Cyber-physical system design automation framework for knowledge-based engineering

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Abstract. Cyber-physical system design automation utilizing knowledge based engineering techniques with globally networked knowledge bases can improve the design process for emerging systems. Our goal is to develop a comprehensive architectural framework to improve the design process for cyber-physical systems (CPS) and implement a case study with Axiomatic Design Solutions Inc. to develop next generation toolsets utilizing knowledge-based engineering (KBE) systems adapted to multiple domains in the field of CPS design automation. The Cyber-physical System Design Automation Framework (CPSDAF) will be based on advances in CPS design theory based on current research and knowledge collected from global sources automatically via Semantic Web Services. A case study utilizing science, technology, engineering, and mathematics (STEM) students is discussed.

Keywords. Cyber-physical systems, design, automation, knowledge-based engineering, artificial intelligence.

1 Introduction

1.1 Project overview

Cyber-physical system design automation utilizing knowledge based engineering techniques with globally networked knowledge bases can improve the design process for emerging systems. Our goal is to develop a comprehensive architectural framework to improve the design process for cyber-physical systems (CPS) (Cyber-physical system virtual organization, 2013). My contribution to this goal is to provide an overall structure to the case study implementation employing Axiomatic Design Solutions Inc. to develop next generation toolsets that utilize knowledge-based engineering (KBE) systems which can adapt to multiple domains in the field of CPS design automation. The Cyber-physical System Design Automation Framework (CPSDAF) will be based on advances in CPS design theory based on current research and knowledge collected from global sources automatically via Semantic Web Services. The team plans to utilize university resources and consultant services to develop a KBE environment utilizing next generation toolsets developed specifically for CPS design automation. The team proposes to further develop, implement, test, and expand the Artificial Intelligence Design Framework (AIDF) for Optical Backplane Engineering funded in part by a NASA Fellowship Training Grant (2004-2006). This dissertation was later published as a book by VDM Verlag in 2008 called Architecting Automated Design Systems. In 2013, the team plans to begin expanding the AIDF and

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develop the next generation architectural framework for CPS design automation (CPSDAF) utilizing a research testbed, STEM students, CPS portal, and case study implementation. This research will provide guidance on KBE system development suitable for multiple domains. CPS design automation will be accomplished by systematically incorporating advances in CPS design theory while developing next generation design automation toolsets with Axiomatic Design, Inc. The CPSDAF will improve on the AIDF by also providing KBE capability to address any type of CPS system for advanced design automation with modules adapted to the particular CPS domain. Based on this approach, the team plans to (1) expand the AIDF into a comprehensive framework for CPS design automation called the CPSDAF (2) utilize university resources to build a validated and verified KBE system configured by the CPSDAF for a particular CPS domain as proof of concept (3) develop next generation toolsets with Axiomatic Design Solutions, Inc. based on the results of the CPSDAF research and KBE testbed, and (4) educate next generation CPS students via STEM initiatives through CPS related university student chapter development managed by Society for Design and Process Society (SDPS) (www.sdpsnet.org). The independent portal development online provides the opportunity for three teams to work collaboratively and in parallel. Portal website domains have already been purchased and are ready for development (a) www.cyberphysicalsystem.com, (b) www.cyberphysicalsystem.net, and (c) www.cyberphysicalsystem.org). The KBE system will utilize advances in Semantic Web Services to acquire knowledge and apply advances made every day in the field of CPS to continuously improve its design automation capability for multiple domains in CPS. As more disciplines are impacted, more modules will be developed for these disciplines and STEM initiatives will be formed to spearhead this development. A systems engineering process model is provided showing the architectural framework focus area (Fig. 1).

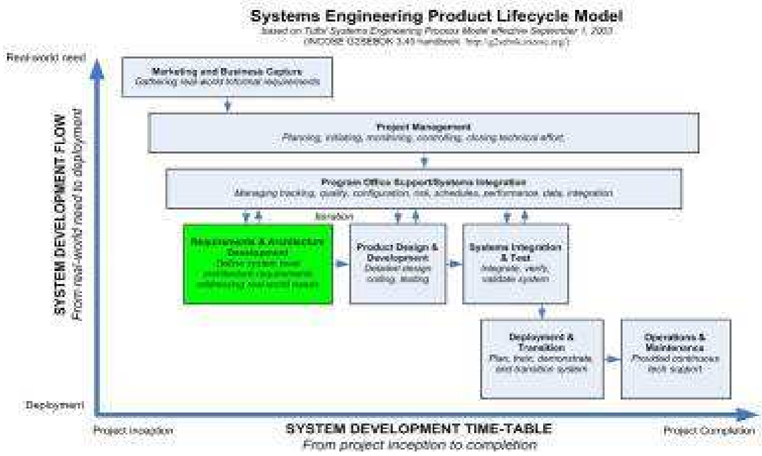

Fig. 1. Tufts' systems engineering process model (see Buede et al., 2002, p.13)

1.2 Intellectual merit overview

My team will advance research for CPS design theory and automation while developing next generation toolsets with the case study. During the exploratory inception phase, the research team and students plan to transfer the experience gained from working on the proof of concept to develop a CPS design automation framework that can guide the implementation of multiple KBE system-of-systems (SoS) that assist in the design automation of CPS applications in various domains with networked KBE systems (Fig. 2). The designed CPS artifacts will be tested, verified, and validated to meet industry specifications.

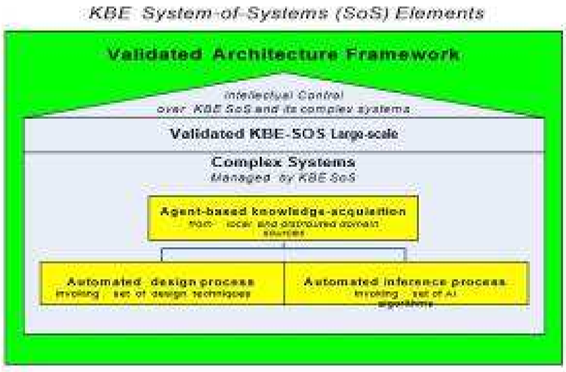

Fig. 2. System-of-systems paradigm for artificial intelligence design support.

