

Mobile 3D visualization for steel structures

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Abstract

Until recently, visualization of 3D models required computational resources available only on desktop computers in office environments. With the advance of technology, it is now possible to visualize substantial 3D models on mobile handheld computers in the field. This paper discusses some of the current technology, discusses the use of the Virtual Reality Modeling Language on mobile handheld computers, shows several examples of 3D structural steelwork models visualized on a mobile handheld computer, and identifies some of the limitations imposed by current technology.

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1. Introduction

Over the past decade, CAD software for construction has gone from simple 2D drafting programs to complex 3D solid modeling systems that support structural analysis, logical product models, project management information systems, collaborative environments, and task scheduling. The hardware on which those programs run has progressed from mainframes to desktop computer and laptops. The size of computer storage and memory has gone from megabytes to gigabytes. Communication between client-server applications has advanced from dialup modems to always on broadband and wireless networks.

Mobile handheld computers and personal digital assistants (PDA) such as PocketPC¹ [1] and Palm [2]

devices are now gaining acceptance as useful tools at a construction site [3]. Software applications previously confined to the engineer's office, are now available on the construction site. They provide a means to have access to project information that is stored locally on the PDA or accessed from a server through a wireless Internet connection. The information can also flow in the opposite direction where the PDA is used to collect data from the construction site and is communicated back to desktop applications for subsequent processing.

Although 3D solid modeling is becoming more popular, there are very few applications for doing 3D visualization on PDAs. A common format used for displaying 3D models on desktop computers is the Virtual Reality Modeling Language (VRML) [4,5], which is a scene description language for representing 3D interactive models on the web. VRML models are displayed in freely available VRML plugins [6–8] for Netscape or Internet Explorer. A VRML browser has also been developed for the PocketPC [9]. Most CAD

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¹Any mention of commercial products does not imply recommendation or endorsement by NIST.

programs can export their models in VRML format; however, the VRML representation of a CAD model is not well suited for viewing on a PocketPC because of its memory and computational limitations. The VRML generated from CAD programs usually does not take advantage of any of the useful features in VRML to make the file sizes smaller and more efficient.

2. Hardware

The most common type of handheld computers are PDAs that run either the Palm or Windows CE operating system. PDAs typically have a screen resolution of 240×320 pixels. This low screen resolution limits the type of 2D or 3D information that can be effectively displayed. Traditional methods of displaying data on a normal sized computer monitor are often not appropriate for PDAs and new visualization paradigms need to be developed. Devices running the Palm OS usually have 16 MB of memory while newer PocketPCs running Windows CE typically have 128 MB of memory. Depending on the operating system, the memory is used to store the operating system, applications, and files and provide memory to run programs. PDAs normally do not have a fixed hard disk. Currently the processors in PDAs are not very powerful or suited to dealing with large amounts of data that might be needed for 3D CAD applications. The first 2D graphics accelerators for PocketPCs are only beginning to be available [10].

The user interacts with the PDA using a stylus to pick menu items or to write on the screen. Some PDAs have a small joystick-like device to aid in navigation. Detachable keyboards can also be used to enter information. Files and applications are usually transferred to and from a PDA by synchronizing with a host computer. Information can be transferred directly between PDAs or other computers by beaming it through an infrared port.

Most PDAs have expansion slots for compact flash (CF) memory, wireless Internet access, and other CF or PC expansion cards such as global positioning system receivers or barcode scanners. Some PDAs have built-in wireless access. There are even PC expansion cards that incorporate a 1 GB miniature hard drive [11]. With this amount of storage on a

handheld device, an enormous quantity of information can be brought to the construction site.

One of the primary limiting factors for displaying 3D data on a PDA is the amount of built-in memory. Adding memory or a hard drive through an expansion slot only increases the amount of space available for storing programs and files. The memory available to run programs is restricted to whatever is built-in to the PDA. For example, in a PocketPC running Windows CE with 64 MB of memory, by default, half of the memory is allocated to storing programs and files and the other half to running programs. The memory allocation between storing and running programs can be adjusted to provide more or less of the built-in memory to each function.

