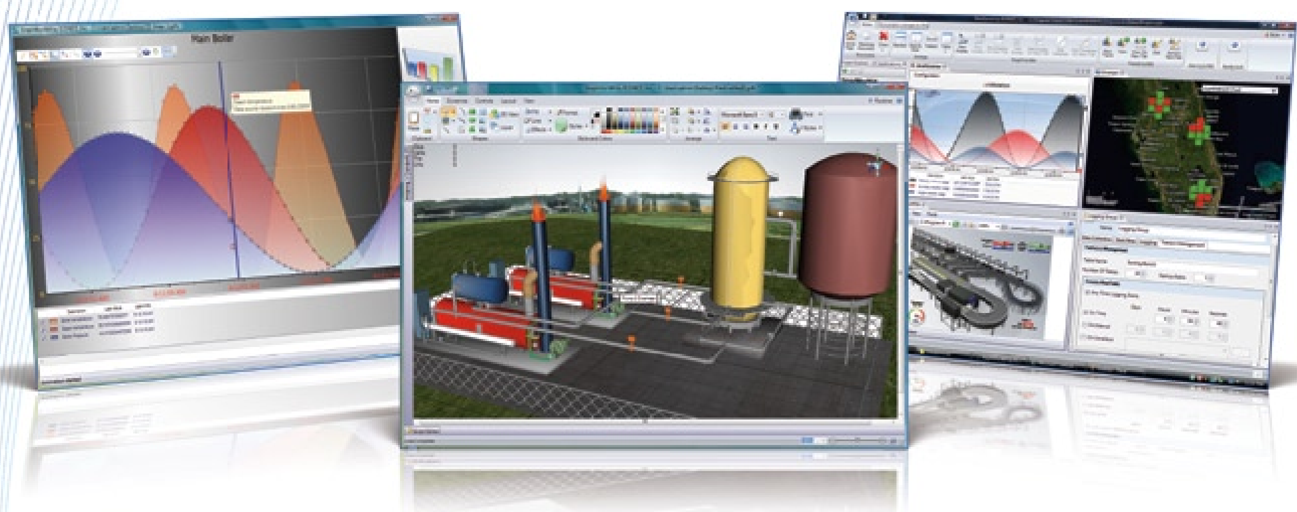
Advanced 3D Visualization for Manufacturing and Facility Controls

Research Brief

June 2010



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Advanced 3D Visualization for Manufacturing and Facility Controls

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***Abstract* — Today's manufacturing and building operations are faced with the need to reduce cost and be more competitive with the fewest of resources. Connectivity to different infrastructures for data gathering and the need to analyze and visualize data in real time is ever more important in today's economic environment. Recently, visualization systems have taken a giant step forward incorporating advanced hardware accelerated 3D graphics into standard off-the commercial product. As a result, providing compelling 3D graphics applications and having access to plant data is the key to having a competitive advantage.**

This paper presents a whole new powerful approach to visualization of manufacturing that greatly reduces the learning curve for developing Human Machine Interface (HMI) applications.

***Keywords* — 3D Graphics, HMI, WPF, XAML, AutomationML.**

I. Introduction

MANUFACTURING systems are comprised of products, equipment, people, information systems, control and support functions for the competitive development, production, delivery and total life cycle of products. The goal consists of satisfying market as well as social needs. Industrial and automotive manufacturers are facing numerous challenges across all phases of the product development process – shorten development times, managing global supply chains, fierce competition, and increasingly complex products. They are in need of solutions that can help them get to market faster, cheaper and with greater functionality and capability.

The best strategy is to adopt, open industrial standards for providing complete integration of multiple systems at the hardware level as well as to choose the latest available software tools that can have long term usefulness and can be current for at least five to ten years.

In past systems 2D graphics for automation were and still are for the most part the dominant approach. Now the landscape is about to change and a new 3D approach is more than just hype. It is not "just a passing fad"; it is now a reality. Modern visualization applications are leading the way to incorporating 3D graphics technology into a vast array of industrial solutions that can meet real customer needs in multiple industries, including:

- Automotive
- Building Automation
- Oil, Gas & Petrochemical
- Food & Pharmaceutical
- Water and Wastewater

among many others.

