Final Report for Period: 08/2011 - 07/2012
Submitted on: 08/13/2012
Principal Investigator: Brilakis, Ioannis .
Award ID: 0904109
Organization: Georgia Tech Research Corp
Submitted By:
Brilakis, Ioannis - Principal Investigator
Title:
Progressive Site Modeling with Videogrammetry

Project Participants

Senior Personnel

Name: Brilakis, Ioannis
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Makhmalbaf, Atefe
Worked for more than 160 Hours: Yes
Contribution to Project:
Atefe, a female US Citizen, was a PhD student that was hired in January 2009 for this project as a Graduate Research Assistant to help in validating the automated calibration component of the research. She left after working for one year on this project.

Name: Park, Man Woo
Worked for more than 160 Hours: Yes
Contribution to Project:
Man Woo was a PhD student that was hired in January 2009 for this project as a Graduate Research Assistant to help in validating the automated point pair matching component of the research. He later changed his research topic to 2D and 3D vision tracking of contruction related entities.

Name: Vasudev, Paavan
Worked for more than 160 Hours: Yes
Contribution to Project:
Paavan was a MS student in Computer Science that was hired in January 2009 for this project as an Hourly Researcher to help for creating a software validation platform for all algorithms generated in this project.

Name: Gupta, Abhishek
Worked for more than 160 Hours: Yes
Contribution to Project:
Abhishek was a MS student in Building Construction that was hired in January 2009 for this project as an Hourly Researcher to help run calibration experiments and record the results.

Name: Rashidi, Abbas
Worked for more than 160 Hours: No
Contribution to Project:
Abbas is a PhD student that was hired in Fall 2009 for this project as a Graduate Research Assistant to help in corresponding point matching and intelligent data smoothing of multi camera videogrammetric systems for spatial modeling. His dissertation topic is closely related to this project.

Name: Fathi, Habib
Worked for more than 160 Hours: Yes
Contribution to Project:

Habib is a PhD student that was hired in Fall 2009 for this project as a Graduate Research Assistant to help in automatic dense 3D reconstruction and large-scale Structure from Motion (SfM) component of the research. His dissertation topic is closely related to this project.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Metalforming, Inc.

Metalforming Inc. is the North American leader in metal building and architectural sheet metal technology. The company sells and services a special machine that is able to automatically cut sheet metal coils into different pieces appropriate to cover a roof. The only input data to this equipment is a 3D wirediagram of the perimeter of the roof. Currently, this information is collected by using a Total Station and a surveying crew.
Our collaborative research aimed to completely automate this data collection process using the concepts introduced in this NSF project. This way, the entire process of cutting roll metal sheets, from data collection to end product, will be automated.

ACE Mentor Program of America, Inc.

The PI is one of the members of the Governing Board of the Architecture, Construction, and Engineering (ACE) Mentor Program, Atlanta chapter. This important program serves high school youth who are exploring careers in architecture, construction, or engineering. The PI is currently the only academic serving on the Governing Board of the Atlanta chapter.
The ACE Mentor program uses a multidisciplinary, team-mentoring model where up to 25 K-12 underrepresented students and 10 mentors meet weekly for two hours. Through a year-long curriculum, the PI schedules several one-day visits or workshops that help to engage, excite, and enlighten high school students to pursue careers in the integrated construction industry.

VentureLab

VentureLab is a unit of the Enterprise Innovation Institute. It is Georgia Tech's comprehensive center for technology commercialization which transforms innovations into companies by developing business models, locating sources of early-stage financing, and preparing new companies for global markets.
The PI has established this partnership to find potential markets for the technology that has been developed during this project. So far, the effort has identified several market opportunities in the construction industry (e.g., progress monitoring, as-built data collection, 3D documentation, and archiving) as well as consumer market (e.g., replacing a tape measure with a smart phone for home improvement contractors).

Other Collaborators or Contacts

Outreach activities were started at Summer 2009. Due to the PI's move from UM Ann Arbor to GATech, new partnerships were established with local contacts. First, partnership with the ACE Mentor Program was established and the curriculum changes of the ACE Mentor Program were discussed, to accommodate two one-day activities the PI had proposed to them. Moreover, partnership with Bentley and Skanska was established for getting access to data that is required in the validation step of the project. The plan was to engage the practitioners into preliminary research tests and follow up with tests on their data.
Later in 2010, the PI partnered with various local and national organizations that advocate for and promote engineering education to K-12 students, as well as school districts of the city of Atlanta that have a large population of under-represented students. To engage and excite high school students to pursue careers in the construction industry, the PI organized a personalized tour for ACE Atlanta students and mentors within the Building Construction department and the School of Civil and Environmental Engineering at GATech. In another program, ACE Atlanta students were involved in a class activity entitled 'Modeling and Communication: A Lego Building Experience' aiming to get familiar with modeling geometrical objects and collaboration concepts.
In the next year, collaboration of the PI with various organizations that deal with K-12 and under-represented students was continued. The PI was appointed to the Governing Board of the Architecture, Construction, and Engineering (ACE) Mentor program, Atlanta chapter. Similar to

the previous year activities, ACE Atlanta students were involved in a class activity entitled 'Modeling and Communication: A Lego Building Experience' aiming to promote their collaboration and construction management skills. Through this year, while partnership with Bentley and Skanska was continued, partnership with Turner construction and Metalforming Inc. was also established. With the help of these partners, several data collection field trips have been carried out in different construction sites. The collected data was used in validation process of different algorithms.
In early 2012, the PI and one of his PhD students were awarded by the NSF I-Corps program to investigate a structured hypothesis/validation approach to develop a disposition plan for the technology that is developed as a result of this project. The team was mentored by the Business Development Manager for Construction at Autodesk. Hence, a very strong partnership was established with Autodesk. Throughout this I-Corps program, the team contacted more than 102 potential customers for the technology ranging from very large construction companies to local contractors; this significantly widened the contact network of the PI.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