There are also several PDAs that run the Linux operating system. Larger pen-based tablet computers run the Windows XP operating system. One manufacturer has even developed a pocket-sized computer that runs Windows XP with a 10 GB hard disk and 256 MB of memory [12].

3. Software

Several CAD and construction related software applications are commercially available for PDAs. In general, the more complex and graphics oriented applications run on PocketPCs with the Windows CE operating system. Applications that run on Palm devices are usually text oriented such as punch list, project management, or scheduling software. Research into collaborative dynamic project management has shown how PDAs and even web-enabled cell phones can be used as wireless display devices for traditional desktop construction management software [13].

A number of 2D graphics applications that display traditional CAD drawings in DWG, DXF, or DGN formats are available for PDAs. Some of the programs can display the drawings directly, while others require that the drawing be converted to a proprietary format that is optimized for the software. Other applications provide the means to markup existing or create new CAD drawings [14,15]. Certainly the low screen resolution and small screen size are limiting factors for the utility of working with CAD drawings on a PDA. Version control of CAD drawings between a PDA and desktop computer is

also of concern. Simple file synchronization may be inadequate when format conversions are taking place on one platform but not the other.

The development of 3D visualization programs is only in its infancy. At least two commercial products are available for developing and delivering 3D content and applications for PDAs and other mobile devices [16,17]. However, these applications are geared towards 3D games and not to 3D visualization for CAD. Research at IBM led to the development of a 3D viewer that can display a subset of VRML [18] on a PocketPC; however, the VRML files have to be converted to a proprietary format before they can be displayed in the viewer.

Pocket Cortona [9] is an inexpensive VRML viewer for PocketPCs that supports most of the VRML specification including application specific nodes. VRML models that are generated by CAD programs can be displayed in Pocket Cortona without modifications. Pocket Cortona can run in a standalone mode or as a plugin to a web browser. In the stand-

alone mode, the VRML file to be displayed is stored locally on the PocketPC. PocketPCs with a wireless Internet connection, web browser, and Pocket Cortona can access VRML models through a web page in the same way they are accessed on a desktop computer.

4. VRML

VRML is an ISO standard [19] for describing 3D geometric objects and their behaviors. Information in a VRML model is arranged in a scene graph that defines the parent–child relationship between VRML nodes. Some common VRML nodes describe 3D shapes, the appearance of the shapes, and geometric transforms that can be applied to the shapes. The shapes include primitives such as boxes, spheres, cones, cylinders, extrusions, and general sets of points and polygons known as IndexedFaceSets. Transforms that can be applied to the primitives include translation, rotation, and scale.

```
#VRML V2.0 utf8
PROTO SquarePlate [
  field SFFloat mySize 1
  field SFColor myColor 1 0 0
] {
  Shape {
    geometry IndexedFaceSet {
      coord DEF POINT Coordinate {point []}
      coordIndex [0 1 2 3 -1]
      solid FALSE
    }
    appearance Appearance {material Material {diffuseColor IS myColor}}
  }
}
DEF PLATESCRIPT Script {
  field SFFloat mySize IS mySize
  eventOut MFVec3f point
  url ["javascript:
  function initialize() {
    point[0] = new SFVec3f (0, 0, 0);
    point[1] = new SFVec3f(mySize, 0, 0);
    point[2] = new SFVec3f(mySize, mySize, 0);
    point[3] = new SFVec3f(0, mySize, 0);
  }
  "]
}
ROUTE PLATESCRIPT.point TO POINT.set_point
}

SquarePlate {mySize 7.5 myColor 1 .7 .3}
SquarePlate {mySize 0.3 myColor 0 1 0}
SquarePlate {}
```

Fig. 1. VRML PROTO for a square plate.

```

Part {
  section ["IB W16X36 DIM:.4028,.1774,.0109,.0075 ME CP:8 MIRROR"]
  len 1.5978
  units "METERS"
  color 0 1 0
  feature [
    "NOTCH length .0889 depth .032 TOP_EDGE START_FACE OFT"
    "CHAMFER length .0889 depth .0889 BOTTOM_EDGE START_FACE OFT"
    "SKEW angle_1 37.38 BOTTOM_EDGE END_FACE OFT"
  ]
}

```

Fig. 2. Example of using the Part PROTO.

