Development of a Senior Design and Internship Integrated University-Industry Collaborative Program to Address the Skills Gap in Advanced Manufacturing

Dr. Immanuel Edinbarough P.E., University of Texas, Rio Grande Valley

Immanuel A. Edinbarough received his B.Sc. (Applied Sciences) degree from PSG College of Technology, University of Madras, India, his B.E.. (M.E.) degree from the Institution of Engineers, India, M.E. (Production Engineering) degree from PSG College of Technology, Bharathiar University, India, and his Ph.D. in mechanical engineering from the Bharathiar University, India. He is currently a professor and director of engineering technology at the University of Texas, Brownsville (UTB). Prior to joining the UTB faculty he was a visiting professor at the Rochester Institute of Technology and an associate professor of production engineering technology at PSG College of Technology, Bharathiar University, India, where he served as the director of the Computer Vision Laboratory and National Cadet Corps – Engineering Division Director. With over 29 years of teaching and research experience in manufacturing/mechanical engineering and engineering technology, he currently teaches in the areas of CAD/CAM/CIM, robotics and automation, product and process design, materials and manufacturing processes, machine design, renewable energy and micro-manufacturing. His current research interests include robotics, CIM, sustainable manufacturing, micro machining and engineering and technology education. He has published several papers in these areas in various national and international conferences and journals. He has worked in heavy and light manufacturing industries, manufacturing pumps, motors, and CNC machine tools in the areas of system design, production planning, and control and manufacturing. Edinbarough also served in paramilitary forces and in the Air Force. He is a Life Member of the ISTE, a senior life member of the IE (India), a member of ASEE and SME, and a licensed Professional Engineer (P.E.) in the state of Texas.

Ms. Adriana Olvera, University of Texas, Rio Grande Valley

Adriana Olvera is currently a lecturer of Manufacturing Engineering at the College of Engineering and Computer Science, The University of Texas Rio Grande Valley (UTRGV). She received her Masters in Architecture from the School of Architecture of the Universidad Nacional Autonoma de Mexico (UNAM), in 2011. She received her Bachelor's in Architecture from Universidad de Monterrey (UDEM), in 2007. Her current research interests include sustainable building design, building automation, and smart environments.

Dr. Jesus Gonzalez-Rodriguez, University of Texas, Rio Grande Valley

Dr. Jesus Gonzalez is currently a lecturer in the Department of Manufacturing and Industrial Engineering of the College of Engineering and Computer Science. He holds a PhD from The University of Sheffield in United Kingdom in Materials Science and Engineering. During the PhD, he received the Foster Research Prize given to the best PhD thesis related to glass technology. His research interest is in the mechanical properties of glass at room and high temperature. Dr. Gonzalez has also a broad experience in the glass industry, specifically in fabrication of automotive safety glass. He worked for Vitro Glass Company for more than 19 years where he held different positions such as Process Engineer, Materials Planning and Logistics Manager, Production Superintendent, Manufacturing Engineer and Glass Technologist. During his time in the company, he co-authored two patents related to glass fabrication and glass coatings processing. Dr. Gonzalez is a Six-Sigma Black Belt and has participated in numerous process improvement projects. He has been trained as well in the Methodology of Inventive Problem Solving (TRIZ) that he applied to solve complex problems. In the manufacturing operations field, he is certified in Production and Inventory Management by APICS, which is the professional association for supply chain management. He is a member of the Society of Glass Technology, based in Sheffield England. He is also affiliated to the alumni society of Armourers & Brasiers' Company, London UK, which is a society that promotes the study of Materials Science.

Development of Senior Design & Internship Integrated University-Industry Collaborative Program to address the skills gap in Advanced Manufacturing

Introduction

We are experiencing a Fourth Industrial Revolution that is transforming the world through artificial intelligence, next-generation robotics, automation, big data analytics, 5G technology and Internet of Things. The manufacturing sector takes full advantage of these technologies to produce innovative products to enhance the human experience. Contrary to the prediction of huge job loss due to these new technologies, more jobs are being created at a rapid pace. This is evident in the number of job openings growing at double-digit rates since mid-2017 [1]. This trend created a new set of problems in finding a matching workforce that will support the growing areas of advanced manufacturing in digital talent, skilled production and operational managers. The digital talent includes programming and managing a pool of computer-enabled machines and equipment.

According to the study by Deloitte and the Manufacturing Institute [2], the skills gap may leave an estimated 2.4 million positions unfilled between 2018 and 2028, with a potential economic impact of $ 2.5 trillion. Further, the study shows that the positions relating to digital talent, skilled production, and operational managers may be three times as difficult to fill in the next three years.

