Combining GPS and CAD

Designing Virtual Models in Real Space

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Combining CAD and GPS in architecture is a challenging task. Both technologies have not much in common. While GPS is used for mapping, CAD is used for modeling and virtual constructing.
The request to design an application, the AmbiViewer, which can be used as design tool in an outdoor environment, brought the technologies together. This paper gives an overview about the GPS-technology and the integration into the modeling software.).

Keywords*: GPS; CAD; augmented reality; interactive modeler; graphic format.*

GPS technology

With the advent of GPS-devices after the selective availability of the Global Positioning System was stopped in May 2000 the use of GPS has become widespread and is already affecting our every day life. In architecture GPS has become part of the GIS-technology and is a core technology in City-Modeling.

Coordinate system

The Global Positioning System (GPS) is created to determine positions on the surface of the globe. Its coordinates are based on longitude and latitude on an ellipsoid coordinate system. Coordinates are measured in degrees on the reference ellipsoid. Therefore they are not equidistant. Modern GPS-devices are based on the WGS84 (World Geodetic System 1984), which is derived from the NAD83 (North American Datum 1983) and the GRS 80 (Geodetic Reference System 1980). To be comparable coordinates must refer to the same reference ellipsoid, or otherwise need to be recalculated. Most European maps are based on the 'Potsdam Datum', which is based on the Bessel-ellipsoid. As example, an aberration found on the "Topografische Karte" (TK) is most likely correlated to a different ellipsoid rather than to incorrect coordinates from on a GPS-receiver.

By comparison CAD-models are located in a local Cartesian coordinate system and the units are expressed in measurements by length in metric units, or maybe statute units.

Devices and protocols

In addition to the ever-confusing usage of different ellipsoids the methods to transform and express GPS-data with computers are diversified as well. There are a variant of manufacture dependent protocols available, namely the Garmin™, SIRF™ and Rockwell™ protocols, and all of them come in different flavors, sometimes even GPS-receiver are transmitting their data using different protocols.

Figure 1
Laptop with connected GPS-receiver

Figure 2
Camera with connected GPS-receiver

The NMEA-protocol

Only one protocol is device independent, the NMEA 0183 standard (National Marine Electronics Association). This standard defines ASCII-based sentences for the use with serial devices. In addition this standard is fixed to a specific baud-rate, 4800 baud for version 1.0, and 38,4 K-baud for 3.0. While the sentences for GPS are only part of the specification, no special care has been taken for them. This leads to the definition of a fixed-decimal format with only four digits behind the decimal point, introducing an error about one meter by definition.

Therefore the choice is only between using a proprietary protocol or the limited NMEA-protocol, or sometimes a deliberately extended NMEA-protocol.

Accuracy

The accuracy of a measurement depends on the quality of the GPS-device's reception or its methods.

Conventional receivers are limited to the satellites' signal and provide accuracy never less than a meter, dependent on the number of satellites-in-view. Differential GPS-devices use a conventional GPS-receiver for an estimate position, on which a corrected signal provided by stationary beacon is overlaid. Availability of differential GPS is therefore limited to the range of the beacons' signal, usually 1000-1500 km from the coastline.

An alternative method of measurement is the combination of two and more conventional GPS-devices in one area. This method is called "Poor-man's differential-GPS". Without a not necessarily absolute fix and thus simply ignoring satellite shifting this method provides distance measurements in sub-meter ranges. It seems that for an outdoor augmented reality system this method is satisfactory, though it is still under examination.

Integration in software

Since there were no means to connect a GPS-receiver simply to a CAD-system, a lot of work went into connecting the devices and interpreting the GPS data and therefore the connecting software, especially with support of multiple GPS-receivers, the interpreter and the geometrical calculations had to be developed.

Now the real-world cameras with receivers are interpreted as viewing-units and as such are integrated as virtual camera-views for the modeling and rendering part of the system.

Current installation

The AmbiViewer-system in its current stage utilizes common off-the-shelf GPS-receivers. They are from different manufacturers all based on the NMEA-protocol. In the beginning only handheld devices were used, because they provided a display and

Figure 3
AmbiViewer-system

Figure 4
Marker with attached GPS-receiver

thus allowed manual input. Now simple GPS-mice based on USB or Bluetooth are in place. They operate within the same level of accuracy and, in the case of USB-mice, do not need an additional power supply and wiring. Combined with a specifically designed hot-shoe they are also easily connected to every kind of camera.

Common software supporting GPS-devices is designed to support only one device, as only one point, the actual position as the location where being is of interests. In contrast the AmbiViewer-system needs a GPS-receiver on each of its connected cameras and on every the marker used as fiduciary feature. As hardware the whole system consists of one laptop computer, at least one camera and a marker-ball, the latter both with attached GPS-receiver. This minimum setup is necessary to determine the viewing direction and field-of-view of the camera. Then with the known geometry of the marker, the distance between marker and camera and some image processing to detect the marker inside the image a connected camera is calibrated on the fly. Simply adding more cameras with GPS to the system creates multiple viewing positions.