This new approach will save time and money, providing the ability to create captivating 3D graphics, to reduce engineering cost and speed up the development time for any project.

II. State Of The Art: Evolution of 3D Industry

Several companies today offer 3D software tools and plug-ins, pre-built 3D data, and services to a growing number of 3D content creators. A global community of hundreds of thousands of 3D enthusiasts as well as professional artists and programmers utilize 3D technology in game development, video production, publishing, film, and graphic arts.

What are the factors affecting the continued evolution of this 3D ecosystem? There are three fundamental changes at work: the rising popularity of new 3D software, the growing global influence of online 3D communities, and the growing availability of pre-built 3D content.

An increasingly rich array of software for creating 3D content is now available. Previously, large, multi-purpose 3D software packages such as Softimage's XSI and Autodesk's 3ds Max and Maya dominated the commercial tools market. Today, also other stand-alone, focused 3D products offer solutions for many functions and technologies specially optimized for particular needs.

Since people started using 3D software, the desire to share the experience with other 3D users has been strong. Today, the interaction among 3D artists is occurring on a much larger scale via the Internet, where very large online communities have formed. In dozens of online communities, 24 hours a day, 3D works in progress are presented and critiqued, technology advances are discussed, and techniques are shared. As an example, the CGSociety community has more than 252,000 registered members, with nearly 100,000 of those being active members.

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The increasing availability of 3D content in today's media has created a powerful gateway to introduce a large number of people to the hands-on use of 3D technology. This hands-on experience is beyond the passive exposure people receive from 3D in movies and even beyond the use of 3D in games. Also, multiple studies indicate that 3D elements of graphical image are perceived better thus making it easier for the designer to implement the idea of his artwork. That is why many companies have been developing industrial 3D solutions:

- Open Inventor® by Mercury: a cross-platform 3D graphics toolkit for the development of industrial-strength interactive 3D graphics applications using C++, .NET or Java that provides functionality of OpenGL at an object-oriented level
- Hoops 3D Application Framework® by Spatial Corp [1]: provides a core graphics infrastructure and functionality for 3D applications and full Application Programming Interface (API) access to a powerful underlying suite of integrated components
- DeskArtes ViewExpert®: offers tools for viewing, verifying, measuring and communicating 3D CAD data files, such as STL, VRML.ZPR and IGES formats

and many others solutions are available to meet the ever growing market needs.

Industries that use 3D graphics technology the most, such as computer games and visual simulation, do not use code generation to represent 3D models. They instead concentrate on embedding efficient rendering algorithms for 3D geometry loaded from a file store. Most 3D applications are too complex to implement atop OpenGL directly, and to implement a 3D view with many objects displayed in it, scene manager libraries are commonly used. With an OpenGL-based scene manager, the software developer is offered a set of higher-level constructs with which to build the 3D application. Quantum3D®'s approach to HMI generation for example centers on the creation of a graphics database (dynamic bytecode) representing the HMI that uses a middleware-rendering interpreter to display the 3D graphics [2].

Although these industrial solutions provide 3D graphics functionalities, today's HMI applications don't need simple digital photographs of in-place equipment converted into recognizable 3D images; they also need real-time data connectivity to provide users a detailed and complete overview of the manufacturing plant itself.

III. 3D Enhances Real-Time Visualization

3D visualization can benefit HMI applications by providing true to life shapes, forms, processes and other details that otherwise are lost when viewed in a traditional 2D manner.

Having a 3D model, set of images or animation allows better interactivity with the idea, process or product. When an idea needs to be presented to the potential client, most times the idea is best received in a 3D form. We live in a 3D world; our eyes and brains are used to seeing and perceiving depth, perspective and form.