The University of Texas Rio Grande Valley has undertaken an initiative to address the skills gap in this very important area of manufacturing. This paper presents the details on the development of an integrated senior design and internship program that has helped to mitigate the difficult-to-fill workforce needs for the partnering industry in metrology and advanced manufacturing through the university and industry partnership. Many more programs of this nature are required to address the problem of the skills gap prevailing in the advanced manufacturing sector.

The senior design project and internship are integrated with the engineering technology curriculum to address this challenging problem of developing human power in the PC-DMIS (Personal Computer-Dimensional Measuring Interface Standard) programming and CMM (Coordinate Measuring Machine) operation. The outcome of this program is a win-win for both university and industry. Also discussed in detail in the paper are the pedagogical aspects of the senior design project that includes the industry-accepted CMM training and the subsequent internship in the metrological department of the industry.

Skills Gap in Advanced Manufacturing

As many as 3.5 million manufacturing jobs will become available by 2025 but because of the skills gap, 2 million will remain unfilled, according to Deloitte's Skills Gap in US Manufacturing 2015–2025 outlook. Six out of 10 open production jobs are unfilled because of a talent shortage and 84% of executives agree there is a talent shortage in US manufacturing [2].
In the lower Rio Grande Valley region, hiring a skilled manufacturing worker can take up to a year. The hiring becomes more difficult if the need is in digital programming, such as programming the complex Computer Numerical Control (CNC) machines, Coordinate Measuring Machines (CMM), robots, etc. By 2025, up to 2 million manufacturing jobs are projected to be unfilled.

Several issues are creating this problem. The Baby Boom generation is retiring. The median age of the manufacturing workforce rose from 40.5 years in 2000 to 44.1 years in 2011, according to Tooling U-SME research. The geographical region also plays a major part with people looking for jobs but not in the localities where jobs are available. Increasingly, workers in smart manufacturing need additional skills in digital manufacturing, including programming.

The manufacturers are taking proactive measures to address this critical problem from the skills gap in advanced manufacturing. The measures include a multi-faceted approach to bridge the gap now and in the long term.

The following measures are taken by the manufacturers to address the skills gap:

1. Reaching out to children as young as nine to build excitement and get the next generation interested in smart manufacturing.
2. Offering scholarships and apprenticeships to attract new talents in manufacturing.
3. Providing on-the-job training and education reimbursements to deepen and broaden the skills of their current employees.
4. Partnering with the local educational institutions and universities to help prepare the future workforce in advanced manufacturing.

Senior Design Projects

The Rio Grande Valley (RGV) in southeast Texas and the northeast of Tamaulipas, Mexico is one of the fastest growing metropolitan areas of the world, holding a regional population of over 3.5 million people between the USA and Mexico. The RGV hosts broadly diverse manufacturing industries and, as a result, educational institutions in the region are working towards incorporating higher education as a dynamic regional element.

The University of Texas Rio Grande Valley (UTRGV) was created in 2013 by the Texas legislature as an unprecedented and remarkable move to bring together the assets of the two most important regional higher education institutions: The University of Texas at Brownsville (UTB) and The University of Texas Pan American (UTPA) [3]. UTRGV is growing as a regional research institution and is projected to emerge as a leader among minority-serving research institutions.

As a young, innovative institution, UTRGV can be proud of its mission to provide high quality, affordable education to the students of South Texas, Texas, the United States and the world. The university will transform Texas and the nation through innovations in student success, research, and healthcare, and commercialization of university discoveries. UTRGV faculty and staff are engaged in expanding the possibilities from the current multicultural and multidisciplinary programs to cross-border collaboration. Collaboration with industries in the region provides an opportunity to deliver a better service to the bi-national community in the 150-mile-wide RGV region.

The College of Engineering and Computer Science (CECS) at UTRGV promotes cutting-edge research with international impact as a path to a better life built on compassion, community, and technology. Every performed activity is foreseen as a promoter for economic prosperity and commitment to the global community. With an extensive selection of undergraduate programs in the engineering field, the Department of Manufacturing and Industrial Engineering provides a setting for technology development and applied research in the Engineering Technology (ENGT) program. According to the program description, engineering technology education primarily emphasizes the applied aspects of science and product improvement, industrial practices, and engineering operational functions [4].