Typically the VRML models exported by CAD programs use IndexedFaceSets and geometric transforms to represent all of the geometry in a model. An IndexedFaceSet defines the *XYZ* geometric coordinates and an index array that describes how the coordinates are connected together to create faces that are displayed. While this provides an accurate visual representation of the geometry, it does not take advantage of several features of VRML to reduce the file size and make the processing of the VRML model much more efficient.

The VRML prototype mechanism (PROTO) allows for the creation of application-specific geometric objects similar to the built-in primitives such as boxes, spheres, cones, and cylinders. For example, the SquarePlate PROTO in Fig. 1 will generate an IndexedFaceSet for a square with a minimal amount of input. The PROTO itself contains an interface definition of two input parameters, mySize and myColor. The actual VRML geometry is an IndexedFaceSet contained in the Shape node and its size is computed in the Script node. The Script node uses a JavaScript function to compute the point variable that contains the coordinates of the corners of the plate. The variable point is ROUTE'd to the Coordinate node to set the point coordinates. The last three lines show how the PROTO is used to model three different size plates with different colors. The third instance of SquarePlate uses the default values for mySize and myColor that are defined in the PROTO.

Research at NIST [20,21] has developed a mapping between the CIMsteel Integration Standard (CIS/2) [22] and VRML. CIS/2 is a logical product model [23] for describing steel structures and has been adopted by the American Institute of Steel Construction as their standard for electronic data interchange [24]. Several vendors of steel CAD software related to

analysis, design, detailing, and fabrication have implemented CIS/2. STEP technology is used to define the CIS/2 schema and the format of a CIS/2 file that is exchanged between steel CAD software packages.

VRML prototypes have been developed that correspond to CIS/2 entities such as parts (beams, columns, braces, clip angles, plates), bolts, holes, welds, and locations. A translator has also been developed that converts a CIS/2 file into a VRML file that use the PROTOs. For example, Fig. 2 is an example of a VRML file for a part. The part is a W16X38 wide flange section that is 1.5978 m long with a notch, chamfer, and skew angle.

Another important feature of VRML, which is usually not implemented in the VRML model exported by a CAD program, is the ability to define one geometric object and create many instances of it.

```

#VRML V2.0 utf8
# located assembly
Axis2p3d {children [
# located part - beam
  Axis2p3d {children [
    Part {}
    Axis2p3d {children DEF HOLE1 Holes {}}
  ]}
# located part - clip angle
  Axis2p3d {children [
    DEF CLIPANGLE Part {}
    Axis2p3d {children USE HOLE1}
  ]}
# located part - clip angle
  Axis2p3d {children [
    Group {children USE CLIPANGLE}
    Axis2p3d {children USE HOLE1}
  ]}
# located joint system - bolts
  Axis2p3d {children Bolt {}}
]}

```

Fig. 3. VRML representation of a beam with clip angles using DEF and USE.

In a typical steel structure there are many identical parts, each with their own location. In the VRML model only one of each type of part needs to be modeled. The rest of the VRML model is built from instances of the defined parts. This is much more efficient than modeling all of the geometry explicitly.

In a VRML file, DEF and USE can be used to reuse identical parts. Any VRML node can have a user-defined name using DEF. Once a node is defined then multiple instances of it can be used with the USE construct. Fig. 3 shows how DEF and USE are implemented with several of the PROTOs that have been developed. The details of the input parameters for each PROTO are not shown. The Axis2p3d PROTO is used to specify the position and orientation of an entity. DEF and USE is applied to the clip angle to that it can be reused. Assuming that the size and layout of the holes that go through the clip angles and the beam are the same, then the holes can also be defined and reused. In this manner the VRML representation of an entire steel structure can be developed.