1.3 Broad impact overview

Any university and corporation intending to improve their design process will benefit from the next generation tools developed for CPS design automation with modular expansion capability depending on domain. The KBE system will be capable of detecting and collecting advances in CPS design principles and technology by automatically securing knowledge from global sources and experts that advance the field on a daily basis. Axiomatic Design Solutions Inc. will improve on next generation toolsets based on CPSDAF research advances. STEM initiatives will be managed in the CPS portal to develop student chapters that network students together across universities to collaborate in the CPS field and develop the modules for the CPSDAF. Additional capability may be provided with a KBE system-of-systems (SoS) application that can manage networked results of KBE systems. Software engineering of the KBE SoS can be improved with expanded modules utilizing CPSDAF guidance. The CPSDAF will generate advanced KBE SoS for CPS design automation like the AIDF (Fig. 3).

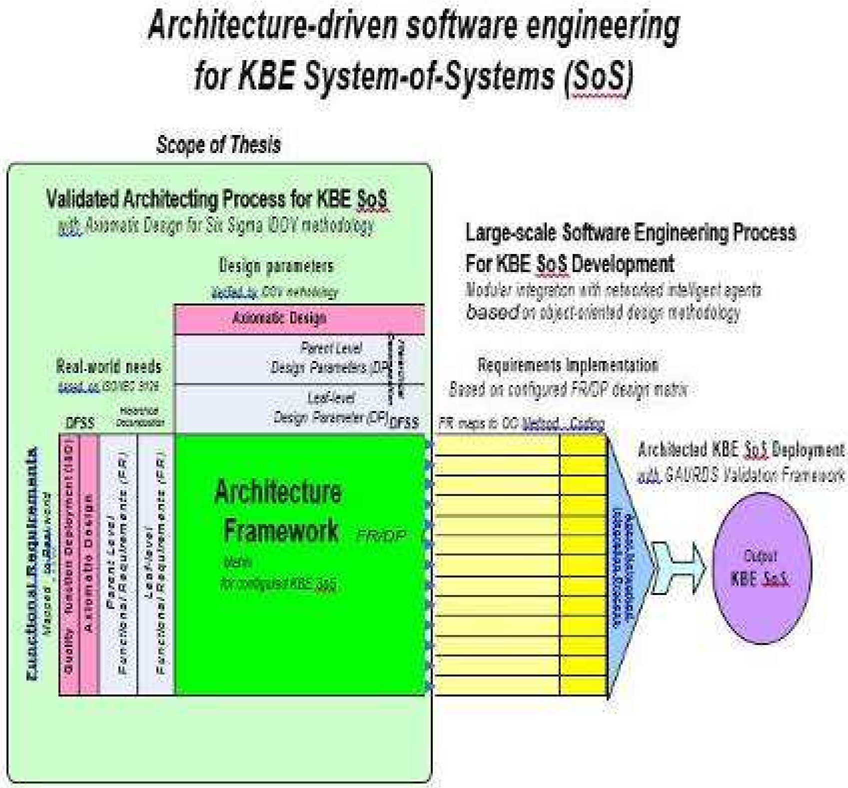

Fig. 3. Architecture-driven software engineering for KBE SoS.

1.4 AIDF expansion to CPSDAF

The Cyber-physical System Design Automation Framework (CPSDAF) will expand on existing embedded system design theory, develop next generation toolsets for CPS with Axiomatic Design Solutions, enable production of novel KBE systems adapted to CPS design automation in various domains by modular expansion, and establish SDPS student chapters to manage CPS student collaboration in STEM portals. These modules will be developed by the students working in teams and displayed in the following portals already purchased for development: (a) www.cyberphysicalsystem.com, (b) www.cyberphysicalsystem.net, and (c) www.cyberphysicalsystem.org. The CPSDAF builds on the experience gained from the NASA Fellowship and years of incremental improvement to the AIDF, culminating to this grant proposal on CPS design automation with student chapter collaboration on CPS modules. Several student chapters have already been established in various universities and will now start the CPS portal development phase.

1.5 CPSDAF guides modular development of KBE systems in multiple CPS domains

The current approach expands on the architectural framework dissertation by combining the university resources with Axiomatic Design Solutions to implement the case study for CPS design automation in multiple domains while developing next generation toolsets and KBE system adapted to CPS product engineering. This proposal expands and implements the CPS version of the architectural framework (AIDF) for design automation utilizing modular, reconfigurable, and scalable KBE systems (Fig 4). Research detail is available in the book Architecting Automated Design Systems published in 2008 (Tanik, 2008) based on the dissertation delivered to NASA (Marshall Space Flight Center) by U. John Tanik in 2006 (Tanik, 2006). The main objective of the dissertation was to produce a comprehensive framework for design automation by proposing the Artificial Intelligence Design Framework (AIDF) for optical backplane engineering case study. Similar to its predecessor architectural framework (AIDF), the CPSDAF provides a comprehensive, modular, reconfigurable, and scalable approach to develop networked knowledge-based engineering (KBE) systems that support the automated design of cyber physical systems of all types in multiple domains. The adapted KBE system for a CPS domain is expected to provide guidance to CPS designers based on automated engineering principles, artificial intelligence recommendations, general design theory, case-based reasoning methods, and other domain knowledge updated online from globally distributed sources.

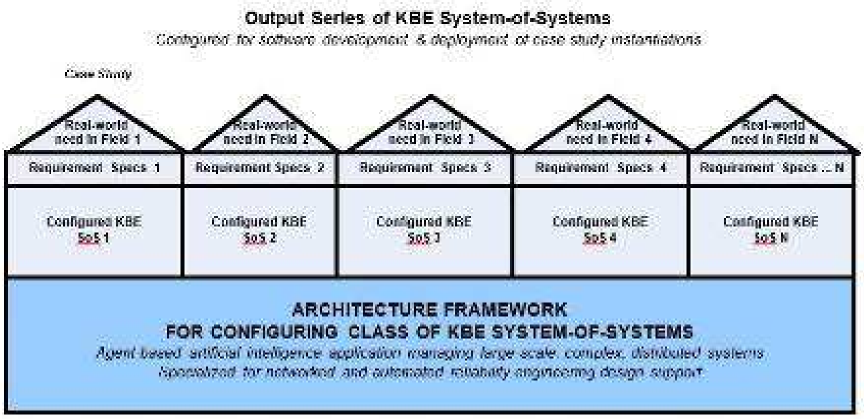

Fig. 4. Architecture-driven software engineering for KBE SoS.