Industries practice a multidisciplinary team approach to tackle complex engineering problems. This approach also improves industrial efficiency and managerial performance. Hence, there is a need to train engineering students who will effectively perform in the multidisciplinary environment. The capstone course provides the opportunity to assemble student teams from different fields of engineering. Thus, the role of the capstone engineering course in engineering education is essential to prepare the students to solve industry challenges. Innovative methods in teaching, including the cross-cultural student integration, have proven effective to enhance success in multidisciplinary engineering design teams.

Senior design projects are essential to demonstrate engineering graduates' industry-readiness [5]. The Engineering Technology program at UTRGV offers a wide range of options from which the students will develop engineering skills to address engineering and technological challenges. At the end of the coursework, the students must complete an industry-related, research-based

capstone project, which in specific cases involves the design and development of a functional prototype.

The senior design project is developed in a two-course sequence of Senior Project I and II. In Senior Project I, students use their time to identify an engineering problem and proceed to develop an optimum solution. At this stage, they also conduct thorough research on the topic and complete planning and design of the project. The subsequent Senior Project II is used to build and test the functional prototype. These capstone courses are planned to develop a yearlong project that will provide students with an opportunity to practice the skills that they have learned and developed through the coursework.

Metrology is the science of measurement.

Skills Gap in Metrology Technology

Quality assurance and related technology are vital for the functioning of multifarious products, including cars and computers that govern the daily aspects of human life. Manufacturing ensures the creation of these products through the production of hundreds or thousands of parts each week. In modern manufacturing, all these parts are produced to high precision to ensure the quality of finished products. A quality assurance engineer or a metrologist ensures that the specifications required for the finished parts meet the stringent tolerance requirements. This is an ongoing process in advanced manufacturing.

The automotive industry relies on automated inspection methods for their parts approval processes since high precision and accuracy is required in the production sample inspections and in the validation of new model launch. Highly specialized industries such as aerospace and medical devices require 100% inspection in most of the cases. It has been observed in our region how the industries are adopting state-of-the-art technology to cope with the new demands of the market.

Coordinate Measuring Machines (CMM) are the backbones of coordinate metrology and the related inspection process. These high precision machines demand technical skills in metrology and computer programming that enable the metrologist or engineer to successfully complete the programming for quick and automated inspection processes in industries. There are not enough highly trained engineering and technology personnel available to meet the industry demand in this advanced manufacturing sector.

The Engineering Technology Department at the University of Texas Rio Grande Valley (UTRGV) has created a CMM and Metrology curriculum; and has equipped its metrology laboratory with a last generation CMM, with characteristics identical to those existing in the

industry. In the metrology laboratory, students can develop the skills to operate and program CMM machines to inspect complex industry parts. This unique set of skills enables the students to integrate faster into this specific field of the industry. A continuous stream of well-trained students in CMM operation and PC-DMIS programming will satisfy the demand of industries in this critical field of manufacturing. The graduated students from this program have already been hired by the local industries; and successfully integrated into the team of engineers serving in the inspection and metrology areas.

Industry-University Partnership to mitigate the shortage in manufacturing workforce

Industries are experiencing labor shortages in highly skilled manufacturing areas like robotics, automation, CNC, CMM operation and PC-DMIS programming [6, 7]. The solution to bridging the skills-gap in these areas is to work with industry as a partner and stakeholder [8, 9, and 10]. At the University of Texas Rio Grande Valley, the Department of Engineering Technology has established partnerships with local industries to develop a CMM training program. The graduates from the training program are hired as interns in their metrology and quality control departments. On successful completion of an internship program, they are hired by these industries to work as CMM programmers and quality control engineers.

Detailed Design of Coordinate Measuring Machine Training

The modern industries have a high demand for engineers and technologists with good quality control skills and knowledge of manufacturing. The CMM manufacturing companies, such as Hexagon Manufacturing Intelligence [11], have put together comprehensive training needs with the help of major worldwide manufacturers, educational institutions and training specialists. These training needs are translated into programs that are designed to fill the skills-gap in dimensional measurement and coordinate metrology.

Two of the Engineering Technology instructors (authors) are trained by the Applications Engineers and PC-DMIS Trainers who are all factory trained to the very latest standard to take advantage of all the software and hardware advancements made. These trainers are using, testing and being trained in the software before it is released to market; this means they have more experience than third party suppliers which will reduce costly mistakes due to inexperience. Therefore, the faculty engaged in training students in the latest CMM machine and PC-DMIS software are fully trained and possess the skills required to handle this advanced training. This aspect of the training program is very much appreciated by the partnering industries.