VRML models using the CIS/2 related VRML prototypes represent a steel structure much more

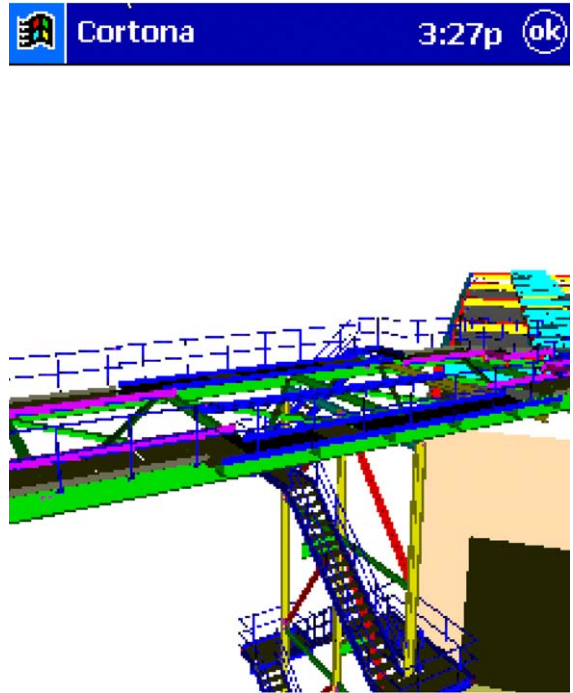


Fig. 5. Steel support structure for the NIST ECS.

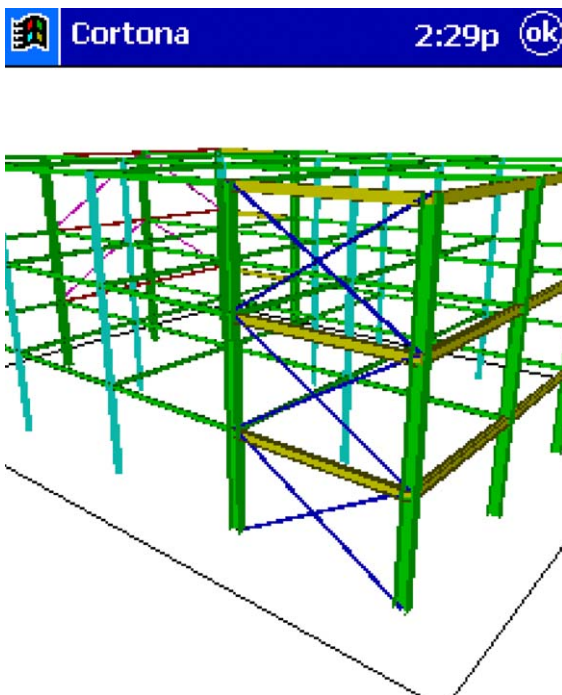


Fig. 4. Three story structure with diagonal bracing.

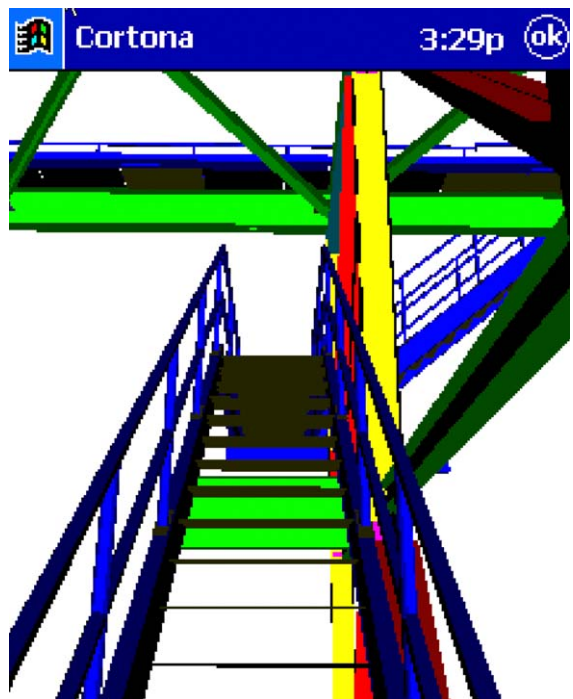


Fig. 6. Detail of the steel support structure for the NIST ECS.