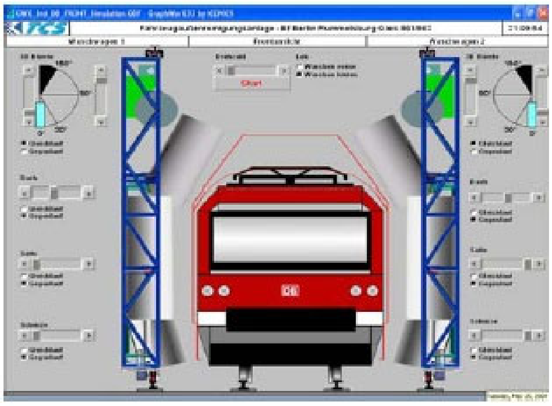

Fig. 1. 2D Automotive HMI graphic (ICONICS[3])

Products come alive when they can be delivered in a 3D format. Process and technologies can be improved, both in function and visualization, by showing them in a 3D environment, especially when the environment can be made to resemble the actual working conditions of the process – rather than a simplified 2D drawing.

Technically, a 3D image is the best way to handle visualization of a large number data and to keep a global vision on a system. It is indeed the most natural way to represent a large number of heterogeneous information.

Fig. 2. 3D Train HMI graphic (Genesis64 suite[4])

HMI displays can take advantages of the following benefits:

- Reduce production costs and time-to-market
- Expedite complicated decision making processes
- Review product in concept and each stage of design and development
- Decrease dependency on the 2D drawing interpretation to avoid production mistakes
- Operate from easy to understandable visual plans.
- Showcase industrial environment and products features from different angles before full-scale production.

Using 3D displays greatly improves design quality because it is a more complete process than 2D design. As a result, many human errors that can occur with traditional 2D design methods are avoided.

This makes 3D HMI solutions a powerful business tool: it can communicate complex subject quickly, reduce costs and errors rate, and make collaboration more efficient and flexible.

IV. Leveraging Advanced Technology

With the convergence of 64-bit, multi-core, multi-processor computing; the introduction of new 64-bit operating systems; and demand for high performance 64-bit native applications, modern visualization solutions provide customers with the greatest saleability, reliability and flexibility.

Designed from the ground up and taking advantage of the OPC-UA communications standard, .NET managed code and SharePoint® technology, the newest HMI solutions allow for connectivity from plant floor and business facilities to corporate business systems.

OPC Unified Architecture (OPC-UA) [5] is a robust, secure and scalable expansion of the highly successful basic COM/DCOM-based OPC standard communication protocol. OPC-UA allows the interoperability of best-of-breed real-time, alarm management and historian systems.

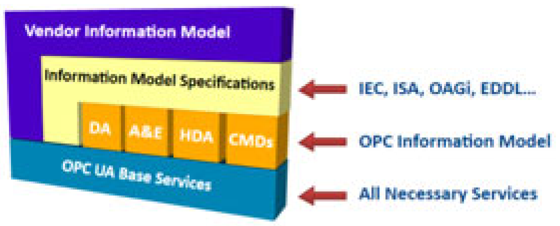

Fig. 3. OPC-UA Specification Layer

This allows for a standard model of plant floor integration with the enterprise. Any industrial or facility control system that is currently using OPC communications can easily add the latest OPC-UA applications to their existing system, giving them the added value of Web services that allow for more enterprise connectivity. The next generation of OPC Data Access (DA), OPC Alarm and Events (A&E) and OPC Historical Data Access (HDA) allows for secure, open connectivity from plants and facilities to the enterprise level, exemplifying the next generation of standard-based communication.

Today, industrial and manufacturing solutions can be developed taking maximum advantage of state-of-the-art graphic hardware acceleration through DirectX10, integrated with Windows Presentation Foundation (WPF) for rich 2D and 3D HMI applications.

WPF [6] is a graphical subsystem in .NET Framework 3.0, which uses a markup language known as XAML (eXtensible Application Markup Language) [7], for rich user interface development.

Innovative HMI applications benefit of the following WPF features:

- Supports vector-based graphics, which allow lossless scaling
- Supports 3D model rendering and interaction in 2D applications
- Interactive 2D content can be overlaid on 3D surfaces
- Offload some graphics tasks to the Graphics Processing Unit found on the computer's graphics card

