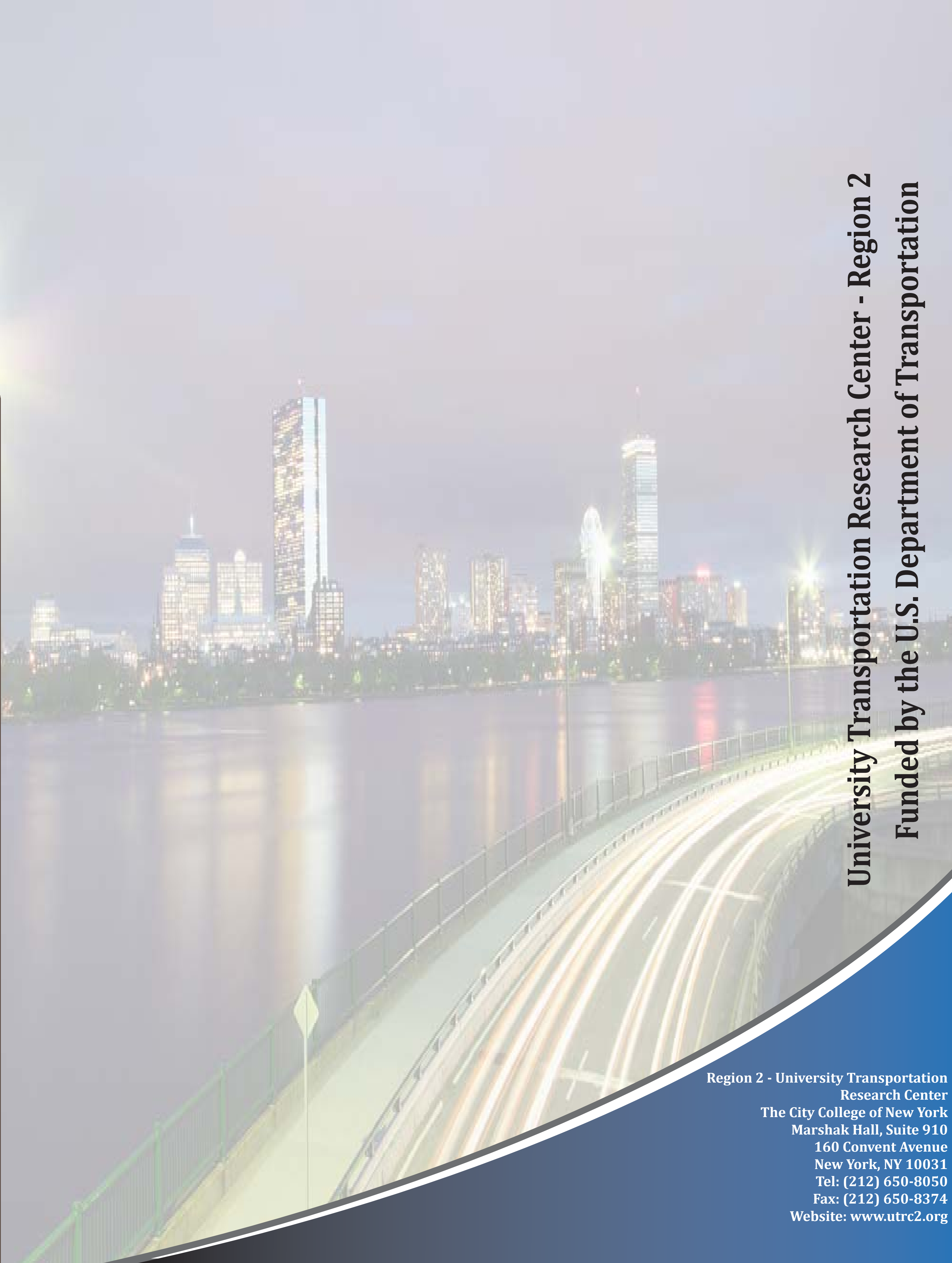
- *Improvement of the inspection process.* This is due to the fact that the inspectors will be using standard inspection forms, which consider the important aspects related to the work being inspected, and make the inspection process less prone to human subjectivity. The inspector has more information available at hand, since the application features the entire manual of standard specifications to use as reference when needed.
- *Enhancement of the collection and distribution of inspection data.* The information is collected directly in the application, and reports are generated automatically, which makes the process faster and easier. Distribution of inspection reports will be electronically, improving the process and making it faster.

- *Elimination of double manipulation, from paper to computer, of data.* Information taken in the field will be stored digitally as it is being collected. This process minimizes the data transferring errors.
- *Elimination of the use of paper forms.* The use of paper could be eliminated since all the inspection work will be done in a mobile computer (i.e. iPAD or Android Tablet), thus helping the environment greatly.

6. Future Work

Future work related to this project can be achieved in several areas. One possibility is to expand the inspection process in the application to other transportation systems, such as airports, railroads, and ports. Another possibility is to apply the program to the construction specifications of other locations. This can be achieved by making direct contact with other state DOTs interested in the application, and modify the aspects in the inspection forms to address the specifications of a particular state. A third option for future work is to expand the application to work in the maintenance process of roads. Finally, as the feedback from the inspectors suggested, the application can be expanded to include the daily safety inspection on the field, including the safety for the personnel and the temporary maintenance of traffic issues. This could also be achieved as a separate application for tablet-type devices.

Currently, The UPRM research team is working on a second phase of the automation process that will provide the ability to create daily reports, generate reports for the project administrator and automatically relate data from different reports to include this information in the administrator's report in order to save time and provide a higher quality assurance. In addition, the improved application will allow for continuous monitoring of project performance, because a daily S curve (cost based) will be prepared based on the inspector's report of work performed by the contractor. By doing so, the inspection team can verify at any time if the project is behind or ahead of schedule, comparing the percent complete at any particular moment with the percent complete calculated from the cost loaded schedule. This could be a very useful tool to check the status of the project and identify problems, so the necessary actions can be taken in order to get back on time or budget. By taking appropriate measures as early as possible with the help of all the tools developed on this new project, several benefits can be achieved including improvements in delivery time and information management throughout the project.



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