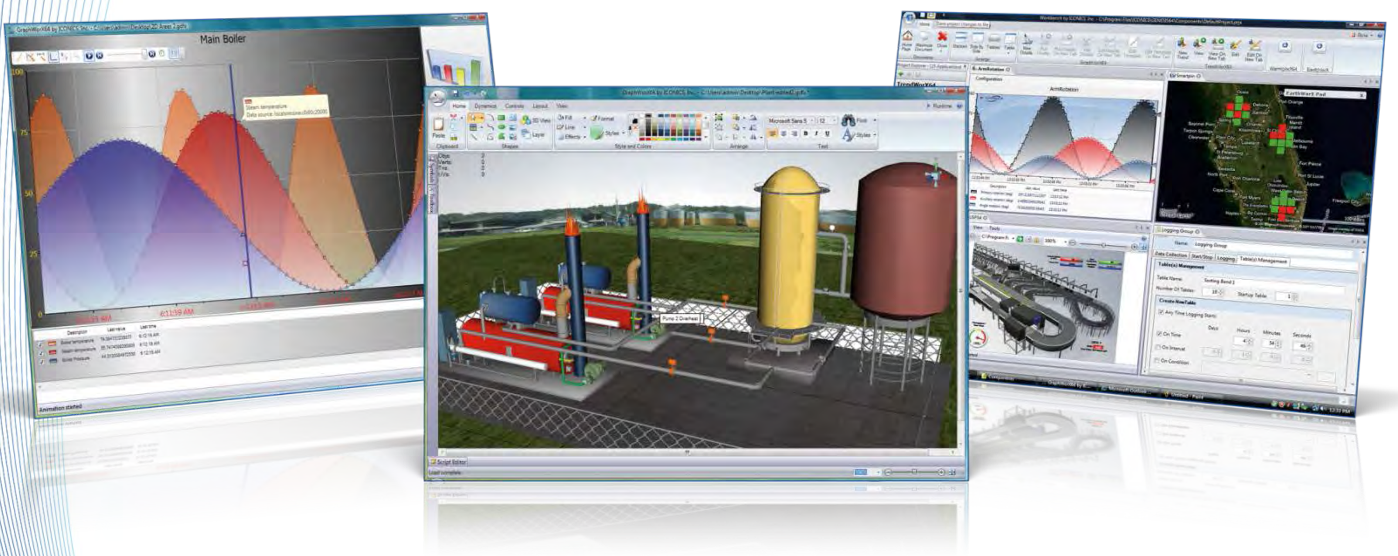
Advanced 3D HMI/SCADA Visualization

Research Brief



Visualize Your Enterprise™

Advanced 3D HMI/SCADA Visualization

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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 shelf commercial products. 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 an overview of a powerful approach to visualization of manufacturing that greatly reduces the learning curve for developing Human Machine Interface (HMI) applications.

***Keywords* — 3D Graphics, HMI, SCADA, 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. Company goals often consist of satisfying market demand while lowering the cost of production. Industrial and automotive manufacturers are facing numerous challenges across all phases of the product development process – shortened 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.

The best strategy to achieve these goals is to adopt open industrial standards for complete integration of multiple systems at a hardware level providing freedom from heavy dependency on single vendors as well as to choose the latest software tools that are built on an architecture that can be scaled and remain relevant for at least five to ten years.

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Using simple two-dimensional (2D) graphics for automation of process control has been the most common approach for some time. With the introduction and optimization of three-dimensional (3D) graphics into process control applications, many companies are seeing increased value in upgrade existing systems. 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.

The inclusion of 3D graphics in to HMI displays has resulted in faster learning of process control systems and a better understanding of operations based on the idea that 3D graphics are better at representing our environment then 2D solutions can be. Overlaying process data on to 3D models can enhance the contextual nature of HMI data showing not only what is happening, but precisely where.

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 engineers and programmers utilize 3D technology for product development, prototyping, engineering analysis.

