Integrating 5D Product Modelling to On-Site 3D Surveying of bridges

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Abstract

In this paper a new process integrating 5D product modelling and 3D on-site surveying for bridge construction is presented. This enables faster and less error prone surveying session preparations, fluent communication of design plans between survey teams, design office and other parties related to the construction project. A prototype system based on a total station and Tekla Structures CAD software is defined, and implemented by programming a .NET add-on to Tekla Structures and tested in field tests in an actually bridge construction project. Tests indicate prototype as a viable tool for surveying, but it still needs further development in usability and measuring features. Results are applicable also to building and road construction surveying.

Keywords: 5D, product modelling, surveying, on-site, real-time

1. Introduction

During a construction project, large amounts of information is generated, shared and exchanged. Studies have however shown that effective communication is hampered by lack of communication channels and processes.[1] One of these information-intense fields is surveying.

Today the state-of-the-art construction surveying tool is a total station. For surveying complex structures such as bridges, a total station is set up for a surveying session by uploading into its memory a specifically prepared simplified 3D surveying model. This model is built using coordinate information derived from printed 2D plans. An example of this kind of surveying model is shown in figure 1. This wireframe model is then used at the work site to mark the position of points to construction workers. The process of remodelling the structure for surveying every time there is a change in the plans is slow and error prone. Finally as-built models are rarely produced and information coming back to the designers from the construction site even during construction is usually only in form of phone conversations or excel sheets consisting of measured point coordinates.[2]

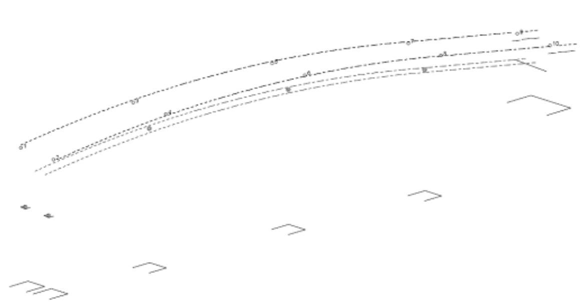

Figure 2. Current way of doing surveying planning: A 3D surveying model of the pilot pedestrian bridge modelled in 3D-Win CAD software, based on coordinates derived from printed 2D design plans.

Due to these factors, in the event of a required change in design, for example due to a prior error, information flows slowly and inconsistently between the different actors in a construction project, causing errors and delays in schedule.[3] To address these problems in the surveying process, research has been done on on-site surveying applications, mainly in the 1990's, and today there are even some commercial applications based on CAD software, namely Bentley MicroStation and Autodesk AutoCAD. None of these solutions have however become widespread, probably because in the past bridge design has been done in 2D, where the application of 3D on-site measuring is not possible. The emergence of Tekla Structures as a viable bridge product modeling software has enabled bridge designers to produce 5D-product models, which in turn enables 3D on-site measuring.[4]

The goal of this research was to define and test a new way of handling the surveying process by integrating 5D product models and on-site measurements. This would enable design plans and as-built information to be seamlessly communicated between designers, surveying teams and other construction site personnel.

2. Method

In this chapter, a new surveying process is defined, a prototype system implementing this process and field tests to test this prototype are described.

2.1 New surveying process

The designer models the bridge as a 5D product model. The model is then saved on a central server where all involved parties can access it via an internet connection. The surveying team can fetch this model directly from the server to the prototype surveying system described in chapter 2.2 and use it to do all surveying tasks required at the construction site. After surveying, the model is uploaded back to the central server where the designer and other involved parties, such as buyers, may immediately inspect surveying results (as-built model). Points that need to be surveyed can easily be marked in the model and change colour to reflect status. Deviations in as-built model relative to original plans are displayed as vector lines.