1.6 CPS field driving need to manage emergent system behavior and mitigate risk

Building a system faster, better, and cheaper has been the hallmark of engineering and historically KBE systems were developed with this goal in mind. Now the challenge is identifying the best CPS design theory and principles and applying them uniformly with next generation technology. Advances in embedded system and system of systems (SoS) design are paving the way for the CPS field to profoundly impact the economies of nations (CPS Steering Group, 2012). These new challenges require a method to capitalize on advances while building on established engineering principles without losing sight of verification and validation needs for new CPS designs. Emergent behavior during design automation could be anticipated with proper design automation techniques in place to mitigate risk. This type of approach provides a platform to structure the large-scale software engineering development process for assuring risk mitigation during automated reliability engineering (Trevino, 2005). Further compounding the issue of increasing and interdependent functional and nonfunctional quality requirements is the strict restrictions imposed by CPS concerns, such as timing concerns for component reliability (UC Berkeley, 2013). An integrated approach to multi-disciplinary system design with vast amount of knowledge is needed providing reliable design guidance with optimized design recommendations with maximum automation to improve quality, save time, and money. Factors impacting both the cyber and physical world simultaneously are now paramount to trustworthy CPS design automation (UC Berkeley, 2013). While cyber-physical systems present many new design challenges, especially for synchronously timed systems that need to interoperate seamlessly. Any timing issue with a particular set of interfacing components may cause serious cascading problems or even system failure in CPS artifacts that rely on precise input/output regulation. For instance, a unique property of a CPS artifact is precise integration requirements (Fallah, 2010). A critical codependence is thus presented to the system design process at all layers and phases, presenting unprecedented and challenging design concerns (Rajkumar, 2012). Hence, the design, construction, verification, and validation of cyber-physical systems pose a multitude of technical challenges that must be addressed by a cross-disciplinary community of researchers, engineers, scientists, and educators. If many of these issues can be addressed via system design automation, many problems can be more effectively addressed during the design process. Interactions among the multidisciplinary knowledge silos may generate increasing system functionality requiring more attention to V&V concerns during system integration. This process must be both comprehensive and adaptable to evolving environmental conditions, fulfilling both end-user needs and the engineering specifications with special emphasis on dependencies and processing speed for CPS design automation. There is a recognized need for an overarching architectural framework to achieve intellectual control over CPS design automation concerns producing a set of reconfigurable, modular, and scalable KBE systems that can assist in the design process for CPS product engineering.

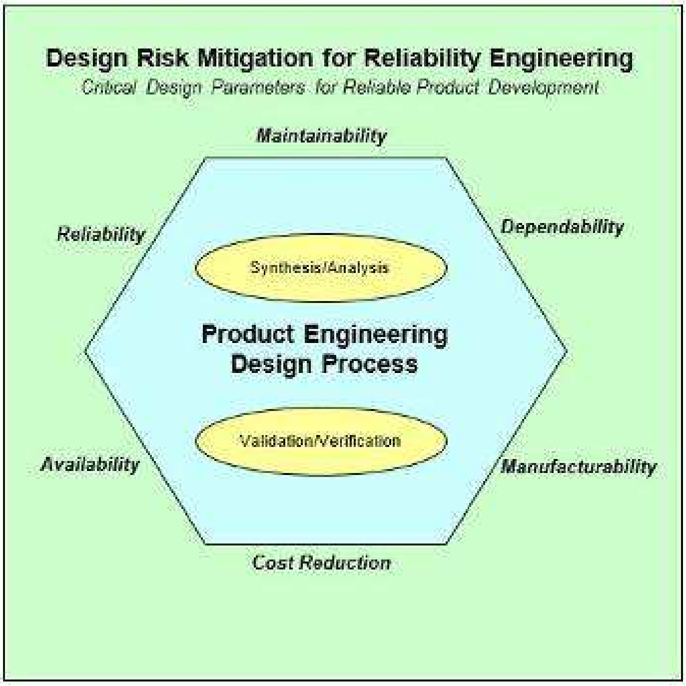

Fig. 5. Design risk mitigation for reliability engineering.

2 AIDF Research Foundation for CPSDAF

2.1 AIDF utilizing axiomatic design principles for KBE system development

The AIDF is an architectural framework to develop a set of modular, reconfigurable, and scalable systems. We discuss aspects of the AIDF as a starting point for our research expansion to develop the CPSDAF for KBE system development for CPS design automation. Knowledge-Based Engineering plays a key role in managing the vital resource of knowledge in a means that is easily accessible to decision making [13]. A centralized set of knowledge repositories are stored within a database to supply data access to the KBE system (Mylopoulos, 1996). While performing daily activities any respective worker can access the data contained within these knowledge repositories via the KBE system. Related to KBE, Artificial Intelligence capability is found in Inertial Navigation Systems (INS) (Shin, 2005) to speech recognition systems (Gevarter, 1983). On a broad-based scale there are several research ideas for utilizing Web Ontology Languages (OWL) to extend the benefits on current systems (Stoilos, 2010). The OWL makes it possible to conduct Artificial Intelligence in various applications based on an Internet standard leveraging Semantic Web advances. Logic for Artificial Intelligence traditionally carries its roots back to first order logic (Djelloul, 2009). One particular example utilizing first-order-logic can be seen in axiomatic systems which provide a set of axioms from which a large set of axioms can be combined in an effort to logically arrive at theorems and corollaries, forming design theory (Hazewinkel, 2001). Axiomatic Design Solutions Inc. utilizes axiomatic design theory developed by MIT for product conceptual design with Acclaro Design for Six Sigma (Axiomatic Design, 2013).

2.2 AIDF requirements managed with Acclaro toolset

The requirements elicitation process for the AIDF was managed by the Acclaro Design for Six Sigma (DFSS) tool by Axiomatic Design Solutions (30). Acclaro DFSS assists in the requirements elicitation and management process for risk mitigation and design parameter identification. Features utilized in the tool to construct the architectural framework for the AIDF include the design matrix and dependency structure matrix functionality, in addition to the Quality Function Deployment (QFD) and the Failure Mode Effects Analysis (FMEA) functionality especially useful for nonfunctional requirements as well. Acclaro DFSS software implements a complete suite of DFSS tools using an axiomatic framework to reduce development risk, cost and time, by applying the axiomatic design process developed at MIT (Axiomatic Design, 2013).

2.3 AIDF configuring KBE system to accelerate design automation

A core infrastructure has been proposed and conceptualized to handle design of complex systems based on an architectural framework. The AIDF has been designed in a manner to allow the incorporation of inputs from a real time environment connected to Web Services and networked knowledge bases to be fed into the reconfigured KBE system according CPS artifact design domain. This is then utilized to choose appropriate actions for adjusting the overall design of the system at key trade-off decision points (Fig. 6) utilizing synthesis and analysis techniques that invoke any of 20 modules that contain knowledge in the form of design theory and related reasoning algorithms acquired from global expert resources. Given the continuous feedback from updated knowledge repositories, the KBE system is able to automatically provide designers immediate feedback on best CPS design tradeoffs. The AIDF provides an overall architectural framework with guidelines to manage axiomatic design theory and various applications of artificial intelligence by developing a respective KBE system for design automation. One aspect relies on knowledge gained from field experts, which is gathered and stored into a knowledge-base. An interface is provided within the system to access this input from distributed knowledge sources which supply data for processing.