What are the factors affecting the continued evolution of this 3D ecosystem? There are three fundamental changes at work: the rising popularity and consistency of new 3D software, the growing global influence reduced costs through prototyping, and the growing availability of pre-made 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. Specific software has also gained traction in specific industries allowing standardization within vertical markets. As the number of standards grows, file formats like COLLADA or 3DS have emerged as ways to transfer models between products, eliminating a frustration in 3D collaboration.

Since people started using 3D software, the desire to share the experience with other 3D users has been strong. Today, the interaction among 3D engineers 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.

The increasing availability of 3D content in today's university curriculum and professional offices 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 rendered pictures. Multiple studies indicate that 3D elements of graphical image are perceived better by human operators than 2D process drawings. That is why many companies have been developing industrial 3D solutions:

- Autodesk Inventor: is an extension of the framework behind AutoCAD to provide 3D prototyping allowing users to shave material and money off of existing products at little to no researching overhead.
- 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
- Google 3D Warehouse: Offering DAE and Sketch Up models from Google's 3D modelling program. [2]

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

For professional applications, rapid prototyping or virtual prototyping has become the industry standard for product and process research. For real-time operations graphics HMI/SCADA software has taken a note from visual simulation industries to concentrate on embedding efficient rendering algorithms for 3D geometry loaded from a file store. These algorithms allow HMI/SCADA software to implement features such as a polygonal reduction of prototyping models to optimize them for real-time viewing. With efficient models for rendering current desktop and web visualization technologies HMI/SCADA software can benefit from the 3D capability of displaying not just process diagrams and maps of operations, but rather the real world view of the operation. Operators can view all assets from any angle or have events like alarms in their system bring information and 3D views to the operator.

With the abilities of SCADA software to bring data to life, 3D HMIs can further contextualize data by bringing an interactive view of operations to operators with real time data driving on-screen values and animations. HMI/SCADA software of the today and the future will not only provide control of a process and visualization of data, but will show real-time, realistic machine assets with 3D modelling.

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.

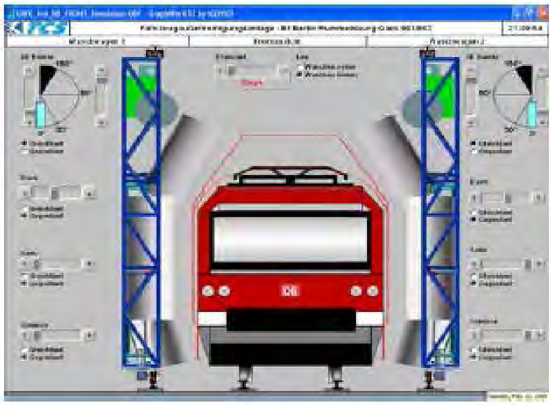

Fig. 1. 2D Automotive HMI graphic (ICONICS[3])

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 only 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.

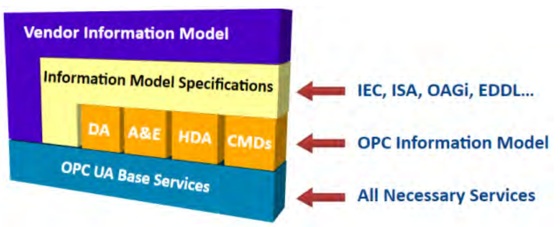

Fig. 3. OPC-UA Specification Layer

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 mark-up language known as XAML (eXtensible Application Mark-up Language) [7], for rich user interface development.

Innovative HMI applications benefit of the following WPF features:

- Supports vector-based graphics
- Supports 3D model rendering and interaction in 2D applications
- Interactive 2D content overlaid on 3D surfaces
- Offload some graphics tasks to the Graphics Processing Unit found on the computer’s graphics card

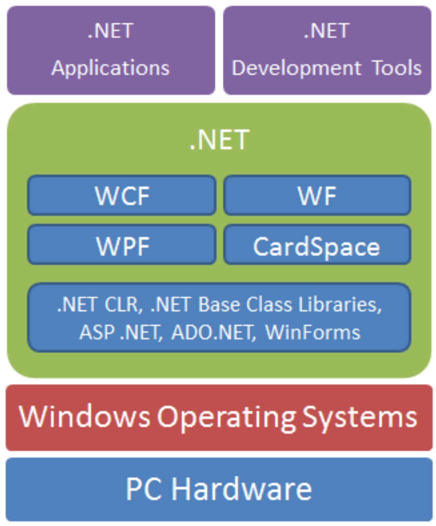

Fig. 4. Microsoft .Net 3.0 Stack

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.