During the first year of the project, no funded activities took place in the Fall semester of 2008 due to the PI's move from UM to GATech. However, two major activities took place in the Spring semester of 2009 (Jan - May):
1) Platform building:
The PI and his team designed and implemented a software platform on C++ meant to be used as the foundation for all algorithms pertaining to this research project.
2) Camera system self-calibration:
A new algorithm was invented that combines tracking concepts with epipolar geometry to create a self-calibration mechanism. This algorithm was implemented on the platform and tested successfully.
In the next year, three major activities took place according to the proposed framework (Fig. 1):
1) The first significant milestone in the research effort, which was the creation of a robust software platform called Gygax (Fig. 2), was successfully implemented. Although it was designed and programmed partially in C++, aiming to benefit from automatic memory management, coherent libraries, and great tools that a managed code written in C# provides, the final software platform was implemented in WPF using C#. Real-time responsiveness, multi-threading approach, and ability to work with a wide range of cameras are some outstanding capabilities of the platform.
2) The SURF algorithm was tested against the window-based matching algorithm described in the proposal to perform automatic and accurate point pair matching. Point pair matching accuracy was satisfactory with both algorithms; however real-time point pair matching was only achieved with SURF due to its less computational load and more distinctive features.
3) The SURF algorithm was also used for point matching between consecutive frames in order to estimate the camera egomotion. 6 DoF camera egomotion was estimated using a novel point matching algorithm and Structure from Motion (SfM) principles.
Findings were presented in a graduate level course at GATech as described in the proposal.
Implementation speed of the research activities was boosted as the team dug deeper into the proposed framework. Hence, seven major activities took place during the third year. Those are mostly related to sparse 3D reconstruction of construction sites and metric accuracy of the results (Fig. 3):
1) After coding several optimizations on the candidate point detection and matching algorithms (i.e., SURF, SIFT, and window-based matching algorithm), SURF was selected because of its run-time efficiency and accuracy. Moreover, epipolar geometry constraints were used to increase the feature point matching accuracy to more than 99%.
2) The most comprehensive triangulation algorithm in the literature was implemented in a C# prototype. This algorithm can accurately model lens distortion effect that is one of the most challenging issues in camera calibration and triangulation. It has direct impact on the metric accuracy of generated point clouds.
3) To evaluate the metric accuracy of sparse point clouds generated from SURF feature points in a pair of stereo frames, several experiments were carried out in completed and under-construction civil infrastructure projects. The results of these evaluations were applied in devising several techniques that helped to increase the metric accuracy of the 3D points.
4) Quaternion 3D point set registration and PnP algorithms were implemented for estimating 6 DoF camera egomotion. The accuracy of these algorithms was thoroughly investigated in controlled environments and real construction projects.
5) The metric accuracy of point clouds after using a sequence of video frames was evaluated by using video data collected from a variety of construction projects. Video streams with different durations were used in order to study the accuracy for short- and long-run applications.
6) A novel window-based stereo dense point matching algorithm (Fig. 4), as described in the proposal, was implemented to convert the sparse point clouds into dense 3D models. A number of state-of-the-art dense point matching algorithms were also implemented aiming to assess the accuracy of the algorithm created by the research team.
7) The PI and his team have devised a novel line detection and matching algorithms that significantly improve the accuracy of dense 3D

reconstruction. This algorithm identifies different planes in the scene and uses this information to refine and smooth the 3D coordinates of co-planar points.
During the last year of this project, the team mostly focused on optimizing the previously generated algorithms and also combining different levels of visual features in the framework. In addition to points, the use of higher level visual features such as lines and planes was considered. Different major activities in this year are the following:
1) Two well-known algorithms for line detection were combined together in order to compensate for limitations of each algorithm using advantages of the other one. This combination was used to detect robust line features that are repeatable and stable with respect to scale variations due to change of viewpoint.
2) Unlike point matching, line matching is still a very challenging task even in the computer vision community. To solve this problem, the concept of generating a multi-dimensional feature descriptor, which is being used for robust point matching, was applied for line matching. The implemented method showed significant improvements in terms of the accuracy of correct matches.
3) Devising the mathematical formulation behind the hybrid bundle adjustment process was the most important research activity in this year. The most important challenge was to represent point and line features with the same number parameter; this allows us to directly use the well-known mathematical packages that are available for solving large-scale optimization problems.
4) A half-plane detection algorithm was introduced to hypothesize and then verify available planar surfaces in a scene. The method uses the information from points and lines in a single formulation to hypothesize planes that a line feature may represent. Results indicated significant run-time efficiency and more accurate plane estimation compared to state-of-the-art algorithms.
5) The acquired information from points, lines, and planes was used in a novel data smoothing algorithm in order to provide more visually appealing and accurate results. In detecting outliers, a distance comparison of their locations with the planes defined by their neighbors was used. Two criteria were considered for outlier detection: a) the distance between points, and b) their visual uniformity. This way, distance comparison did not take place between points that belong to opposite sides of an edge, as those points are likely to have significantly different depth.
6) Several case studies in different environments were sued to validate the entire framework. Those cases include a) large-scale, outdoor environments such as bridges and buildings; b) indoor scenes such rooms and corridors. Fig. 5 shows some of the results.

