IoT Based Approach for Assembly Modeling System with Adafruit Cloud

Mahnoor Khalid Paracha[1], Mubashir Ali[2], Aneela Mehmood[3], Mehreen Qamar[4]

[1]Department of Computer Science, Bahauddin Zakariya University, Multan, Pakistan
[2]Department of Software Engineering, Lahore Garrison University, Lahore, Pakistan
[3,4]Department of Computer Science, Lahore Garrison University, Lahore, Pakistan

***Abstract*– In this technological world, the Internet of Things (IoT) is new emerging technology which is revolutionizing the real world objects (i.e., cars, home appliances, baby monitor, etc) into automated virtual objects. These real world objects are connected by the help of embedded devices to the internet where they collect and share data by means of low cost computing. IoT has also a great impact in manufacturing zone and it brings changes in business prototypes. But in the application of current enterprises, an obstruction is encountered by computer aided software's when they deal with dynamics, uncertainties and complexities. It is proclaimed that the problem can be solved by adopting IoT and cloud services in systems of enterprise. In this research paper, challenges in creating composite product's assembly plans are discussed and IoT based approach for automation of assembly modeling system is presented by integrating cloud services. Adafruit cloud service and IoT are proposed in developing advanced systems from existing assembly system which deals automatically with complexities. The new approach has modularized architecture which is stable and flexible. Automated algorithm for assembly planning and object-oriented templates is proposed for reusing the system parts. This approach efficiently reduces the complexity of system as well as decrease the error rate.**

***Keywords*– Assembly Modeling, Internet of Things, Automation, Object Oriented Templates, Cloud Computing and Adafruit Cloud**

I. INTRODUCTION

Assembly modeling systems are used to create and integrate the assembly of components [1]. It has a great influence in availability of Computer aided design (CAD) systems [2]. Two type of methods are used in assembly modeling, first is from top to bottom and second is from bottom to top. Bottom to top assembly was carried out in 1980 and according to that first structure of designs of machine's components are carried out by designers with the help of CAD tool and then the whole design scheme is analyzed, after that the product model is established by defining the assembly relations of those components. The main focus in CAD is on analysis and design of individual components. However, in practical application, rather than examining the individual components themselves, there is need to examine assembly of components. A well-organized development would be the introduction of software package which will allow the designers to design and assemble the individual components and then to perform analysis on the assembly. If a designer wants to inspect the performance of assembly, he needs to generate a model of assembly from the assembly drawing [3]. Fig. 1 shows the procedure of design iteration. But in the assembly planning and modeling of components or in the applications of enterprises, a bottleneck is encountered by CADs while dealing with uncertainties, dynamics and complexity. To support assembly modeling effectively, advanced methodologies and tools should be used [4].

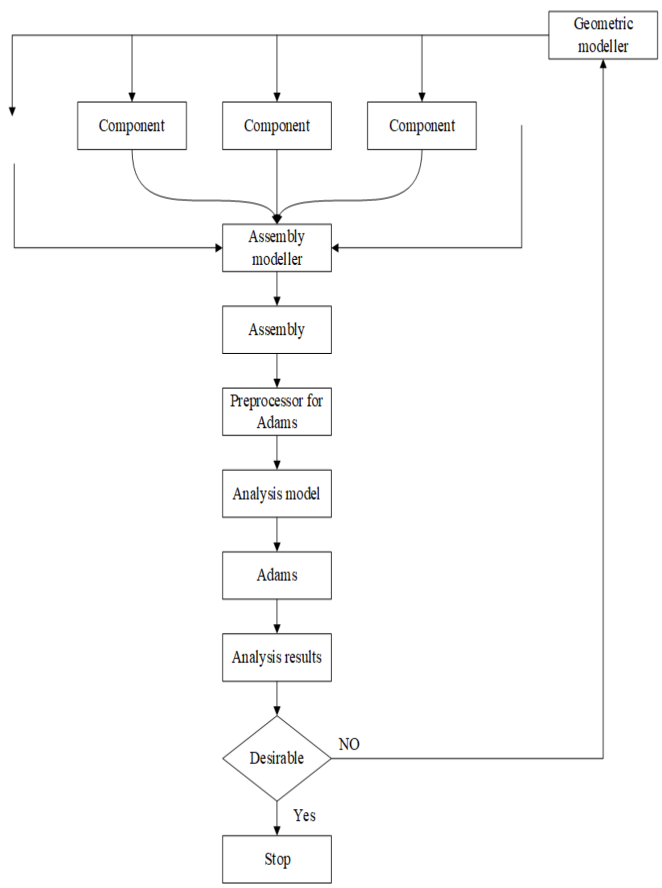

Fig. 1. Design iteration process [3]