The students that go through the CMM training program are educated in the best programming practices and techniques which will help to speed up programming time and reduce the cost to the industries that they will be serving. The students that graduate from the program are fully

competent at using PC-DMIS to the required standard.

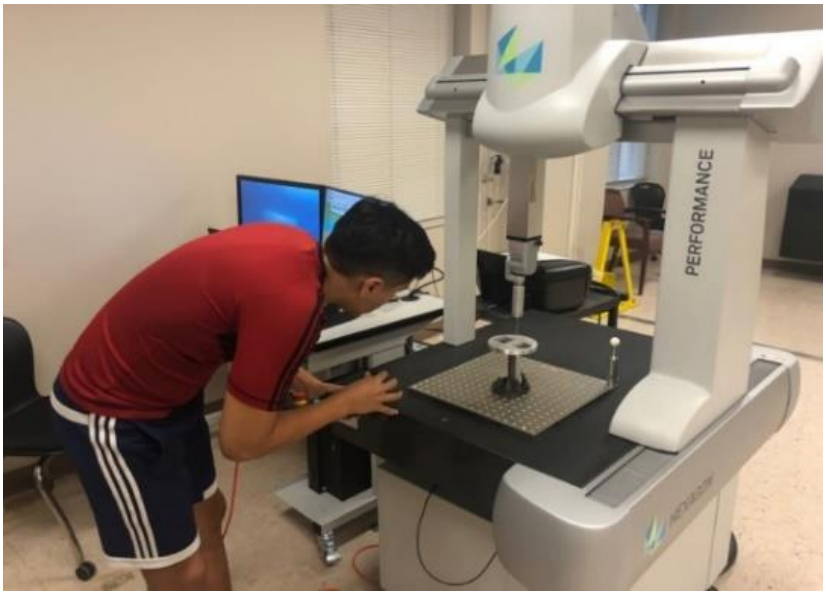

Fig. 1 Hexagon Global Performance Coordinate Measuring Machine

The rationale behind the selection of CMM and PC-DMIS training

The following criteria were used in the selection of the OEM PC-DMIS trainer to train the instructors that have provided the industrial acceptance to the CMM training program.

- As the OEM (Hexagon) can certify that the instructors achieve the level of understanding required for PC-DMIS using the latest versions.
- Trainers have over 30 year's metrology experience in the industry
- New state of the art dedicated PC-DMIS Training center
- Regular classroom-based and online training schedules with access to software and CMM's to include practical and theoretical exercises.

Emphasis on Hands-on Metrological Activities on CMM

A typical CMM is composed of three orthogonal axes, X, Y, and Z that operate on a three-dimensional coordinate system. Each axis has a scale system that indicates the position of the axis. The machine will read the input from the touch probe, as directed by the operator or a computer program.

The Hexagon Global Performance Bridge CMM (Figure 1) has been used in the training program. This machine was selected for the training because it is the most common types of CMM used in the industries. Many of the industries in the region use this type of CMM for their metrology and

inspection applications. In a moving bridge CMM, the measuring head determines values for the X-axis by moving back and forth across the bridge. Values on the Y-axis are determined by moving the entire bridge over the granite base. A fixed bridge CMM determines values on the Y-axis by moving the table rather than the bridge. The added rigidity that comes from keeping the bridge immobile reduces measuring uncertainty, but because the table needs to be mobile its maximum load is more restricted.

The training program covers the fundamentals of coordinate metrology and CMM operation. Also, the programming aspect of CMM using the PC-DMIS software is thoroughly covered. The outcome of the training program is to enable the students to fully operate the CMM with adherence to safety standards. Also, students should able to program the CMM using the PC-DMIS software for inspecting a range of moderately complex industrial components.
The students who have successfully completed the CMM training have the option to choose their senior design projects in the field of coordinate metrology and CMM.

Senior Design Project on CMM

The senior design projects that surround the use of CMM reinforce the training that they have received on CMM and PC-DMIS programming. One of the recent senior projects on CMM is presented in the following sections.

Development of precision inspection procedures using CMM takes time and money in terms of equipment and training. The investment made on CMM saves money on inspection tasks in the long run; however, it takes considerable time and effort in developing inspection programs. This means that the inspection personnel must be trained in different areas of manufacturing, such as interpretation of engineering drawings, GD&T, and inspection procedures. An inspection plan generated from the CAD drawing will greatly help the CMM programmer/inspector in developing the PC-DMIS programs quickly with more accuracy.