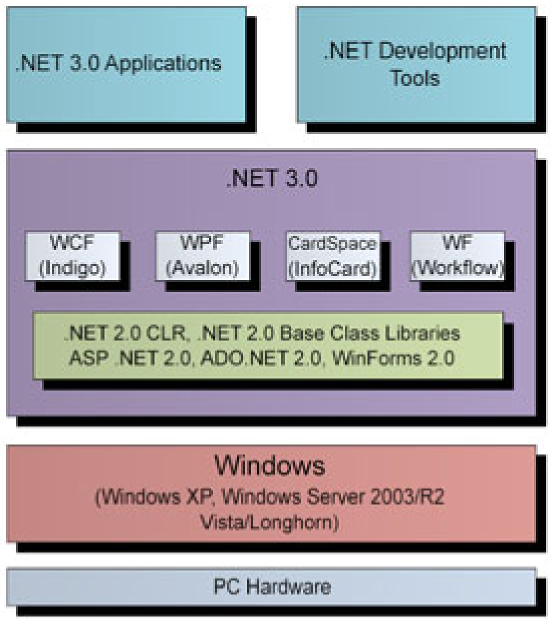

Fig. 4. Microsoft .Net 3.0 Stack

The specific advantage that XAML brings to WPF is that XAML is a completely declarative language. As a result, the developer (or designer) describes the behaviour and integration of components without the use of procedural programming. This allows someone with little or no traditional programming experience to create an entire working application with no programming.

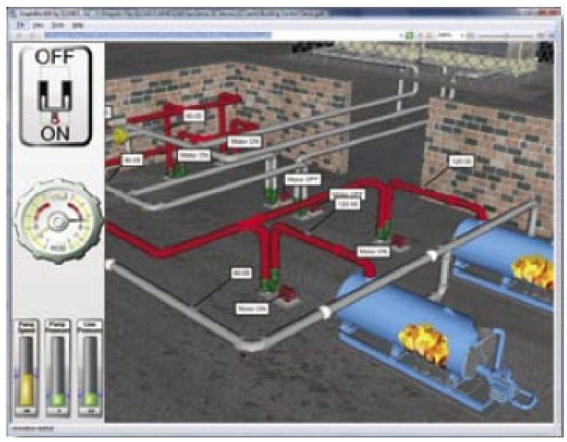

Fig. 5. 3D Facility Control WPF and XAML [8]

Although it is rare that an entire application will be built completely in XAML, the introduction of XAML allows application designers to more effectively contribute to the application development cycle. Using XAML to develop user interfaces also allows for separation of model and view; which is considered a good architectural principle.

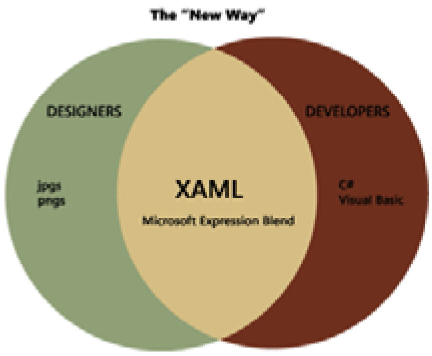

Fig. 6. XAML between designers and developers

V. Bridging The Gaps In Your Design And Manufacturing Workflow

Compared to several years ago, the automotive industry has been very rapidly changing. New business workflows, processes, procedures and manufacturing techniques must support environments that inevitably reduce the manufacturing design and preparation time in developing a new automobile. This requires engineering systems that improve collaboration, driven by the asset utilization of factory resources and substantial reduction in costs. By using this new approach and system, savings in time and cost of process and material planning are possible, and the reliability of the plan result is greatly improved.

As customer demands diversify, product lifecycle is shortened and global competition among companies becomes fiercer, automotive companies strive to discover new paradigm shifts and technologies for rapid and cost effective ways of developmenting new products.

As a result, the goal consists of adopting several specialized standards under one umbrella to supports as many aspects of the engineering chain as possible.

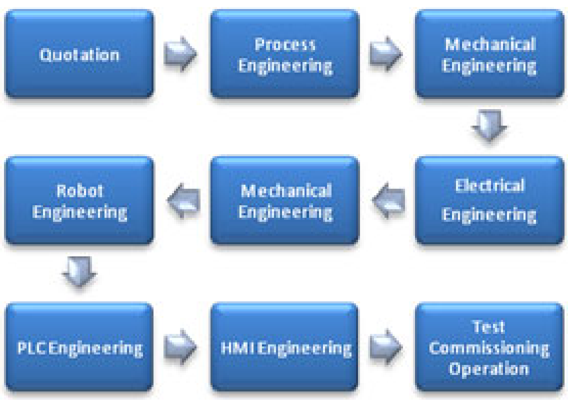

Fig. 7. Engineering chain

This is the innovation brought by AutomationML™ (Automation Markup Language) to achieve reliability, availability of knowledge, independence and cost effectiveness, by combining well accepted standardized formats already deeply used in the market.