efficiently, effectively, and intelligently than the VRML models exported from a CAD program. Therefore much larger models can be displayed in a VRML browser on a handheld computer. With this capability, 3D visualizations of CAD models of steel structures can be viewed in the field at a construction site.

5. Examples and conclusions

The following VRML models were displayed on a Compaq iPAQ H3670 PocketPC with 64 MB of memory running Pocket Cortona. The memory allocation was adjusted so that 40 MB was available to run programs. All steel parts with the same cross section have the same color, but all parts with the same color do not necessarily have the same cross section. All I- and T-beams are green, yellow, and cyan. All other sections are red, magenta, or blue except plates, which are gray.

Fig. 4 is a VRML model of a simple three story steel structure with diagonal bracing. This model is small enough that the user can easily interactively move around the structure. Fig. 5 is a VRML model of the steel support structure that is part of the emissions control system (ECS) ductwork for the NIST Large Fire Research Facility [25]. This model contains over 1600 parts and is a good example of the limitations of displaying VRML on a PocketPC. To minimize the number of polygons that are displayed, the thickness of the webs and flanges have been ignored. Nevertheless, it takes about 5 min for the model to display and is so large that the user cannot interactively navigate through the model. The only way to move around in the model is with predefined viewpoints in the VRML model. Small details such as the handrail look incomplete because of the low screen resolution. Fig. 6 shows more detail of the structure in Fig. 5. A close up view of a connection is shown in Fig. 7. The location of the head of several bolts is shown as a black cross.

These examples show how 3D visualizations of steel structures can be displayed on a PocketPC. The VRML models are generated directly from CIS/2 files and use V RML prototypes and other features to make the VRML files smaller and more efficient to process. Although there are limitations to the size of a VRML model that can be effectively displayed on a Pock-

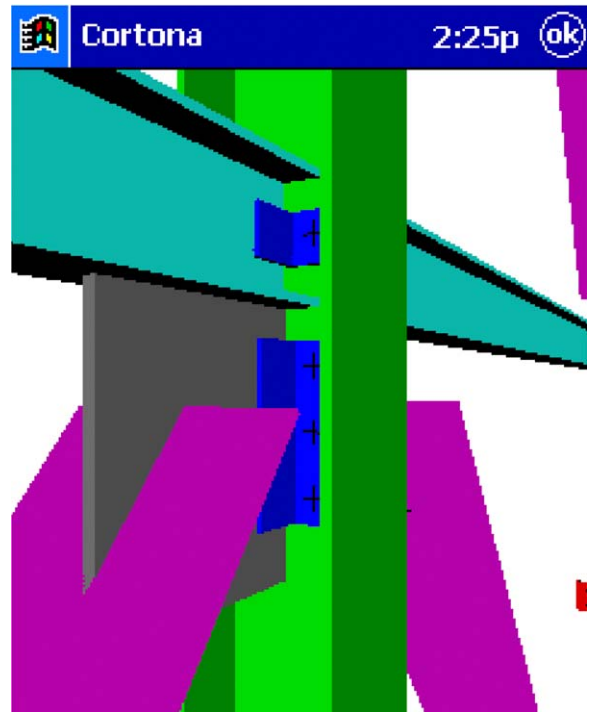


Fig. 7. Close up view of a connection.

etPC, the inevitable improvements in processing power and graphics accelerators for handheld computers will provide an improvement for 3D visualization in the future. Within several years, it should be practical to make 3D visualization on PDAs a commonplace tool at construction sites.

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