2.2 Prototype system

A Trimble 5605 DR total station and a Panasonic Toughbook CF-19 laptop computer suitable for field use were used as base components for the prototype system. A surveying software solution was needed to view and manipulate the 5D product model. Also a hardware solution for realizing data communication between the laptop and the total station was needed. Several software and hardware solutions were evaluated, and the following components were chosen to be realized in the prototype: Tekla Structures CAD as software solution and Satelline 3AS/d radio modems for realizing wireless serial port data communication. A surveying software was developed with Microsoft C#.NET language, that works as a user interface for the system and acts as a link between Tekla Structures and the total station's external command interface.

For the system to work, the bridge product model used must be modeled directly in the same coordinate system as is used at the construction site. The total station must be setup and oriented normally using the total stations basic setup process. When the total station and the bridge product model are in the same coordinate systems, measurements can be done.

2.2.1 Hardware

This section describes the prototype hardware. The main component was a Trimble 5605 DR total station, which was used to measure points selected from a bridge product model running on a laptop computer. Communication between the laptop computer and the total station was realized via serial port connection. The laptop could have been virtually any computer with a serial port and capable of running Tekla Structures CAD software, but for this prototype a Panasonic Toughbook CF-19 laptop was chosen because of its suitability for field use.

Since the surveying system was intended to be used by one person, and as the surveyor needs to hold the prism at the point being measured, the commands would have to be sent wirelessly to the total station from the position being measured. In the prototype system this was realized via Satelline 3AS/d radio modems, which are specifically designed to transmit serial data wirelessly. The system setup is visualized in Figure 2.