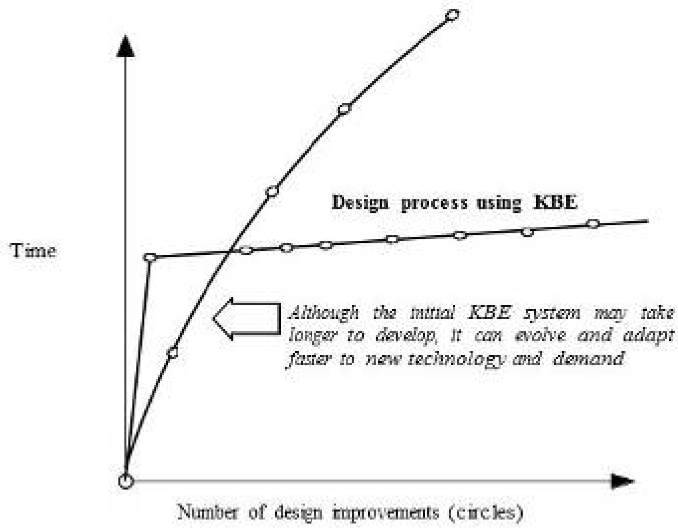

Fig. 6. KBE provides more design improvements over time.

3 CPSDAF based on AIDF to guide KBE implementation

The architectural framework will be designed to handle all types of CPS design automation concerns when building KBE systems, such as the tight integration and emergent properties, as well as codependence of the computation, physical, and network system layers. The Cyber Physical System Design Framework (CPSDAF) is based on the AIDF (Fig 1) comprised of (1) the Knowledge Assimilation Engine (KAE), (2) Knowledge Correlation Engine (KBE), and (3) Knowledge Justification Engine (KJE). As an initial step, the KAE provides a mechanism to assimilate global knowledge into the KBE system with intelligent agents gathering relevant global information that could impact the design process from Semantic Web Services. Then, the assimilated knowledge must be processed and correlated for design automation in the KCE. This design automation is accomplished by analysis and synthesis techniques based on the Common Knowledge Acquisition and Design Support (CommonKADs) standard (Schreiber, 2000). During KBE system analysis or synthesis, one or more modules are activated to work together to solve a design problem. These modules are housed in the design engine block and AI engine block of the AIDF. The NASA case study for optical backplane engineering had 20 modules in total. A set of 11 design modules are managed by the design engine block and another 9 AI modules are managed by the AI engine block (Table 3). These modules were shown to be reconfigurable and scalable. Finally, the KJE provides a mechanism to output desirable recommendations and their justifications as design rationale.

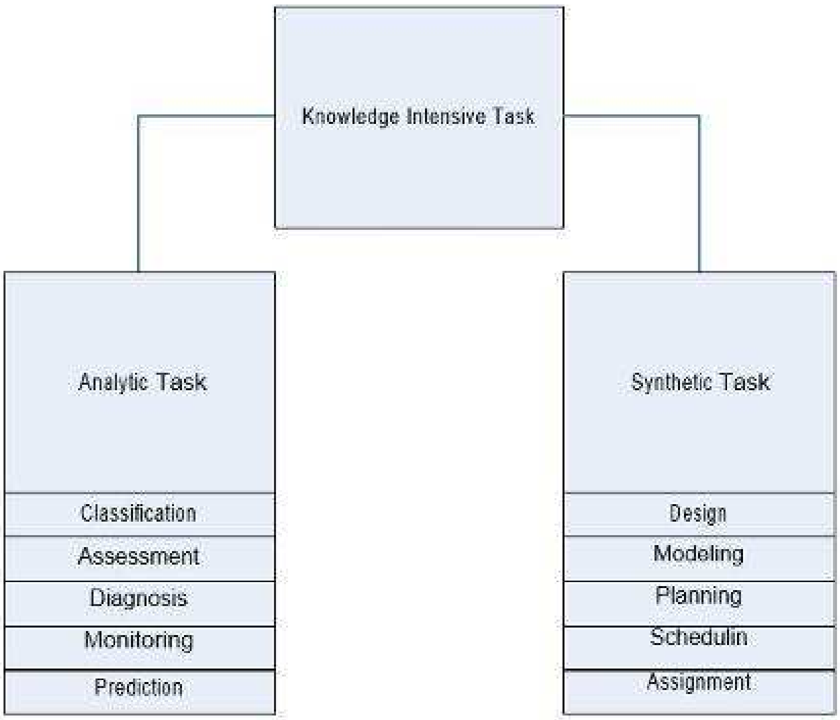

Fig. 7. CommonKADS Hierarchy of Tasks.