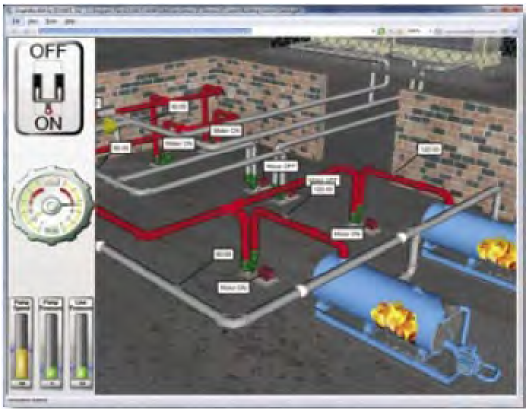

Fig. 5. 3D Facility Control WPF and XAML [8]

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.

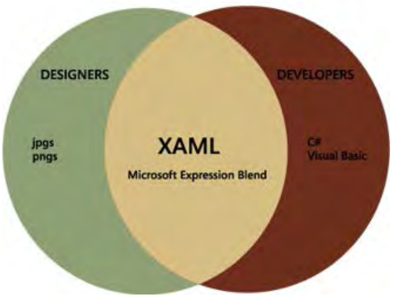

Fig. 6. XAML between designers and developers

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 developing new products.

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

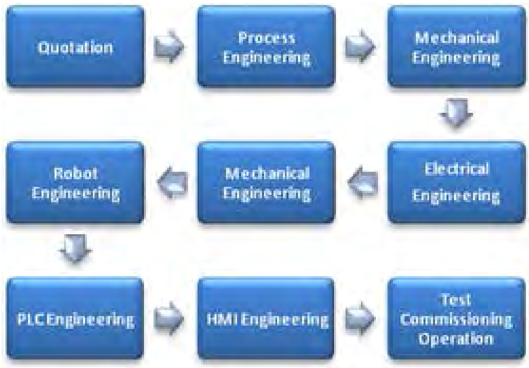

Fig. 7. Engineering chain

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.