VI. The Glue For Seamless Automation Engineering: <AutomationML/>

The engineering cost of an automation project is typically 60% of the total project cost. In the past optimization strategies have addressed the bought-in parts well; a wide area to increase efficiency is still in engineering, for example:

- Factory plans are manually redrawn in other tools for production line planning
- Companies suffer from heterogeneous CAD (Computer-Aided Design) tool where CAD systems do not collaborate
- Conveyor Sequences are developed with office tools and are not reusable with PLC programming.

AutomationML [9], as an open intermediate format, improves automation engineering, reducing costs associated with that. AutomationML is a neutral data format based on XML for the storage and exchange of plant engineering information. The goal is to interconnect the heterogeneous automation CAD tools of modern engineering production planning of the different disciplines, e.g. mechanical plant engineering, electrical design, visualization development, PLC, robot control.

AutomationML describes real plant components as objects encapsulating the different aspects of the plant operation. An object can consist out of other sub-objects, and can itself be part of a bigger composition. It can describe a screw, a claw, a robot or a complete manufacturing cell in different levels of detail.

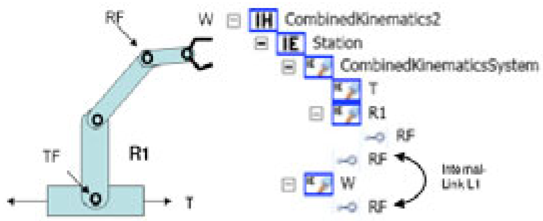

Fig. 8. Combined kinematics system with and additional reference to a gripper

Typical objects in plant automation comprise information about topology, geometry, kinematics and logic, where logic comprises sequencing, behaviour and control. AutomationML incorporates different standards through strongly typed links across the formats:

- *Topology* implemented with CAEX (IEC 62424): properties and relations of objects in their hierarchical structure
- *Geometry* implemented with COLLADA of the Khronos Group: graphical attributes and 3D information
- *Kinematics* implemented with COLLADA: connections and dependencies among objects to support motion planning

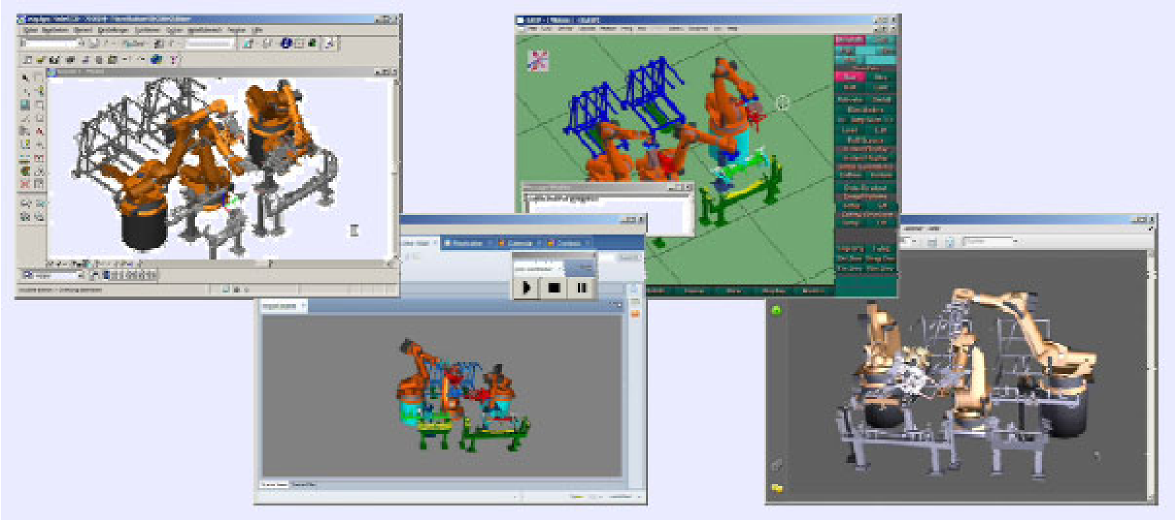

Fig. 9. Production cell used in different CAD tools

Logics implemented with PLCopen XML: sequences of actions, internal behaviour of objects and I/O connection tools