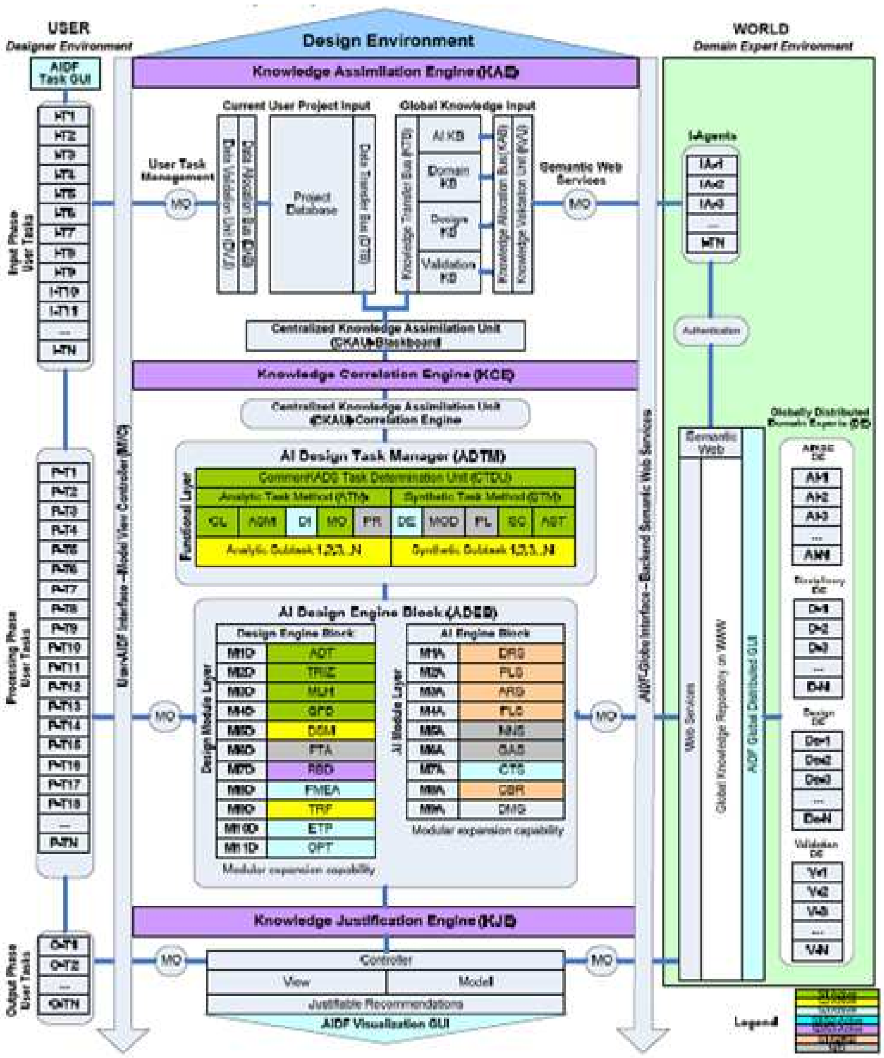

Fig. 8. AIDF architecture to be expanded with CPSDAF (Tanik and Grimes, 2005).

Table 1. AIDF Design Automation Support Modules to be expanded and scaled in CPSDAF (Tanik and Grimes, 2005).

#	AIDF Modules	Mechanism provided
M1D	Axiomatic Design Theory (ADT)	Provides an automated mechanism for hierarchical decomposition of FR and DP, provides 2 axioms, 11 corollaries, and 23 theorems for the rules base stored in the AI Engine Block
M2D	Theory of Inventive Problem Solving (TRIZ)	Provides an automated mechanism for invention, especially by searching the Semantic Web for

		appropriate DPs
M3D	Hierarchical Multi-layer Design (MLH)	Providing an automated mechanism for going from FR to DP to components, calculation of reliability and cost
M4D	Quality function deployment (QFD)	Provides an automated mechanism to ensure the customer guidelines are included in the quality of the design
M5D	Design structure matrix (DSM)	Provides an automated mechanism to determine component to component interaction
M6D	Fault Tree Analysis (FTA)	Provides an automated mechanism to predict component failures, where the calculations are based heavily on quantitative Boolean operators
M7D	Reliability Block Diagram (RBD)	Provides an automated mechanism to estimate system reliability, where the calculations are based heavily on various engineering equations, such as MTTF (Mean time to Failure)
M8D	Failure mode and effects analysis (FMEA)	Provides an automated mechanism to associate weights for each type of failure to assess fault qualitatively and trace root cause
M9D	Technology Risk Factor (TRF)	Provides an automated mechanism to assess individual component risk on a cluster, mainly by associating any given component with a multiplier that affects the DSM
M10D	Entropy (ETP)	Provides an automated mechanism to assess level of disorganization in system design during design process
M11D	Optical Backplane Engineering Domain (OPT)	Provides an automated mechanism to manipulate domain-specific knowledge for inference, specifically in field of optical backplane engineering
M1A	Domain Rule Support (DRS)	Provides an automated mechanism for domain rule support, in terms of executable rules used by the inference engine
M2A	Predicate Logic Support (PLS)	Provides an automated mechanism for logic support
M3A	Algorithmic Reasoning Support (ARS)	Provides an automated mechanism for miscellaneous algorithmic reasoning support
M4A	Fuzzy Logic Support (FLS)	Provides an automated mechanism for fuzzy logic support
M5A	Neural Network Support (NNS)	Provides an automated mechanism for neural network support

M6A	Genetic Algorithm Support (GAS)	Provides an automated mechanism for genetic algorithm support
M7A	Conant Transmission Support (CTS)	Provides an automated mechanism for component transmission support
M8A	Calibrated Bayesian Support (CBS)	Provides an automated mechanism for calibrated Bayesian support
M9A	Data Mining Support (DMS)	Provides an automated mechanism for data mining support

Table 2. Component DSM example with five components.

	C1	*C2*	*C3*	*C4*	*C5*
C1	***X***				*X*
C2		***X***	*X*	*X*	*X*
C3	*X*		***X***		*X*
C4		*X*		***X***	*X*
C5		*X*		*X*	***X***

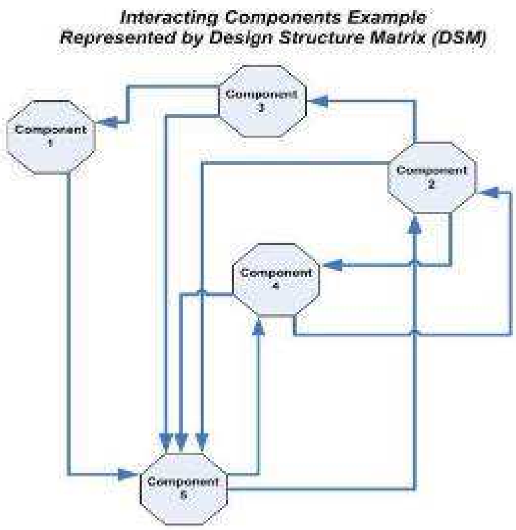

Fig. 9. Interacting component diagram that can be represented by DSM.