Virtual models and absolute coordinates

Computational virtual models and global positioning data in absolute coordinates are not naturally matching parts. A point expressed in GPS-coordinates is always a real position on Earth, while a point in a CAD-model is always a location in virtual space. This principal distinction in paradigm marks the problems and difficulties of combining global positions and virtual models. Even the problems originated by using different coordinate systems, result from the two entirely different concepts.

It affects three main areas: applying geo-spatial data to existing models, creating models solely based on geo-spatial data and/or for geo-spatial purposes, especially mapping, and using GPS as tool in new forms of design like Augmented Reality. It is evident that none of these areas are considered vital parts of CAD. For a variety of reasons, there is still little to no effort to integrate GPS into architectural design.

GPS-coordinates in CAD-models

In CAD it is a common procedure to define a three-dimensional coordinate space, create a model and a surrounding virtual world and store it in a dedicated file or folder. Other models or project are stored similar, thus there is almost none correlation between those models. Modeling in global space is different. Every model is located on the global grid and all models with GPS-coordinates applied are correlated.

There are two approaches to combine absolute GPS-coordinates with computer generated virtual

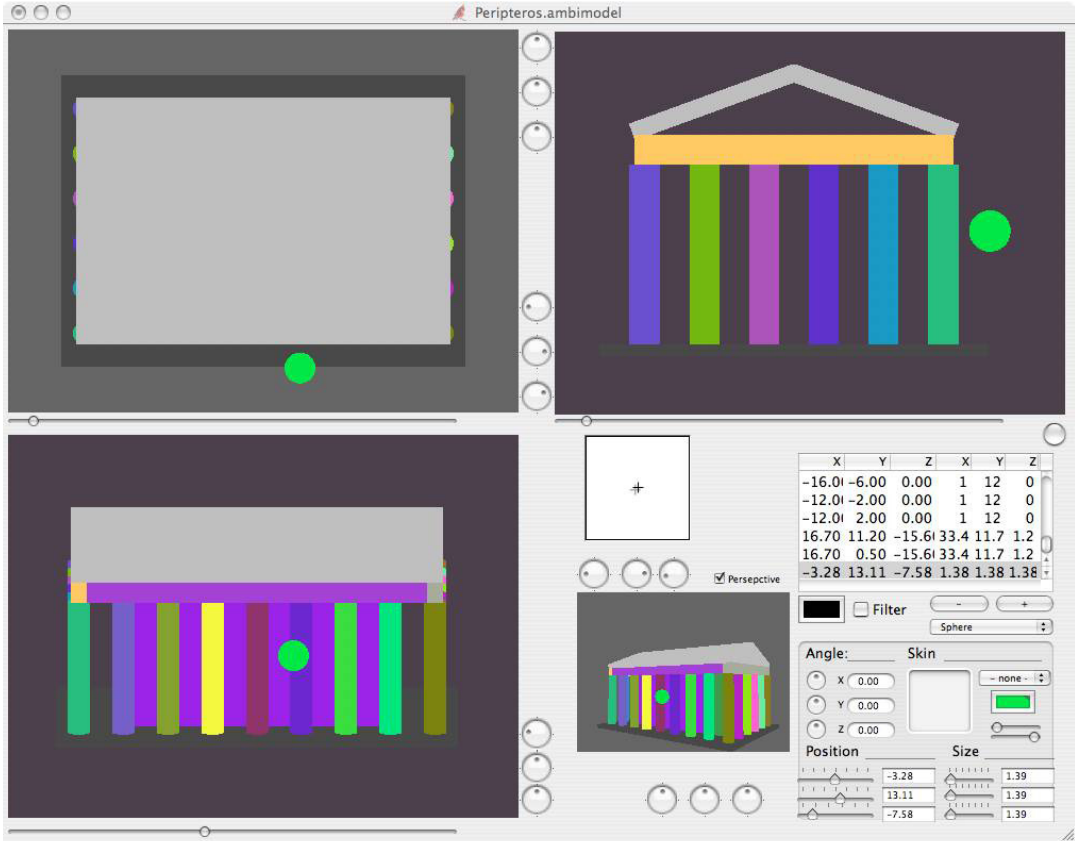

Figure 5
Interface of the Interactive Modeler with visible marker ball

models: establishing the whole model in GPS-coordinates or reference some well-chosen real-world positions to virtual points in the coordinate space of the model.

Model in absolute coordinates

Establishing a whole three-dimensional model in GPS-coordinates at first hand seems to be a practical implementation. Every point of the model is defined by a global position thus allowing locating even the smallest shape on the Earth's surface.

A closer look reveals some essential shortcomings. With all data represented in an ellipsoid coordinate system all measured distance are calculated using complex algorithm, and modification by hand, e.g. moving two walls by maintaining their distance, are impossible without the underlying calculations. This demonstrates both the difficulties, as it is cumbersome to represent a three-dimensional model in GPS-coordinates, and the necessity doing so.

One example of this approach is the 'Keyhole Markup Language'(KML) used by the family of 'Google's Earth' application to locate virtual models on digital maps or satellite images.