Aspect*	Format*	Organisation*
Topology	in work	<AutomationML/>
Geometry	COLLADA	KHRONOS
Kinematics	COLLADA	KHRONOS
Motion Planning	COLLADA	KHRONOS
Sequencing		PLCopen for efficiency in automation
...		

Fig. 10. AutomationML standard

VII. Digital Prototyping: Beyond 3D Design

Over the past couple of decades, there have been several dedicated software applications available to engineers to create HMI applications. Major drawbacks of such dedicated software include the advanced knowledge required although their lack of integration with 3D computer-aided-design (CAD) software. Consequently, designers and engineers have been working in isolation from one another resulting in duplication of work, increasing design change time and cost, and longer time to market.

In today's global market, as manufacturers work to reduce design cycle and cost margins, industry experts are championing Digital Prototyping as a way to cost-effectively validate design ideas and accelerate the development of competitive products.

Digital Prototyping gives manufacturers the ability to virtually explore a complete product before it is built and put into production. This is done so they can create, validate, optimize, and manage designs from the conceptual design phase through the manufacturing phase of product development. By using a digital prototyping, manufacturers can boost design efficiency and innovation by visualizing and simulating the real-world performance and characteristic of a specific design, and save time and money by reducing the number of physical prototypes that are built.

Autodesk® Inventor™ [10] is a solution that is redefining traditional CAD workflows by helping engineers focus on the functional requirements of a design to drive the automatic creation of 3D models (i.e. steel frames, rotating machinery, tube and pipe runs etc.) that can be used to realize compelling 3D HMI applications.

Reducing the time spent on geometry allows engineers to spend more time innovating design and catch errors before they reach production.

Fig. 11. Digital Prototyping with Autodesk® Inventor™

At the same time, this approach helps manufacturers to realize the benefits of Digital Prototyping with minimal disruption to existing workflows. This provides the most straightforward path to creating and maintaining a single digital model in a multidisciplinary engineering design and prototyping environment.

VIII. Leveraging 3D in HMI Applications

Many industrial and manufacturing systems have a need to create HMI visualization applications using numerous 3D file formats, usually provided by third-party companies. This has been a hurdle and challenge in the past, since it required several software tools installed in the same platform and necessitated a deep knowledge of miscellaneous 3D applications. Consequently, time and money were lost and productivity was compromised.

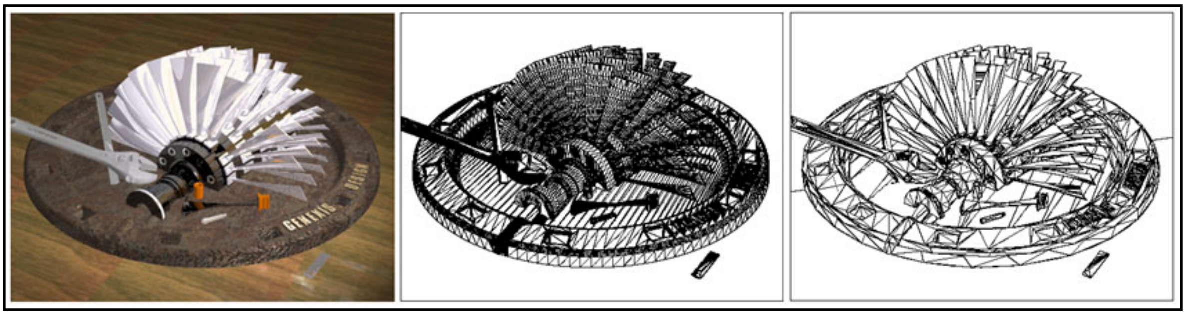

Fig. 12. Polygons reduction algorithm applied to turbine blades

Providing a world-wide industry standard and universal cross conversion of 3D file formats that allows high fidelity translation, optimization and viewing is the solution for numerous companies in the 3D industry. Okino's PolyTrans™ [11] is one of the most extensive and accurate 3D CAD and animation translation tool available today.