4 Case Study

4.1 Next generation modules, standards, and tools developed by STEM students and consulting services

The following features in the Acclaro toolset can be enhanced or expanded to meet CPS needs, e.g. Information architecture & system architecture view, design matrix, DSM, FMEA, FTA, TRIZ, PRA, and other risk mitigation and V&V techniques. These features will be further enhanced based on new research findings and theoretical innovation, in terms of synergistic design principles, methodologies, and industrial best practices to meet the needs for converging multidisciplinary engineering domains that require the tight conjoining of synchronous software and hardware concerns anticipated in cyber physical system design automation. Topics and standards found in the Software Engineering Body of Knowledge (SWEBOK) and Project Management Body of Knowledge (PMBOK), design processes such as IEEE 12207, Rational Unified Process (RUP), and agile development, will be considered in module development. Automation of key industrial standards will be provided such as software requirements specifications (SRS) with IEEE 830, software design descriptions (SDD) with IEEE 1016, and project management plan (PMP) according to IEEE 1058. The Acclaro Design for Six Sigma (DFSS) tool will be improved and many functions will be added to the tool that will support CPS design automation. Knowledge engineering functions will be automated with concept mapping technology such as Cmaptools by the Institute of Human Machine Cognition (IHMC). Various architecture views are provided, such as application architecture, information architecture, systems architecture and UML architecture. Automation of the detailed design process of software and system engineering concerns will be accomplished by applying artificial intelligence techniques to the Unified Modeling Language (UML) and the Systems Engineering Language (SysML). If a medical case study is selected as a CPS domain, then additional domain modules can be added such as the Unified Medical Language System (UMLS). An example CPS case study might be the design automation of a clinical decision support system relying on wireless technology collecting information remotely from sensors on the human body. The CPSDAF will be the framework to develop a KBE system that can automate the design process (Fig 10, 11) for such a CDSS with validation target areas (Fig. 12). Sensors have become essential components in medical systems (Dmytruk, 2007). Certain types of sensors can transform physical measurements of ambient temperature, heart rate, pulse, blood pressure, perspiration, flow rate, and acceleration into electrical signals that provide inputs to cyber-physical systems (Norton, 1989).

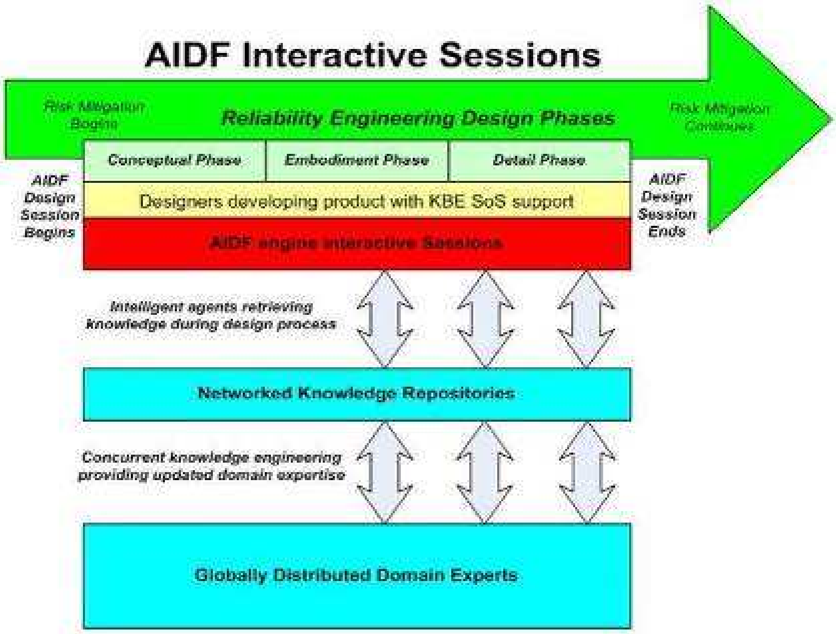

Fig. 10. Interactive AIDF sessions with KB network and agents.

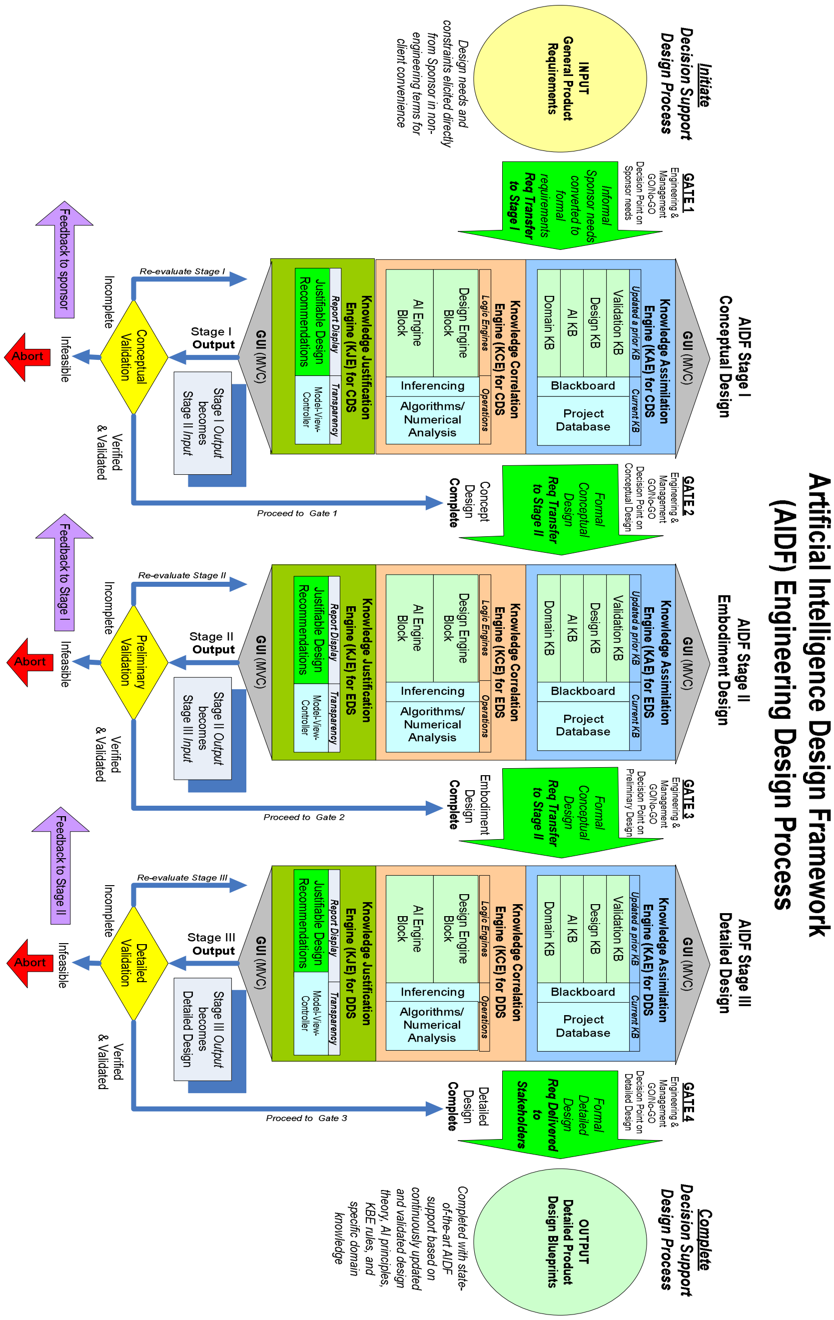

Fig. 11. AIDF Design Process Detail producing blueprints for KBE of CDSS system (Example case)