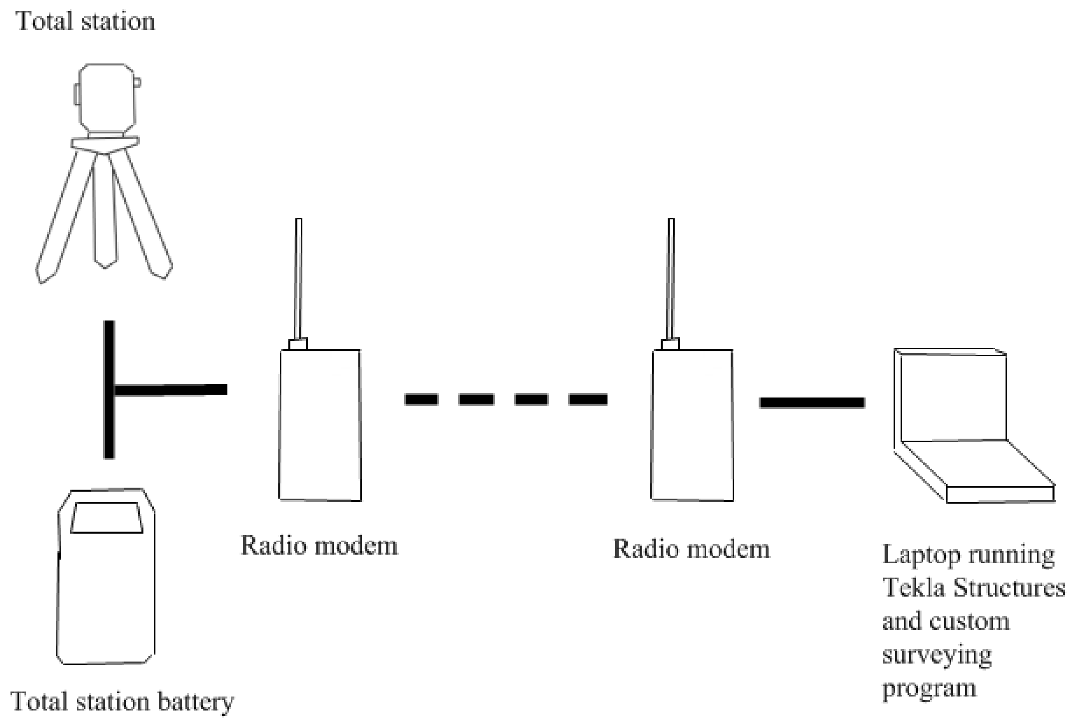

Figure 3. Prototype hardware setup

2.2.2 Software

The software solution was based on using Tekla Structures CAD and the programming interface it offers. A custom surveying software, a user interface, was needed to command the total station using only the laptop, basically acting as a link between Tekla Structures and the total station. Microsoft Visual Studio and C#.NET and Tekla Structures open programming API was used to realize a light software solution which communicated with Tekla Structures to allow the user to select points from the bridge product model using normal Tekla Structures user interface and snapping functionality. The commands were then executed on the total station by sending them via serial port connection, using the total stations serial port command interface.

The system can be used to guide the surveyor towards a selected point to mark it in the field for construction workers; the surveyor selects a point from the product model. The coordinates of this selected point are then displayed on the screen and the total station can then be commanded to measure and guide the surveyor to the selected coordinates. Alternatively the user may want to do an as-built measurement; select and point a feature, such as corner of a concrete slab, in the field. Then click the same feature in the product model, and the software adds a vector line displaying the difference in position, directly in the product model.

Figure 3 demonstrates a screenshot of the combined Tekla Structures and surveying software user interfaces.

2.3 Field tests

The prototype system was tested in a series of field tests at an actual bridge construction site. First test was conducted by measuring selected points from the 5D product model and comparing them with points marked in the field by traditional measuring methods. Second test was measuring points in a finished component and visualizing the data in the model (as-built). The product model was provided by the bridge designer in Tekla Structures format. The model is presented in figure 3. The prototype system and an operator during field tests are displayed in figure 4. Wireless transfer of product model via internet server between designer and survey team was not tested, but instead model was transferred by memory stick.

3. Result

Setting up and orienting the total station to the construction site coordinate system was straight forward. However since the bridge product model that was used had x- and y-coordinates reversed compared to the construction site coordinate system, problems occurred. After the problem was identified, it was solved finally by switching x- and y-coordinates manually in the surveying software user interface.