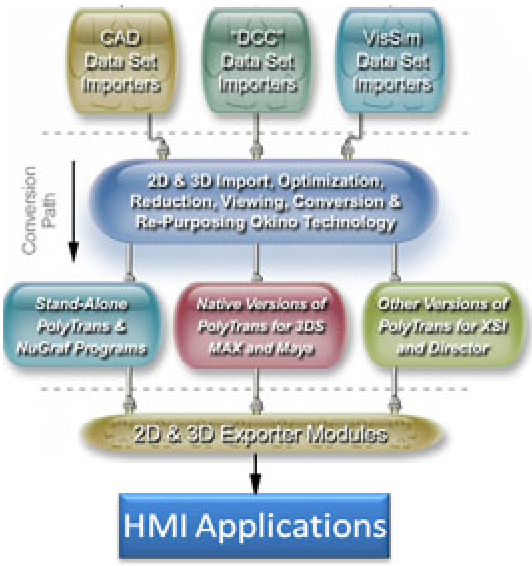

Fig. 13. 3D file conversion with PolyTrans™

It is a powerful production pipeline tool that performs accurate, robust and reliable translations between the most popular 3D file formats.

IX. Low-Poly 3D Models For Industrial And Manufacturing Systems

3D HMI applications are often confronted with either very dense and over-sampled surfaces or models, which are far too complex for the limited hardware resources of modern Personal Computers.

As many applications in computer graphics and related fields, HMI applications can benefit from automatic simplification of complex polygonal surface models, usually coming from 3D CAD drawings. Recently, much research has gone into this subject in order to develop the most effective polygons reduction algorithm. The goal simply, consists of retaining the quality, fidelity and the appearance of the original 3D drawings while reducing the overall number of polygons.

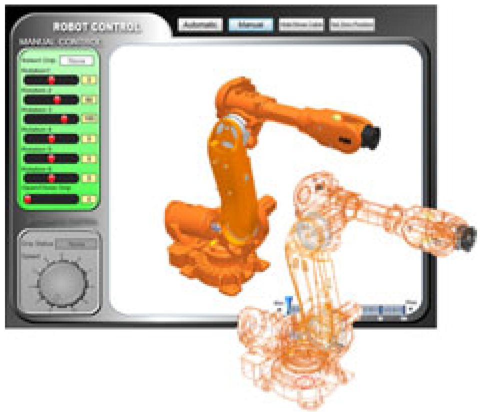

Fig. 14. 3D drawings imported in ICONICS HMI

The core of the polygon reduction algorithm is based on the "Edges Contraction" technique [12]-[13]. Edge contraction simply means that the two end vertices of a model edge are replaced by a single new vertex. This target vertex is usually somewhere in between the other two, in a place where it best approximates the original model. This edge contraction step removes a vertex and one, two, or more faces from the model, depending on the mesh neighbourhood.

When this step is repeated several times, it results in a simpler model, which is an approximation to the original.

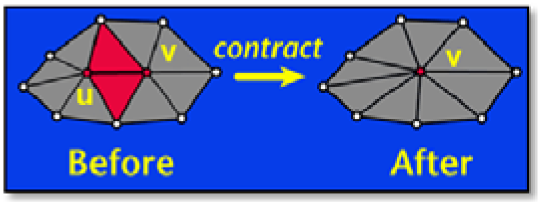

Fig. 15. "Edge Contraction" technique

Since data is removed from the original model the resulting model will only be a very close approximation; each of these steps is associated with a given increase in error (cost of contraction) that is recalculated at each step. Then the lowest cost contraction is performed again until the desired target face count is reached. Simplification can also be stopped when the lowest error contraction is above a certain error threshold.

$$\mathrm{cost}(u,v) = \|u - v\| \times \max_{f \in Tu}\left\{ \min_{n \in Tuv}\left\{ \left(1 - f.normal \bullet n.normal\right) \div 2 \right\} \right\}$$