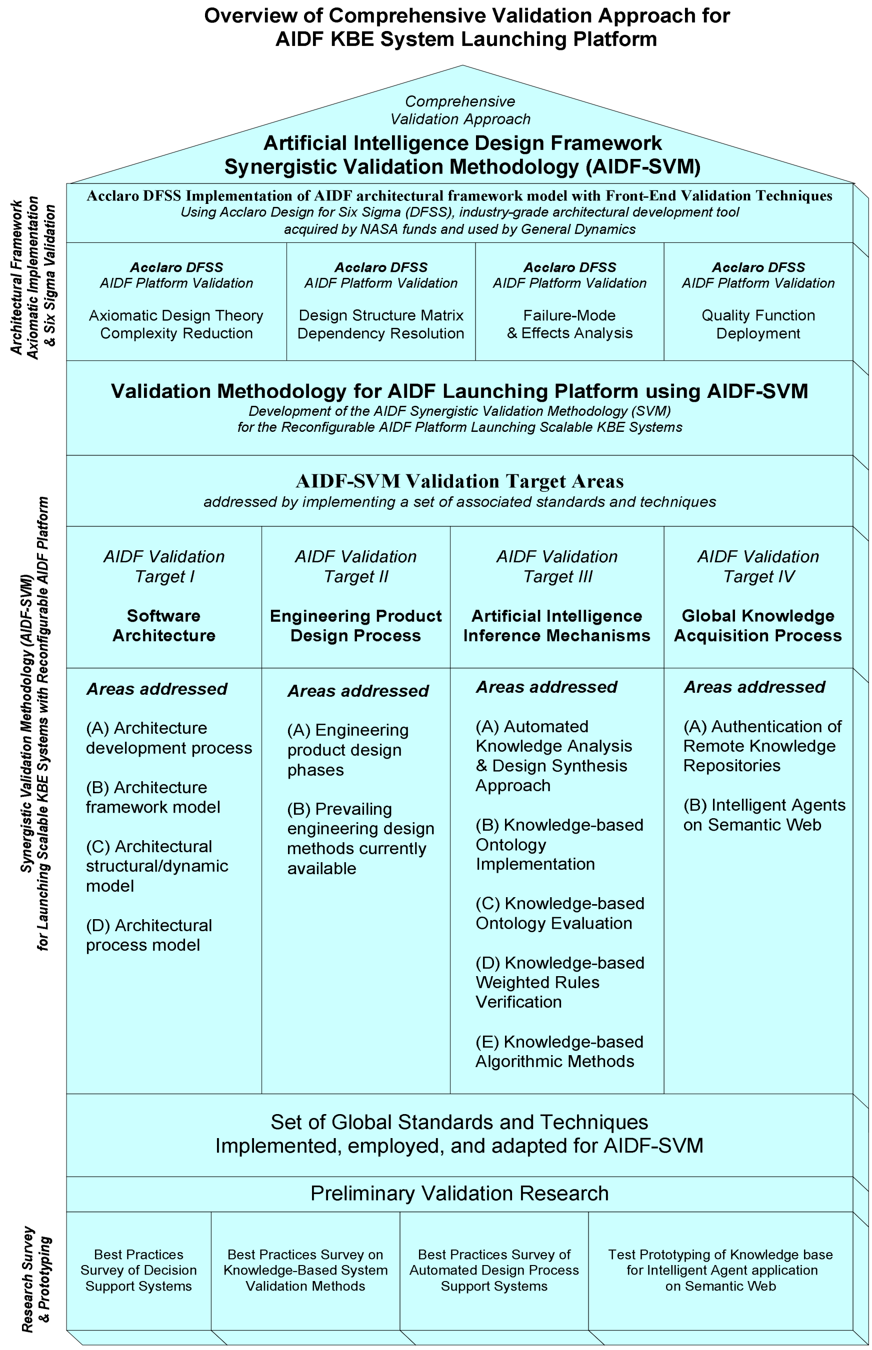

Fig. 12. Comprehensive Validation Approach for KBE SoS based on AIDF.

4.2 Reporting on CPS portal sites

We plan to report results of activity using CPS portal sites. Every semester, reporting of results will meet Specific, Measureable, Attainable, Relevant, and Time-sensitive (SMART) goals. The following
(1) Specific goal of collaboration will be achieved with a group of talented university students who would like to learn and apply their skills to the design of a cyber-physical system as a team project;
(2) Measurable goal of module research is achieved with concept mapping technology (http://cmap.ihmc.us/) and standard project management techniques using the Rational Unified Process (RUP);
(3) Attainable goal of intellectual empowerment is achieved by mentoring through the CPS portals;
(4) Relevant goal of increasing diverse computing enrollment achieved since they are in line with the U.S. agenda emphasizing the importance of teaching computing in STEM development;
(5) Time-sensitive goal of semester completion is achieved by meeting specific benchmarks as provided by the RUP and agile approach for design automation with university and K-12 students.
The SMART objectives of teamwork collaboration, modular research, intellectual empowerment, increasing diverse enrollment, and semester completion are achieved, respectively, with the objectives of:
(1) building cross-disciplinary awareness among students,
(2) engaging STEM students in highschools with experiential projects accessible online, (3) involving SDPS for long-term support,
(4) involving under-represented students in CPS activities, and
(5) teaching students system specification according to prevailing industry standards.

Table 3. CPS Portal development displaying results of research spanning four years.

Portal	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Cyberphysicalsystem.com PIs directing consulting services with Axiomatic Design Solutions Inc.	Web 1.0 site	Web 2.0 site	Web 3.0 site	Production of next generation toolsets for CPS design automation and management
Cyberphysicalsystem.org PIs with directing UAB graduate and undergraduate students work with K-12 mentoring	Web 1.0 site	Web 2.0 site	Web 3.0 site	Design Theory and CPS Automation Research management
Cyberphysicalsystem.net PIs directing case study implementation of KBE SoS	Web 1.0 site	Web 2.0 site	Web 3.0 site	CPS Design automation testbed output management

References

Axiomatic Design. (2006). Axiomatic Design Press Release for collaboration with dissertation work. 2006. http://www.amazon.com/Architecting-Automated-Design-Systems-Urcun/dp/3639002555.