Findings: (See PDF version submitted by PI at the end of the report)

An unexpected and significant finding that was uncovered in the first year is that continuous self-calibration of a camera set is necessary to maintain adequate accuracy. This unexpected problem, however, gave insights to an equally unexpected but very successful solution. Instead of treating a set of concurrent frames as coming from the camera set of two independent cameras for calibration purposes, the novel calibration algorithm treats them as being consecutive, and coming from the same camera. This allows tracking algorithms to be used for finding the spatial and rotational differences of the camera set.
Major findings of the research team during the second year can be summarized as follows:
1) Basic point matching algorithms based on SURF, available in the literature, mostly use the 64 dimensional descriptors which are calculated only based on pixel intensity. Therefore, the color information of images is simply neglected. Findings signify that using this additional information, higher accuracy can be achieved by discarding more outliers.
2) Accumulated errors through the estimation of 6 DoF camera egomotion is the most significant reason that causes most of the algorithms fail in relatively long sequence of frames. To address the problem, the PI reduced the accumulated errors by re-estimating the camera motion between frames with a predefined interval (key-frames). This way, the information acquired from frames in the interval is only used to estimate the approximate motion between key-frames. This initial estimation can be used in non-linear optimization as the starting point. Findings show significant increase in reliability of the algorithm for long time usage.
In the third year, major findings are the following:
1) In the state-of-the-art camera calibration algorithms, the lens distortion of a camera is modeled by using five coefficients. These coefficients are usually very small numbers and therefore minor inaccuracies involved in their estimation may not have any noticeable impact on the metric reconstruction accuracy of close-range (<1m) objects. However, this project deals with far-range (>15m) objects and these coefficients can have significant impact on the outcome. The research team found out that for far-range objects, the fourth and fifth lens distortion coefficients have to be zero. This modification in the calibration results significantly increased the metric accuracy of the generated point clouds.
2) Dense point matching in object boundaries is a very challenging process since the background of the object can be different in two views. Therefore, in the object boundaries, any window-based matching algorithm would fail with high probability. The research team found out that by using the novel line detection and matching algorithm, the boundaries of planar objects can be accurately estimated. Since most of the objects in a construction scene are planar, this information significantly improves the dense reconstruction accuracy.
3) Almost all of the line detection algorithms in the computer vision community are only able to detect part of an edge in the scene. The research team found out that the angle of gradient of each pixel in an image refers to the probability of belonging to a line. Using this information, almost every useful line in the scene can be completely detected.
In the last year of this project, the team mostly focused on enhancing the output accuracy by introducing new approaches. While existing fully automatic stereo reconstruction systems are showing great promise in 3D reconstruction of outdoor scenes, their main priority is to achieve a visually appealing model via smoothing or interpolating the 3D data; this may fill the holes in the model and/or smoothen bumpy areas but

significantly affects the Euclidean accuracy of the measurements. Unlike these techniques, the primary goal of this project is to provide accurate measurements. To fulfill this objective, a number of innovations were introduced and below are related findings:
1) One of the most important and inherent characteristics of civil infrastructure or construction site scenes is the abundance of lines and planar surfaces. The proposed framework takes advantage of this feature and subsequently leads to a more accurate and reliable 3D reconstruction. The team has found out that compared to points, lines and planes provide higher level information and could also be detected and parameterized more accurately. The use of a combination of points, lines, and planes allows better understanding of the scene and more reliable estimations of the 3D geometry of the structure (Fig. 6).
2) Several camera calibration experiments were designed to assess the effect of camera calibration process on the output accuracy. The results indicated a significant variation for estimated intrinsic camera parameters (i.e., focal length, principal point, and distortion coefficients) even for experiments with similar distance between the calibration pattern and camera set. This may happen because of the complex structure of the lens or slight changes in the zoom/focus while collecting data. However, this variation is almost negligible for estimated extrinsic parameters (i.e., rotation and translation). Therefore, it is preferred to include the intrinsic camera parameters in the bundle adjustment process (i.e., global optimization in SfM) while the extrinsic camera parameters can be considered as known and hence excluded from the optimization process. A multi-step stereo camera calibration procedure was then designed based on the findings from those experiments.
3) Visual feature matching across different views of a scene is a fundamental task in machine vision applications. In terms of point features, this problem has been successfully addressed by previous studies that form a descriptor vector for each point based on its local neighborhood. Motivated by the same approach, a novel algorithm was devised to construct a descriptor vector for each line segment (Fig. 7); this averagely allows more than 95% correct matches which is satisfactory in the given application. This finding is very important since it shows that the feature descriptor concept is functional in both point and line matching.
4) Points in each pair of corresponding planar regions are related by a specific matrix that maps the planar region in two views. An innovative approach was proposed to estimate this matrix for each planar region available in a scene. Findings indicate that this matrix helps to adjust points and lines belonging to the corresponding plane and hence avoids any interpolation or smoothing of the 3D data.

Training and Development:

During the period of Jan - May 2009, the majority of the effort spent by the graduate student participants has been on coursework that has engaged the students with the worlds of signal processing, stereo vision and programming. Additionally, the students had the opportunity to devise hypotheses, prepare their first experiments, run tests, and record results.
In the fall semester of 2009, the graduate students mostly engaged in the courses from the machine vision world ranging from digital image processing to computer vision. Moreover, the students experienced a real software development process by participating in the creation of the software platform required as the basis for implementing all algorithms pertaining to this research project. They were then able to start and conduct research implementation in order to achieve the predefined goals and capabilities.
In the spring semester of 2010, the students primarily focused on the courses from 3D reconstruction and mapping in computer vision and robotics. They gained basic knowledge on working with videos and make some inferences from their embedded information. They had the opportunity to use graphical models in the research and make inferences based on probability theory.
Through the third year, the graduate students mostly engaged in implementing different steps of the proposed framework. The validation process of each step provided great opportunities for these students to collaborate with project managers in different types of construction projects. This greatly enhanced the perception of these students regarding to the construction industry in the US and the possible areas of research that can improve the competitiveness of this industry.
The graduate students were also involved in training several undergraduate students who were interested in doing research in construction information technology. These trainings not only provided a real experience for graduate students in leading a team of researchers but also motivated the undergraduate students to pursue their education in this field. These experiences will have significant impact on the career success of these graduate students in academia.
The training of the graduate students continued during the last year of this project. The two leading PhD student researchers (Habib Fathi and Abbas Rashidi) mostly involved in performing different case studies for the validation purposes and also writing several proposals for NSF and other funding organizations. Those efforts helped them to comprehensively study the process of designing experiments for scientific validation. The proposal writing was also an invaluable experience for them to understand the correct style of writing a research proposal which is helpful in their future academic career. Those students were also asked to give lectures in a research methodology class that was taught by the PI. They were encouraged to actively involve in the course preparation process.
Moreover, Mr. Fathi participated in the NSF I-Corps program along with the PI in order to investigate the technology transfer. He received invaluable education through this course about different ways that startup companies can be established and function. The outcome for the student was to establish a startup company called 'PointForest'.