Fig. 16. The edge cost formula

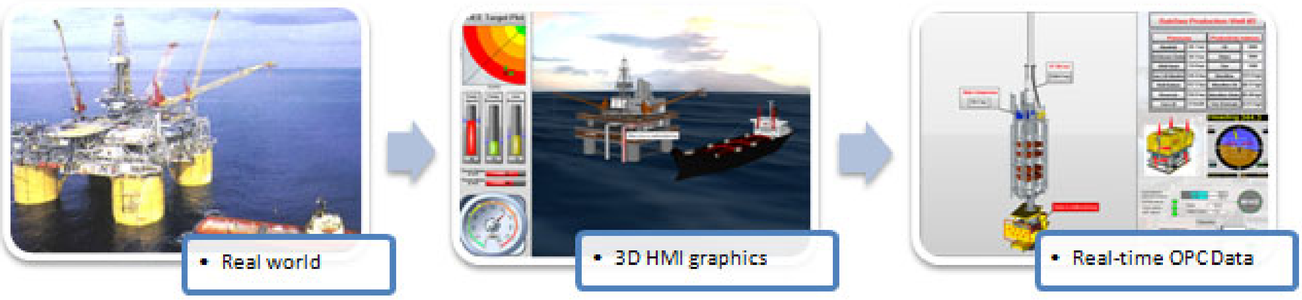

Fig. 17. 3D oil and petrochemical display

Fig.16 shows the edge cost formula where *Tu* is the set of triangles that contain *u* and *Tuv* is the set of triangles that contain both *u* and *v*.

The effectiveness of a polygon reduction algorithm is best demonstrated by showing a model before and after it has been simplified (Fig.12). Most research papers demonstrate their results using highly tessellated models in the neighbourhood of 1 million polygons, reducing them to 50,000 polygons with similar visual results after rendering.

X. Conclusions: Elevate HMIs To New Levels

The goal of the next generation in industrial automation software consists of giving the user the power to quickly and efficiently create HMI integrating graphics, real-time manufacturing data and business information.

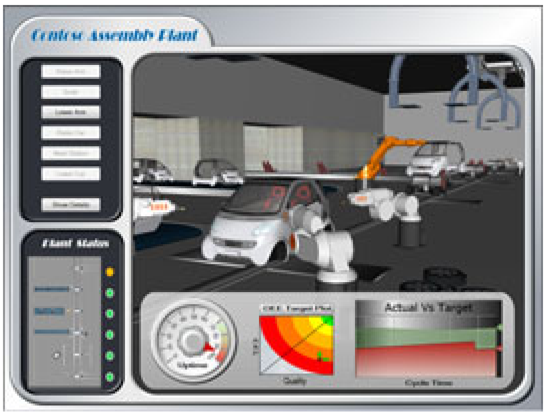

Fig. 18. 3D GENESIS64 automotive factory

Fig. 17 and Fig. 18 are few examples of real HMI visualization applications that users are able to create with the powerful tools and the innovative technologies available today.

In this paper we walked you through 3D graphics planning, creation and data connectivity, step by step, ultimately demonstrating the industry standards available today to reduce engineering, development costs and total cost of ownership. We also described the main features to achieve this ultimate goal:

- Hardware Accelerated 3D Graphics
- 2D and 3D XAML, WPF Visualization
- OPC-UA for real-time data connectivity
- AutomationML, Digital Prototyping
- 3D file format conversion and polygons reduction

Manufacturing and facility control operators, who want to extend and branch out of the traditional 2D graphics, and provide a real-time 3D visualization, may need some guidance, training and orientation to learn these new powerful standards based technologies. Through this process, the gap between design and manufacturing workflow will be ultimately reduced.

Built on the foundation of high-performance graphics hardware subsystems, Human-Machine-Interface (HMIs) systems in the future will require a higher level of sophistication with respect to configuration and overall operation. The promise of 3D graphics brings HMI visualization applications to a new level of awareness for today's manufacturing and facility controls designers. What is needed now are automated software tools that make designing, prototyping and automated generation of HMI visualizations systems an easier process.

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