Ayliffe, M. H., Kabal, D., Khurana, P., Lacroix, F. K., Kirk A. G., Tooley, F. A. P., & Plant, D.V. (1998). Optomechanical, electrical, and thermal packaging of large 2D optoelectronic device arrays for free-space optical interconnects. Paper presented at Optics in Computing 1998.

Berger, C., Kossel, M. A., Menolfi, C., Morf, T., Toifl, T., & Schmatz, M. L. (2003). High-density optical interconnects within large-scale systems. Paper presented at Photonics Fabrication Europe.

Buede, D., Forsberg, K., & Mooz, H. (2002). Systems engineering processes. *Incose Insight 5*(1), 11-15.

Cho, N., Song, S-J., Lee, J. Y., Kim, S., Kim, S. & Yoo, H-J. (2005). A 8-µW, 0.3-mm2 RF-powered transponder with temperature sensor for wireless environmental monitoring. Paper presented at Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium.

Chung, L. & Cooper, K. (2002). A knowledge-based COTS-aware requirements engineering approach. Paper presented at Proceedings of the 14th international conference on Software engineering and knowledge engineering.

Cyber-physical systems Virtual Organization. (2013). http://cps-vo.org/. Accessed April 15, 2013.

Daniloff, G. Y. (1999). Continuous glucose monitoring: long-term implantable sensor approach. *Diabetes technology & therapeutics, 1*(3), 261-266.

Design, Axiomatic. (2013). Acclaro DFSS Summary. http://www.dfss-software.com/dfss_summary.asp.

Djelloul, K. (2009). From exponential to almost linear decomposability of finite or infinite trees. Paper presented at Proceedings of the 2009 ACM symposium on Applied Computing.

Dmytruk, K., Smutok, O., Ryabova, O., Gayda, G., Sibirny, V., Schuhmann, W., Gonchar, M. & Sibirny, A. (2007). Isolation and characterization of mutated alcohol oxidases from the yeast Hansenula polymorpha with decreased affinity toward substrates and their use as selective elements of an amperometric biosensor. *BMC biotechnology*, 7 (1):33.

Fallah, Y. P., Huang, C., Sengupta R. & Krishnan, H. (2010). Design of cooperative vehicle safety systems based on tight coupling of communication, computing and physical vehicle dynamics. Paper presented at Proceedings of the 1st ACM/IEEE International Conference on Cyber-Physical Systems.

Gevarter, W. B. (1983). An Overview of Artificial Intelligence and Robotics. Volume I-Artificial Intelligence, Part B-Applications. DTIC Document.

http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA364025.

Hackmann, G., Guo, W., Yan, G., Lu, C. & Dyke, S. (2010). Cyber-physical codesign of distributed structural health monitoring with wireless sensor networks. Paper presented at Proceedings of the 1st ACM/IEEE International Conference on Cyber-Physical Systems.

Hazewinkel, M. (2001). *Encyclopedia of Mathematics*, Supplement III: Springer.

Kim, J-Y., Choi, D-N., Kim, H-J, Kim, J-M. & Kim, W-T. (2012). Abstracted CPS model: a model for interworking between physical system and simulator for CPS simulation (WIP). Paper presented at Proceedings of the 2012 Symposium on Theory of Modeling and Simulation-DEVS Integrative M&S Symposium.

Kim, J. E. & Mosse, D. (2008). Generic framework for design, modeling and simulation of cyber physical systems. *ACM SIGBED Review, 5*(1):1.

Kirk, A. G., Plant, D. V., Ayliffe M. H., Châteauneuf, M. & Lacroix, F. (2003). Design rules for highly parallel free-space optical interconnects. Selected Topics in *Quantum Electronics, IEEE Journal of*. 9 (2), 531-547.

Krogh, BH., Lee, E., Lee, I., Mok, A., Rajkumar, R., Sha, L. R., Vincentelli, A. S., Shin, K., Stankovic. J. & Sztipanovits, J. (2008). Cyber-Physical Systems, Executive Summary. CPS Steering Group, Washington DC. Accessed 13 September 2012. http://precise.seas.upenn.edu/events/iccps11/_doc/CPS-Executive-Summary.pdf.

Lee, E. A., & Seshia, S. A. (2010). An introductory textbook on cyber-physical systems. Paper presented at Proceedings of the 2010 Workshop on Embedded Systems Education.

Ma, X., Tu, X., Huang, J. & He, J. (2011). A cyber-physical system based framework for motor rehabilitation after stroke. Paper presented at Proceedings of the 1st International Conference on Wireless Technologies for Humanitarian Relief.

Mo, J-W. & Smart, W. (2004). Lactate biosensors for continuous monitoring. *Frontiers in bioscience: a journal and virtual library*. 9:3384.

Mylopoulos, J., Chaudhri, V., Plexousakis, D., Shrufi, A. & Topologlou, T. (1996). Building knowledge base management systems. *The VLDB Journal-The International Journal on Very Large Data Bases*, 5(4), 238-263.

Paris, D. E., Trevino, L. C. & Watson, M. D. (2005). A framework for integration of IVHM technologies for intelligent integration for vehicle management. Paper presented at Aerospace Conference, 2005 IEEE.

Rajkumar, R. R, Lee, I., Sha, L. & Stankovic, J. (2010). Cyber-physical systems: the next computing revolution. Paper presented at Proceedings of the 47th Design Automation Conference.

Schreiber, G. (2000). *Knowledge engineering and management: the CommonKADS methodology*. the MIT Press.

Shin, E-H. (2005). Estimation techniques for low-cost inertial navigation. UCGE report (20219).

Simons, R. N., Savich, G. R. & Torres, H. (2009). Free-Space Optical Interconnect Employing VCSEL Diodes. Glenn Research Center. http://www.techbriefs.com/component/content/article/5920.

Stoilos, G., Stamou, G. & Pan, J. Z. (2010). Fuzzy extensions of OWL: Logical properties and reduction to fuzzy description logics. *International Journal of Approximate Reasoning*. 51 (6), 656-679.

Tanik, U. J. & Grimes, G. (2005). Intelligent design framework for optical backplane engineering. Paper presented at SoutheastCon, 2005. Proceedings. IEEE.

Tanik, U. (2008). *Architecting Automated Design Systems.* VDM Verlag.

Tanik, U. & Adviser-Grimes, G. J. (2006). UAB Dissertation: Artificial Intelligence Design Framework for Optical Backplane Engineering.

UC Berkeley (2013). Cyber Physical Systems. Accessed April 15, 2013. http://cyberphysicalsystems.org.