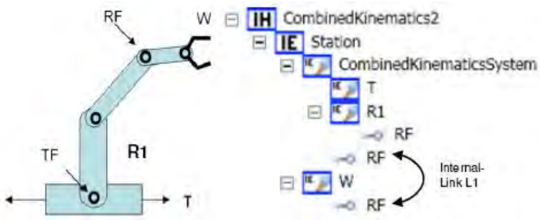

Fig. 8. Combined kinematics system

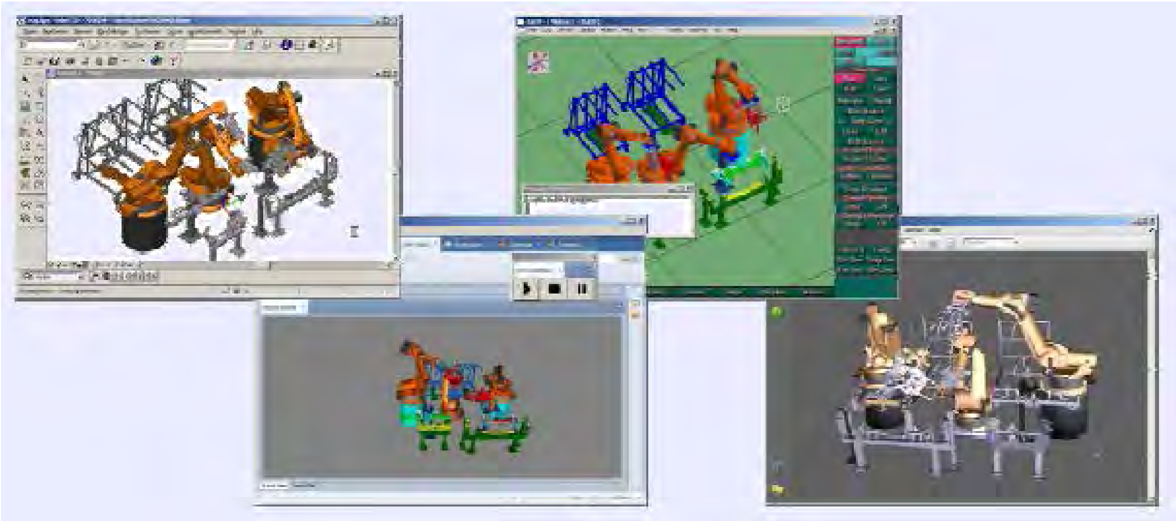

Fig. 9. Production cell used in different CAD tools

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
- *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	XML	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 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.

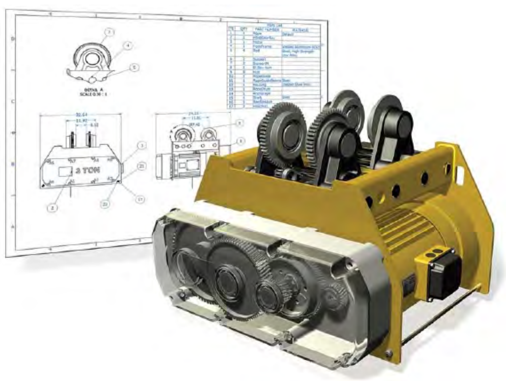

Fig. 11. Digital Prototyping with Autodesk® Inventor™

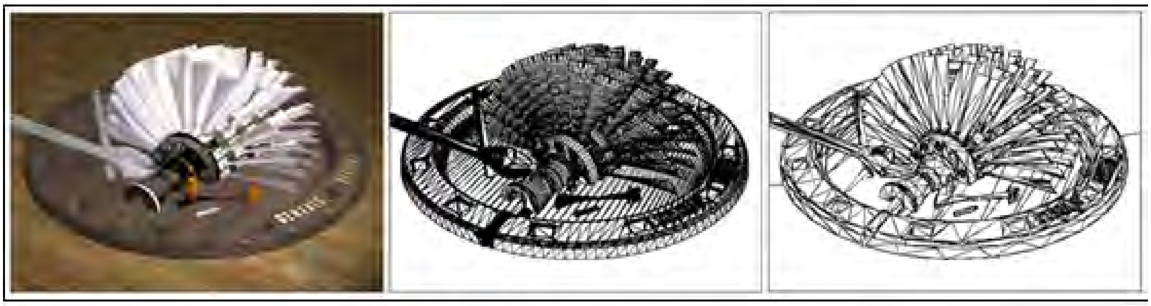

Fig.14. Polygons reduction algorithm applied to turbine blades

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

Manufacturing and Industrial systems with existing 3D models or who have the need to create 3D content for HMI visualization historically have used third party systems to develop graphics. "3D" graphics were then brought into HMI applications as various still images. With the vast number of 3D modeling programs available there has been little integration to SCADA systems due to the issues that arise with file formats and import/export capabilities. While companies have been hesitant to require 3D graphics in HMI, SCADA software vendors had historically avoided 3D based on the capabilities of computer graphics and perceived value to customers.

With more and more 3D content available via online sources or from other divisions of the companies themselves, 3D integration to HMI applications has seen an increase recently as the time of development has decreased enough to allow for companies to realize the benefits of 3D without incurring the cost in development time that once hindered the inclusion of 3D graphics. Complex 3D displays can be made in minutes with imported 3D models.

To further aid development, 3D models have become commonplace in a number of industries, resulting in some websites creating offerings for 3D content built by users and published for other users to include in their own work. As discussed earlier there are a number of different ways for manufacturing companies to incorporate existing 3D graphics into their HMI applications. But for companies that do not have the capability, infrastructure or manpower to create 3D graphics specific to their application, websites like Google's 3D Warehouse allow users to download free models to use in their applications. Most models can be downloaded in Google's own format or in the COLLADA (.DAE) format for inclusion into HMI applications.