Hence, the goal of the senior project is to automatically generate an inspection plan for the CMM based on the CAD data of the component. Students have successfully developed a user-friendly program that automatically generates an inspection plan for the CMM.

Integrated CAD and Computer Aided Inspection Planning

The following feature-based design approach was used to develop an inspection plan for the CMM:

1. Generation of data based on Initial Graphics Exchange Specifications (IGES) [12] & Standard for the Exchange of Product (STEP) of the CAD file.

2. Retrieve inspection information such as dimensions, and tolerances from the IGES and STEP data.
3. Generate Computer Aided Inspection Plan (CAIP) for the CMM [13].
4. Transfer the CAIP information to the PC-DMIS software for part inspection [14].

The senior design students have successfully integrated the CMM into the CAD/CAM environment through this project. The above feature-based inspection planning is developed during the design stage itself. This plan saves time and effort in the inspection and mistake proofing process.

Figure 2 shows a student engaged in the development of PC-DMIS program for the component that needs inspection using the inspection plan generated from the CAD data. A total time of 20 min was taken to develop the PC-DMIS program while working with the inspection plan. On the other hand, a total time of 50 minutes was taken while working directly with the PC-DMIS software. A substantial amount of time saving was noticed through this approach of developing PC-DMIS programming with the help of the inspection plan generated from the CAD data.

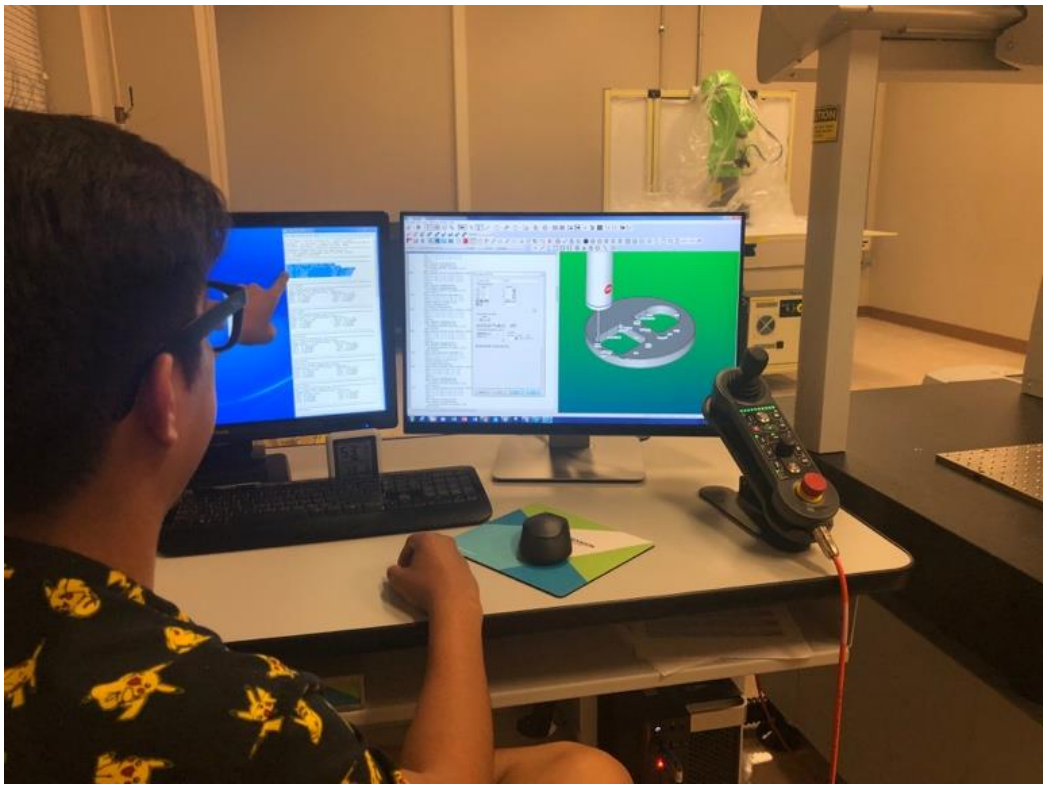

Fig. 2 Student developing a PC-DMIS program using the inspection plan

Results of the CMM based Senior Design Project:

A total of 60 % of the time was reduced by using the Inspection Plan along with PC-DIMS compared to only using PC-DMIS. This was possible due to the flexibility of the inspection plan. Having the exact coordinates alongside the PC-DMIS enables the CMM programmer to quickly develop the inspection program for the component. Inspection time is reduced since the reference data is provided before the machine setup. Cost of CMM visual guidance is also reduced since operators/technicians will be provided with data that will not be cluttered with information like an engineering drawing/blueprint in order to start the inspection process.