Outreach Activities:

A new activity has been designed by the PI and board of directors of the ACE Mentor program. In 2009, the PI presented a two-day curriculum to under-represented Atlanta high school students. The first day focused on classroom activities that introduce the students to the research and

the importance of science, technology, engineering and math. The second day focused on hands-on activities at the PI's laboratory, in collaboration with the project's industry partners.
The activity for the ACE Program was also implemented in stages (3 1-day events) throughout the academic year of 2009-2010. At first, a modeling bridges activity took place in October, with a competition on who will design the cheapest bridges that meets the specifications. The second event took place in November 2009. A personalized field trip on the GATech campus was organized for ACE Atlanta students. As part of this tour, the students visited the PI's laboratory and had the opportunity to try out the reality capturing devices and software of the PI. The third event was a classroom activity for ACE Atlanta students planned to engage the students in modeling activities. The activity involved modeling by having half a team building a Lego Building based on the instructions (in the form of specific work packages and a project schedule) that was given to the other half. This tested both their 3D modeling skills and their communication abilities.
The activities for ACE program were continued in the next year. Two one-day events were held. First, a bridge modeling activity took place aiming to make the students familiar with designing the cheapest bridge that meets the specifications. Second, a building modeling activity was held to engage the students in modeling and management activities.
In the summer of 2010, 2011, and 2012, a number of under-represented Atlanta high school students along with their teacher spent 2 months in the PI's laboratory. They were heavily involved in designing and constructing different types of models, such as a building, a bridge, and a harbor model, that were used as controlled environments in the validation process of this proposal.

Journal Publications

Zhu, Z. and Brilakis, I., "Comparison of Optical Sensor-Based Spatial Data Collection Techniques for Civil Infrastructure Modeling", Journal of Computing in Civil Engineering, p. 170, vol. 23, (2009). Published, 10.1061/(ASCE)0887-3801(2009)23:3(170)

Brilakis, I., Lourakis, M., Sacks, R., Savarese, S., Christodoulou, S., Teizer, J., and Makhmalbaf, A., "Toward Automated Generation of Parametric BIMs based on Hybrid Video and Laser Scanning Data", Advanced Engineering Informatics, p. 456, vol. 24 (4), (2010). Published, 10.1016/j.aei. 2010.06.006

Brilakis, I., Fathi, H., and Rashidi, A., "Progressive 3D Reconstruction of Infrastructure with Videogrammetry", Automation in Construction, p. , vol. , (2011). Accepted, doi:10.1016/j.autcon.2011.03.005

Jog, G., Fathi, H., Brilakis, I., "Automated Computation of the Fundamental Matrix for vision Based Construction Site Applications", Advanced Engineering Informatics, p. , vol. , (2011). Accepted,

Rashidi, A., Fathi, H., Brilakis, I., "Innovative Stereo Vision-Based Approach to Generate Dense Depth Map of Transportation Infrastructure", Transportation Research Record, Journal of the Transportation Research Board, p. , vol. , (2011). Accepted,

Fathi, H., Brilakis, I., "Automated Sparse 3D Point Cloud Generation of Infrastructure Using Its Distinctive Visual Features", Advanced Engineering Informatics, p. , vol. , (2011). Submitted,

Dai, F., Rashidi, A., Brilakis, I. and Vela, P., "Comparison of Image- and Time-of-Flight-Based Technologies for 3D Reconstruction of Infrastructure", ASCE Journal of Construction Engineering and Management, p. , vol. , (2012). Accepted,

Rashidi, A., Dai, F., Brilakis, I. and Vela, P., "Optimized Selection of Key Frames for Monocular Videogrammetric Surveying of Civil Infrastructure", Advanced Engineering Informatics, p. , vol. , (2012). Submitted,

Books or Other One-time Publications

Brilakis, I., "Chapter 10: Visual Pattern Recognition Technologies for Mobile Systems at Construction Sites", (2011). Book, Accepted
Editor(s): Anumba, C. and Wang, X.
Collection: Mobile and Pervasive Computing in Construction
Bibliography: Brilakis, I. (2011) "Chapter 10: Visual Pattern Recognition Technologies for Mobile Systems at Construction Sites", Chapter of the Mobile and Pervasive Computing in Construction

Rashidi, A., Fathi, H. and Brilakis, I., "Innovative Stereo Vision-Based Approach to Generate Dense Depth Map of Transportation

Infrastructure", (2011). Conference paper, Published
Collection: Proceedings of the 2011 Transportation Research Board Annual Meeting, 23-27 January 2011, Washington, DC
Bibliography: Rashidi, A., Fathi, H. and Brilakis, I., "Innovative Stereo Vision-Based Approach to Generate Dense Depth Map of Transportation Infrastructure", Proceedings of the 2011 Transportat

Fathi, H., Brilakis, I., and Vela, P., "Automated 3D Structure Inference of Civil Infrastructure Using a Stereo Camera Set", (2011). Conference paper, Published
Collection: Proceedings of 2011 ASCE International Workshop on Computing in Civil Engineering, June 19-22, Miami
Bibliography: Fathi, H., Brilakis, I., and Vela, P., "Automated 3D Structure Inference of Civil Infrastructure Using a Stereo Camera Set", Proceedings of 2011 ASCE International Workshop on Comp