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. This is especially relevant to companies using models imported from internal files which often hold very exact information with low tolerances. The result is 3D HMIs which are far too complex for real-time viewing and operation.

As with 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 [11]-[12]. 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.

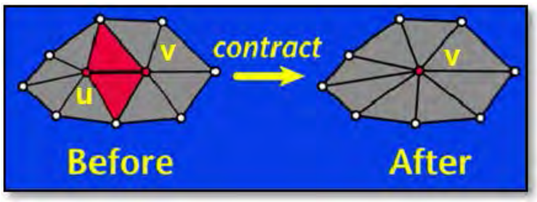

Fig. 15. “Edge Contraction” technique

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.

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

Fig. 16. The edge cost formula

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.

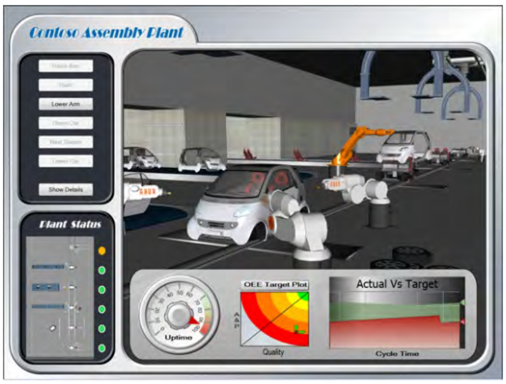

Fig. 18. 3D GENESIS64 automotive factory

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. 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 Polygon Reduction

In order to take advantage of the advanced 3D graphics of today’s HMI, manufacturing and facility control operators who want to extend and branch out of the traditional 2D graphics may need some guidance, training and orientation to learn these new powerful technologies. Through the inclusion of 3D graphics into real-time control HMI displays the gap between design and manufacturing workflow will ultimately be 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.

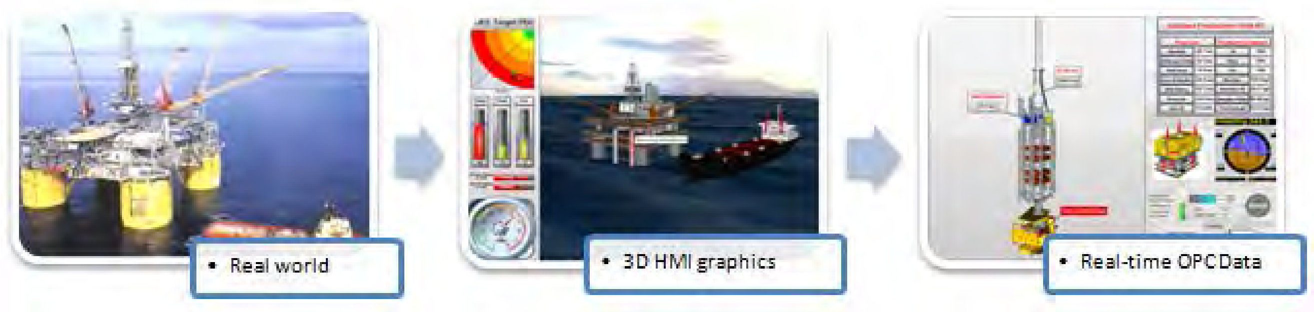

Fig. 17. 3D oil and petrochemical display

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ICONICS is leading the way in cloud-based solutions with its HMI/SCADA, analytics, mobile and data historian to help its customers embrace the Internet of Things (IoT). ICONICS products are used in manufacturing, building automation, oil & gas, renewable energy, utilities, water/wastewater, pharmaceuticals, automotive and many other industries. ICONICS' advanced visualization, productivity, and sustainability solutions are built on its flagship products: GENESIS64™ HMI/SCADA, Hyper Historian™ plant historian, AnalytiX® solution suite and MobileHMI™ mobile apps. Delivering information anytime, anywhere, ICONICS' solutions scale from the smallest standalone embedded projects to the largest enterprise applications.

ICONICS promotes an international culture of innovation, creativity and excellence in product design, development, technical support, training, sales and consulting services for end users, systems integrators, OEMs and Channel Partners. ICONICS has over 300,000 applications installed in multiple industries worldwide.

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