Conclusion

The UTRGV's Department of Engineering Technology has had enduring partnerships and collaborations with several companies in the region and across the border in Mexico for many years. These collaborations were developed through faculty taking initiatives in bringing the senior personnel of the companies to laboratories and forging relationships by helping them with testing and small projects through senior design projects.

These personnel are part of the industry advisory board and help the program grow through their valuable suggestions. These companies also provide internships to the students and help them join their workforce. In the present case, the industry that partners with the university in the CMM training benefits tremendously from the supply of much-needed workforce for their quality departments. This is significant since the qualified PC-DMIS programmer and CMM operator is very difficult to hire and retain in the Rio Grande Valley.

We believe we have taken a holistic approach to support our regional industry and community. We offer training to our students in cutting-edge technology and we motivate them to innovate by taking advantage of modern tools such as automation and information technology. Through our capstone projects we explore the integration of metrology with industry 4.0 and at the same time fill the gap of the technical knowledge in this specific area of technology.

Measurement technology will keep changing to adapt to the evolution of global manufacturing. We are preparing our students not only to help the industry to tackle those rapid advancements but also to be the agents of change.

Hence, the home-grown talent in this technology is of immense help to the industry in recruiting highly skilled manpower in advanced manufacturing and with retention; as most of the students prefer to stay close to home after graduation. The engineering technology department is taking initiatives to train students in collaborative robotics, CNC etc., and provide certifications in these areas. Through industry-university partnership students, faculty and all stakeholders win!

Acknowledgment

The authors would like to thank the Dean's office, College of Engineering and Computer Science that provided the funds to acquire the HEXAGON Global Performance CMM 5.5.5 and the training. Also, the thanks go to the engineers at SATA USA, LLC for their valuable suggestions and partnership in CMM training and development.

References

[1] Bureau of Labor Statistics, "Job openings and labor turnover survey," August 7, 2018.
[2] 2018 Deloitte and The Manufacturing Institute skills gap and future work study, https://www2.deloitte.com/us/en/pages/manufacturing/articles/future-of-manufacturing-skills-gap-study.html.
[3] The University of Texas Rio Grande Valley http://www.utrgv.edu/en-us/
[4] The University of Texas Rio Grande Valley - Engineering Technology program http://www.utrgv.edu/_files/documents/admissions/undergraduate/dp-engineering-technology-bs.pdf
[5] Fornaro, R.J., Heil, M.R, and Alan L. Tharp, A. L., 2006, "Reflections on 10 years of sponsored senior design projects: Students win–clients win!" The Journal of Systems and Software 80 (2007) 1209–1216.
[6] Cliff Mirman, "Pathways for Integrating Industry into an Engineering Technology Program", Proceedings of the 2018 Conference for Industry and Education Collaboration, San Antonio, TX.
[7] Kornecki, A.J., Khajenoori, S., Gluch, D., Kameli, N., 2003. "On a partnership between software industry and academia." Proc. of the 16th Conference on Software Engineering Education and Training, Madrid, Spain, pp. 60–69.
[8] Otieno, A. and Mirman, C., 2003, "Engineering Technology Capstone Experience: An Industry Based Partnership," Proc. CIEC 2003 Conference, January 28 – 31, Tucson, Arizona, Session Number 9041.
[9] Shin, Y.S, Lee, K.W., Ahn, J.S. and Jung, J.W., 2013, "Development of Internship & Capstone Design Integrated Program for University-Industry Collaboration," Procedia - Social and Behavioral Sciences, 102, 386 – 391.
[10] Motoyama, Y., 2013, "Long-term collaboration between university and industry: A case study of nanotechnology development in Japan," Technology in Society 36 (2014) 39–51
[11] https://www.hexagonmi.com/en-US
[12] Smith, Bradford M., and Gaylen R. Rinaudot. Initial Graphics Exchange Specification (IGES): Version 4.0 Society of Automotive Engineers, 1988.
[13] Lin, Yeah Jaw, "A Generic Algorithm for CAD-Directed CMM Dimensional Inspection Planning" The University of Akron, 1999.
[14] Kamrani, Ali, "*Feature*-Based Design Approach for Integrated CAD and Computer-Aided Inspection Planning", Springer-Verlag London, 2014.