Rashidi, A., Dai, F., Brilakis, I., and Vela, P., "Comparison of Camera Motion Estimation Methods for 3D Reconstruction of Infrastructure", (2011). Conference paper, Published
Collection: Proceedings of 2011 ASCE International Workshop on Computing in Civil Engineering, June 19-22, Miami
Bibliography: Rashidi, A., Dai, F., Brilakis, I., and Vela, P., "Comparison of Camera Motion Estimation Methods for 3D Reconstruction of Infrastructure", Proceedings of 2011 ASCE International W

Fathi, H. and Brilakis, I., "Machine Vision-Based Infrastructure As-Built Documentation Using Edge Points", (2012). Conference Paper, Published
Collection: Construction Research Congress
Bibliography: Fathi, H., and Brilakis, I. (2012) ?Machine vision-based infrastructure as-built documentation using edge points?, In: Construction Research Conference

Fathi, H. and Brilakis, I., "A Videogrammetric As-Built Data Collection Framework for Digital Fabrication of Sheet Metal Roof Panels", (2012). Conference Paper, Published
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Bibliography: Fathi, H. and Brilakis, I. (2012) "A Videogrammetric As-Built Data Collection Framework for Digital Fabrication of Sheet Metal Roof Panels", In: EG-ICE

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Bibliography: Fathi, H., and Brilakis, I. (2012) ?Recovering the 3D structure of poorly textured infrastructure scenes using point and line features?, In: ASCE International Conference on Comput

Koch, C., S. German, S. Rashidi, A., Zhu, Z. K?nig, M., and Brilakis, I., "Achievements and Challenges in Vision-based Inspection of Large Concrete Structures", (2012). Conference Paper, Accepted
Bibliography: Koch, C., S. German, S. Rashidi, A., Zhu, Z. K?nig, M., and Brilakis, I. ?Achievements and Challenges in Vision-based Inspection of Large Concrete Structures", In: 1st Internation

Dai, F., Rashidi, A., Brilakis, I. and Vela, P., "Comparison of Image-Based and Time-of-Flight-Based Technologies for 3D Reconstruction of Infrastructure", (2012). Conference Paper, Published
Bibliography: Dai, F., Rashidi, A., Brilakis, I. and Vela, P. ?Comparison of Image-Based and Time-of-Flight-Based Technologies for 3D Reconstruction of Infrastructure", Proceedings of the 2012

Rashidi, A., Dai, F., Brilakis, I. and Vela, P., "A Novel Approach for Automated Selection of Key Video Frames for 3D Reconstruction of Civil Infrastructure", (2012). Conference Paper, Published
Bibliography: Rashidi, A., Dai, F., Brilakis, I. and Vela, P. ?A Novel Approach for Automated Selection of Key Video Frames for 3D Reconstruction of Civil Infrastructure", In: ASCE Internation

Web/Internet Site

URL(s):
http://www.cit.gatech.edu/

Description:
Provides a short description of the award.

Other Specific Products

Product Type:

Software (or netware)

Product Description:

A sensor platform was created for interfacing hardware (cameras) and software while providing robust data structures for the researchers. This platform, titled Gygax, was written in C# and Visual Studio 2010, using Windows Presentation Foundation for the graphical user interface. It uses encapsulated dynamic link libraries to receive video frames and other information from a variety of cameras, video files, and image files. The Intel OpenCV (Open Computer Vision library) has also been integrated in its C# version (EmguCV), to provide a wealth of machine vision algorithms for the researchers.

Sharing Information:

This software will be posted on the CIT website http://www.cit.gatech.edu in the section reserved for prototypes.

Product Type:

Software (or netware)

Product Description:

A C# based software was created for video-based sparse 3D reconstruction of construction sites using SURF feature points in the scene. This software receives a stereo set of video data as input and progressively generates a sparse 3D point cloud of the environment.

Sharing Information:

This software will be posted on the CIT website http://www.cit.gatech.edu in the section reserved for prototypes.

Contributions

Contributions within Discipline:

The accomplished software platform in managed code provides a base to connect to any number of cameras through the Ethernet network or USB port with real-time responsiveness which can be used in all NSF projects of the PI and any other projects in this specific field. The software provides a powerful capability to perform basic operations on image streams read from the cameras such as image stream controls, buffering, image caching, video files encoding, and communication with the cameras.
In addition, the new calibration algorithm is the first step towards permanently solving the camera system calibration problems for all remote sensing and stereo vision applications. This will have tremendous impact in the area of aerial photogrammetry, as it can potentially bring the sensor and maintenance cost down by not requiring highly accurate manual setups or periodic re-calibrations. It is also valuable for the 'Vision Tracking of Project Related Entities' NSF project of the PI, as it will allow faster camera network deployments and automated calibration corrections. The stereo camera calibration procedure that has been designed enhances the Euclidean accuracy of the outcome by exploiting the knowledge about parameters that affect the accuracy most.
Also, the robust point pair matching algorithm implemented in this research can be used in most of 3D reconstruction projects. It is able to match points in different views with high accuracy and hence facilitates the creation of 3D point clouds in stereo vision community. The sparse 3D reconstruction prototype created by the research team is a useful package that can be used in any stereo reconstruction application that needs good metric accuracies, as a stand-alone package or as a part of a broader application. The window-based dense point matching algorithm can be also used in any vision-based construction application that needs matching non-feature points across different views.
A point and line-based half-plane detection algorithm has been also recently generated that finds the best estimation of planes associated with each line segment available in the scene. Half-planes are hypothesized using a single 3D line and a 3D point. This significantly reduces the computational cost for plane searching process that is necessary in the existing methods.
Below are other contribution of this project:
- Faster and more flexible 3D scans of infrastructure scenes and construction sites due to the mobility of the sensor system
- The data resolution is virtually limitless, since both macro and micro data sensing is possible by adjusting the distance of the sensor system to its targets and using the proper lenses
- Ability to perform in outdoor environment, and scan large scale objects without the need for projecting artificial patterns on the surface of the object or using markers
- Hybrid approach for camera set motion estimation allows dealing with broader range of scenes from highly textured surfaces to poorly textured but consisting of straight lines

Contributions to Other Disciplines:

The novel line detection and matching algorithm significantly improves the state-of-the-art stereo vision-based line detection and matching. This algorithm has significant impact on computer vision and robotics applications that need to use 3D lines for different purposes.
Another important contribution of this project is the hybrid bundle adjustment process which is directly applicable in the computer vision community. Mathematical relationships that have been invented for a stereo-based hybrid bundle adjustment process can be used for solving the large optimization computer vision problems. The main challenge that has been addressed is to parametrize 3D points and lines as well as their reprojections in the 2D image space with the same number of parameters such that the available mathematical software packages can be used directly.