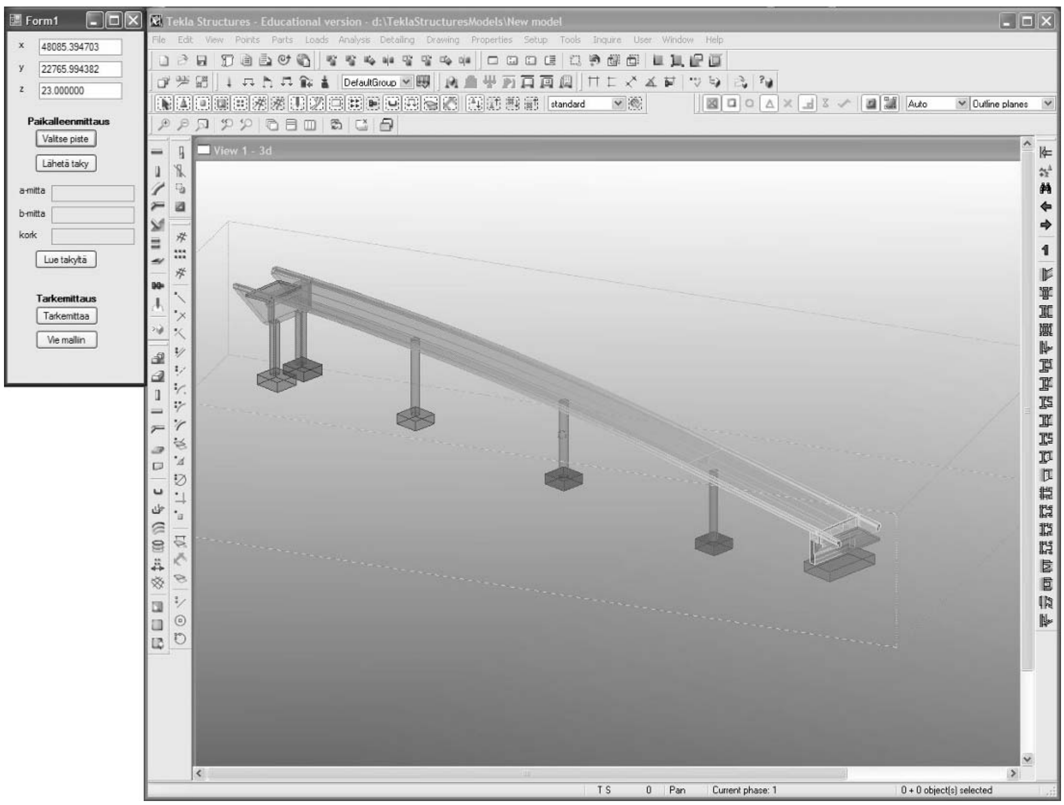

Figure 4. User interface of the surveying software (left side). Product model of the pilot pedestrian bridge is currently open in Tekla Structures (right side).

In the first field tests points previously measured by traditional methods were measured with the prototype system and yielded same results. This was of course the expected result, as only the method of writing and reading the data from the total station differs.

In the second test a finished component, bridge foundations, were measured. The actual foundations located at the construction site are shown in figure 5. The corners of the concrete cast were partially broken and posed a challenge on where to position the total station measuring prism. Finally all four corners were successfully measured and as-built vectors were immediately visible in the product model.

The as-built vectors generated in the product model are shown in figure 6.

4. Conclusion

The tests indicated that a 5D product model in Tekla Structures CAD software could be used directly to make on-site measurements.

As mentioned in chapter 1, several similar systems have been developed before, but using Tekla Structures and in-model vectors to indicate differences from planned positions is new. Tekla Structures also offers possibilities for sharing the different versions of the design plans with the different parties of the bridge construction project, over the internet. Optimal use of these plan sharing features would of course require wireless internet access at the construction site, which can be realized using different techniques, either by existing mobile phone GPRS or 3G network, or a WiFi network specifically setup for the construction work.

The cost effectiveness of a surveying process can significantly be improved by using position measuring directly from a 5D product model of the bridge, since survey preparation is faster, less labour intensive and error prone.

Figure 5. The prototype system at the field test site. Measured bridge foundations in the background (right).

Figure 6. Finished bridge foundations, partially covered in gravel.

The main challenge with the use of the system is that a surveyor often needs to move to difficult locations. A laptop is somewhat cumbersome to carry unless there is a specifically designed carrying harness. A visor type high quality display would solve this problem. The quality of current state-of-the-art visor displays is however not good enough.

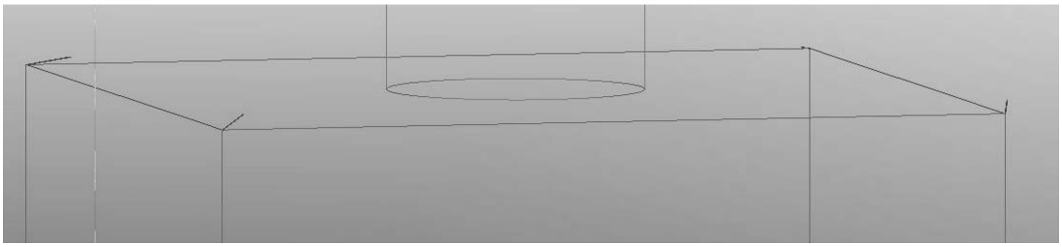

Figure 7. Vector lines in the product model displaying measured points relative to planned.

Further development is also needed in the surveying software user interface, to make it easier to use and also able to measure points relative to planes and lanes, which is a requirement in bridge surveying. Also road measurements are often done by the same survey teams as bridge measurements and they need to be done with the same surveying equipment. The results obtained are applicable also to building and road construction surveying.

Companies involved in funding this study have expressed interest in continued development of the prototype presented in this paper.

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