Models with referenced coordinates

Referencing the model to global space is more suitable. If the shape of a model is defined as geometry in a local coordinate system where the origin lies within or near to the model's extent then only one point, usually the point of origin has to be represented in global coordinates.

This approach has some advantages compared to a model solely in absolute coordinates. It is more flexible, because there are no changes in editing and modifying the model, and moving the model in global space is as simple as changing one pair of coordinates. In addition renderings and visualizations are not slowed down due to complicated calculations. One example of this approach is "CityGML.

Also the AmbiViewer-system system is based on this technique by referencing cameras and markers to the model's coordinate space.

Earth models

Right now we are watching incredible progress in cartography tools and mapping service. This year Google has released his new "Google Map" with all major cities in the USA three-dimensional displayed on the Internet (which in fact is '2.5D'). The application software "Google Earth" already shows three-dimensional models for more than a year. Microsoft's "Virtual Earth Platform" even goes further by mapping three-dimensional shapes with images from the surfaces to provide an almost photorealistic model.

However, the geometry of these models is taken from the real world objects. To make no mistake, the concepts are based on mapping, not on designing.

CAD and design models

Although some progress can be seen and some methods to apply GPS-informations to CAD-models are already in place, the overall outlook remains dim: With the exception of 'SketchUp' by 'Google' none of the common graphics formats can store GPS-coordinates, and neither major CAD-application do support GPS-data or GPS-receivers in a native manner.

While there is already some demand, one point remains underestimated: Every architectural model will be referenced to a global position for the foreseeable future. Besides the actual usages of GPS in GIS, City-modeling and Augmented Reality the support of global coordinates in CAAD will be inevitable.

AmbiViewer

Specifically designed for the use in architecture the AmbiViewer-system is developed from scratch to mix virtual architectural objects into real-world images directly on the building site by utilizing cameras and GPS-receivers connected to a computer. While it is very similar to other Augmented-Reality systems the inherent Interactive Modeler transfers it into a design tool.

Photomontage

Photomontage is a preliminary technique to produce composite images. With fixed locations in the coordinate space of the model this method is common to combine real-world images with virtual world renderings. Many CAD-systems provide support for the overlaid technique of photomontage.

Augmented Reality

The setup of the AmbiViewer-system is very similar to conventional Augmented-Reality-systems (AR). Cameras and models are referenced with real-world coordinates to virtual model coordinates, and vice versa.

One major design aspect was flexibility. Most AR-systems are bound to specific location when only there the infrastructure is provided to allow real-time tracking, with head-mounted-displays and other important gadgets important to visualization, but not necessarily to design. In addition the concept of tracking a marker is uncommon in AR, because it is more desirable to combine tracking and capturing in one device.

As result of these trade-offs the AmbiViewer has become deployable and affordable. With standard GPS-receiver attached to standard cameras and inflatable marker balls the whole system with laptop fits in a backpack.

The prototype

The actual prototype of the AmbiViewer is capable of composing the view of a virtual model into in a real-time video stream at a location anywhere on the surface of this planet. As fiduciary feature the three-dimensional marker as single-colored ball with an attached GPS-receiver is located on the spot where the desired building should be located.

The virtual model of the prototype consists of shapes, which are directly rendered into OpenGL. These object-oriented shapes are ordered as a tree in a local coordinate system. To alter the model the Interactive Modeler is introduced.

Graphic format

As preliminary step a binary format for reading and writing was created, which is full functional but lacks the compatibility with any other format. A model can be saved and loaded as a file, its coordinate is relative to the marker. The absolute GPS-coordinates of the marker actually are stored persistently.

The search for an appropriate data format is still an ongoing task.

Interactive modeler

The concept of the Interactive Modeler as vital part of the AmbiViewer-system was developed to establish an outdoor design environment. Although this modeler is still very basic compared to fully fledged CAD-systems, it only allows the construction of basic shapes, and it is a suitable tool to design three-dimensional models while being on-site. The added feature of manipulating the model makes it a unique tool in CAD.

Scenic rendering

A model rendered in real space has no need for atmospheric surroundings like a blue sky or a horizon, because these parameters are taken out of the real-world.

Synchronizing the environmental settings, especially the lighting, will be a major task in future versions of the system. Because all necessary parameters are known by means of the GPS-device, the position, the time of the day and the day of the year, the exact position of the sun can be easily calculated and applied to the virtual model as global light pointing from the very same position in model coordinates.

In addition it is contemplated, that analyzing the already deployed marker would gain even more environmental information. If a marker is rendered in the virtual model with similar shape, position, color and shininess, its appearance can be designed exactly as the real-world marker. Then the virtual lighting can be adjusted by comparison, either manually or, more desirably, computational.

Conclusion

Although CAD and GPS are not natural matching technologies the need to advance and create new tools forces even architect to develop new applications. The combination of GPS and CAD lead to the system here presented as AmbiViewer. With OpenGL and video streaming the embedded Interactive Modeler can provide some unique results.

Still under development the AmbiViewer-system shows an alternative to exclusive virtual visualizations. Projecting and displaying virtual models on the exact site of a non-existing building enables designers to have a unique experience on the site and also an insight into the state of the desired building.

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