Contributions to Human Resource Development:

Five graduate students have received (and Two PhD students will continue receiving) training under this project. The courses taken, along with the research experience that has been acquired are valuable for their future. Two of them graduated with a MS degree, and their involvement in this project brought them in contact with surveying companies that have hired them as full time employees.
Among the others, two PhD students, who were involved in the general steps of the research, have worked on another NSF project of the PI entitled 'Vision Tracking of Project Related Entities' owing to the valuable knowledge acquired in this research effort. Also, another PhD student has started to work on another NSF project of the PI entitled 'Reciprocal Reconstruction and Recognition for Modeling of Constructed Facilities' due to the 3D reconstruction and robotic experiences acquired through this project. The other two PhD students are continuing their research and hoping to earn their PhD on this subject by the end of next year. They have now competent knowledge in the field of robotic which enables them to integrate the automation concepts in the construction industry.
As part of the NSF I-corps program and owing to this project, the PI and one of his PhD students were also involved in the technology transfer process. Now, they have a comprehensive vision about how a successful startup company should be established and function. The course broaden their perspective in terms of the business aspect of the technology.

Contributions to Resources for Research and Education:

So far, this project has contributed a WPF software package including a ten thousand line C# platform, besides the previous five thousand line C++ one, on top of which all algorithms will be implemented and educational hands-on exercises will take place. Currently, it includes most of the basic algorithms necessary in this specific field ranging from providing unprocessed frames to automatic camera calibration and point matching.
The software platform was available for students in the PI's graduate level course in GATech offered in spring semester of 2010. The students experienced working with different computer vision algorithms and libraries via doing homework and final project on top of this platform.
A sparse 3D reconstruction prototype has also been created. This prototype is currently used in all the PI's NSF projects that need 3D reconstruction of different objects. This prototype has been incorporated to the PI's graduate level course in GATech to provide the opportunity for students to experience 3D reconstruction of real objects and the effect of different parameters in the metric accuracy of the final result.

Contributions Beyond Science and Engineering:

The PI and one of his students have presented the outcome of this project to more than a hundred construction companies during the NSF I-Corps course. All of them have shown significant interest in using this technology in daily activities. As a result, a startup company has been established to pursue this goal and make the technology commercially available in the construction industry.
The project has also gained significant interest from Metalforming Inc., the North American leader in metal building and architectural sheet metal technology, for as-built data collection of roofs. The research team and the industry partner believe that there is a great opportunity to commercialize this videogrammetric technology in the roofing industry. Upon success, it will change the current practice of as-built data collection of roofs from using a Total Station to a cheap, safe, and automated videogrammetric method.

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Categories for which nothing is reported:

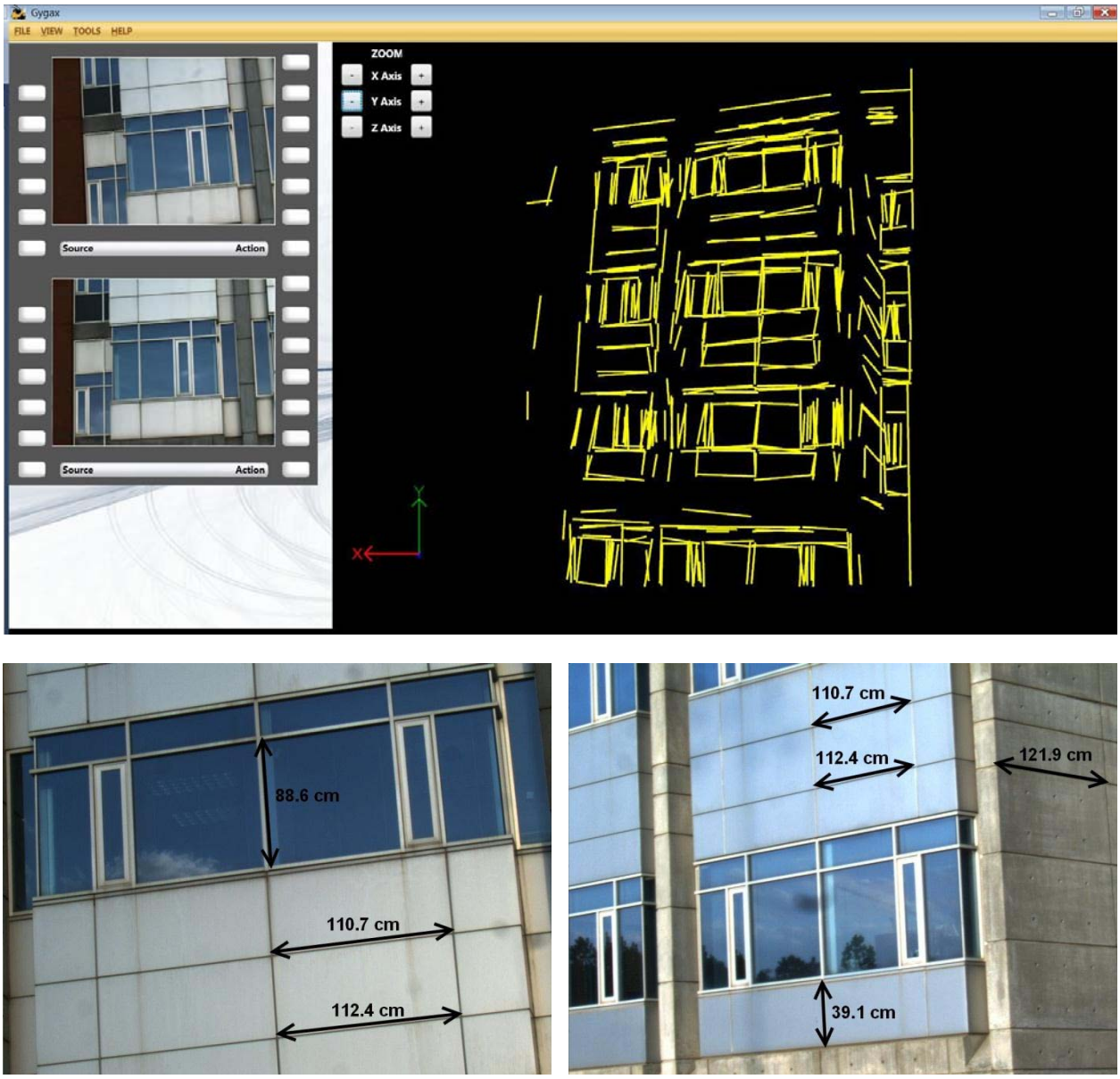

Fig. 6: Using points, lines, and planes to extract accurate measurements from a facade

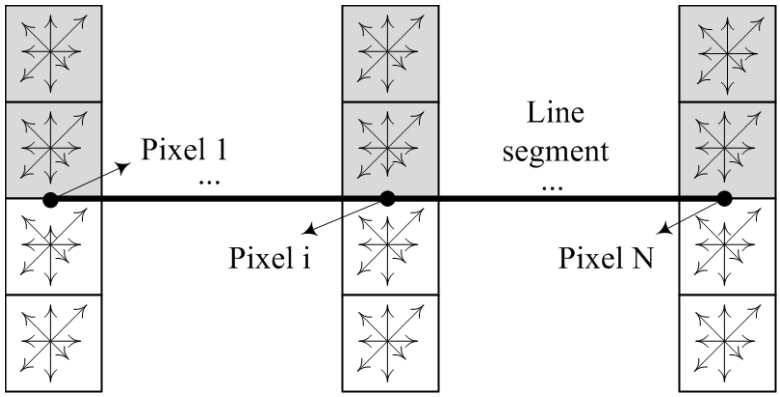

Fig. 7: Schematic process for constructing a line descriptor

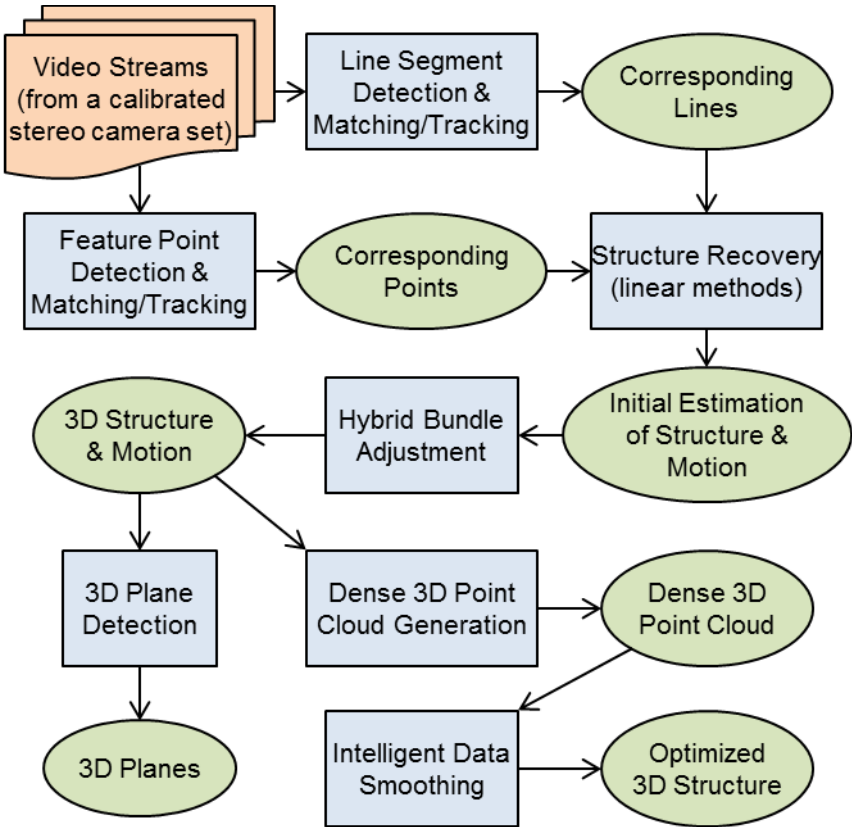

Fig. 1: Overview of the videogrammetric framework

Fig. 2: Gygax software platform

Fig. 3: Overview of the sparse 3D reconstruction process

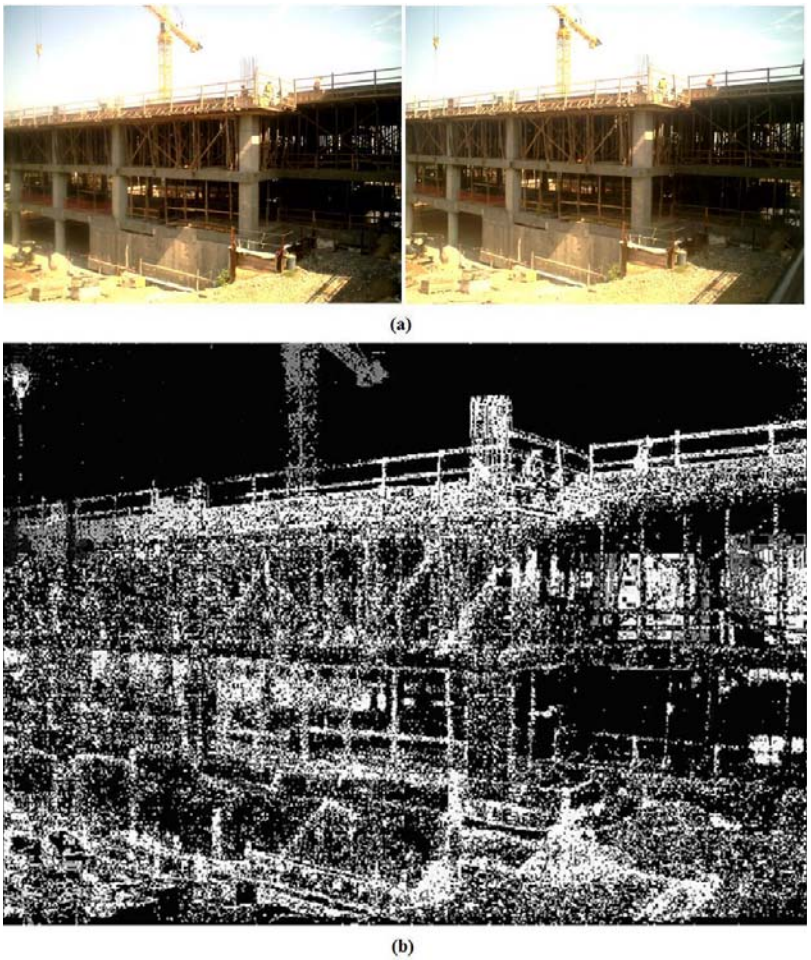

Fig. 4: Window-based dense point matching

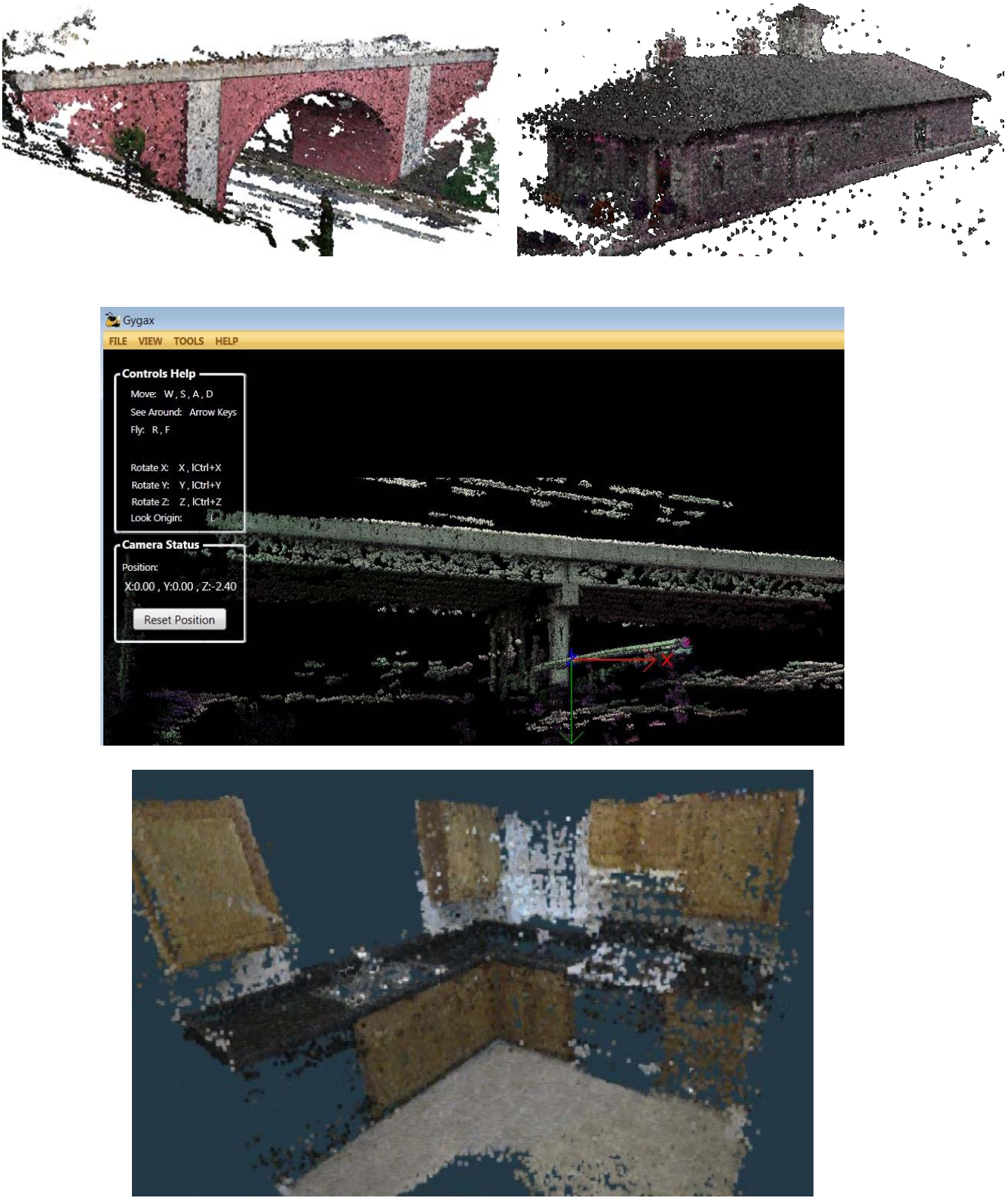

Fig. 5: Different case studies for validation purposes (two bridges, a building, and a kitchen)