Products are designed by more complex features and greater number of parts and components [5]. Modern mechanical products are developed by large number of parts because of complex functionalities [6]. The complexity of a product is related to their dynamics with respect to time and the number of design variables [7]. Mainly, products complexity have two main sources, one is uncertainties of design requirements and the other is number of involved parts in the structure of product[8]. These complexity sources have formed many critical challenges for CADs. To solve this obstruction, it is proclaimed that adoption of IOT would be helpful [9]. It is because, IoT is the new emerged technology which is helping in the automation of the real objects. It has successful applications in industry, education and healthcare [10].

In this paper, an approach for automated assembly planning is introduced. IoT is suggested as a good solution for simplifying the complexity and uncertainties of assembly modeling. Section II identifies challenges and limitations of previous procedures in automated assembly modeling. In section III, object oriented templates are suggested to meet the essentials of modularity, expandability and decentralization. Section IV propose automated algorithms with Adafruit cloud where all the data is stored, and managers can access it any time. In the section V, assembly of aircraft's machinery and diesel engine is used for the case study. Section VI concludes the research work.

II. LITERATURE REVIEW

As the world is getting smaller, the manufacturing environments are globalizing. In other words, many resources (which are interacted with each other) are involved in production and considered able during the decision making in business activities. This makes challenges for enterprise systems (ESs) when they deal with modularity, decentralization and expandability. On the ESs development, the recent progress has been given by [11] and [12]. Enterprise systems [12] for modeling and the relation with IoT is briefly discussed below.

- ***Enterprise System for assembly modeling automation***

The assembly modeling becomes difficult when products structures becomes complex. This difficulty depends upon complexity and data availability. There would be significant impact by adopting IoT in the modeling systems [9]. These impacts are as follows:

A). Complexity: Number of components included in system that describes the system's complexity. Modern products are complex because they have more components and also involve uncertainties in their manufacturing processes. These both factors increase the systems complexity. In the decision support systems, the rising complexities have been discovered widely in the surveys. For example, the qualitative and quantitative data in the design of complex products was investigated by [13]. Their approach was to represent and utilize qualitative data and vague for managing complexity. [14] purposed an architecture (based on java) which deals with distribution of information systems in industrial applications. [15] works to monitor the changes in industrial applications which occur at real time.

B). Availability of data**:** For defining the inside business activities a production company has to clear its boundaries by its residential environment. The organized company has hierarchal based architecture and decision makers can access all the data and information from a centralized database. The paradigm of system was computer integrated manufacturing (CIM). To achieve high productivity, utilization of system resources could be optimized by CIM but this involved high cost and lack of adaptability. To improve the adaptability of system, the boundaries of manufacturing system with environment become unclear and the system also becomes dynamic. In collaborations of inter and intra enterprises, close connections are needed. Moreover, the data should be easily accessed [16]. Albeit the requirements cannot be met up by any system. Many researchers have proposed modeling systems. For example, map-based relation model, hierarchal tree based model and the object-oriented models. Whereas the assembly relations are concerned, liaison diagram models and polychromatic models are examples of relational models. These models use matrices as they represent the relations efficiently and can be programmed easily. Matrices were first used by models [17] which represents the assembly of products. They developed connection, interference and contact matrices for describing the structure of products. This model was improved by [18] model of binary matrix. But both models have limitations. It was that interference model is not applicable when there are inclined surfaces for assembling in the parts. [19] extracted a relation matrix which was for connection information of parts but it required manually input of object relation chart. [20] proposed an interference and neighboring matrix which was same as the contact matrix. [21] approach was to simplify the process of modeling by developing the connection and interference matrix, but it just considered functional parts.

- ***Assembly Modeling and the IoT***

Main challenge for constructing enterprises by ES is to attain system capability on dealing with complexity. For this purpose, the assembly modeling should be modularized, decentralized and fully automated. First of all, service oriented architecture and modularized tools will be used by IOT. Secondly, adafruit cloud will be used so that the users can access any data for decision making and this will also help to achieve modeling and planning of assembly [22].

III. OBJECT ORIENTED TEMPLATES

In computer aided design systems (CADs), product modeling and planning is done on a different place and product parts are developed at other place. The product structure is desired to be modularized so that the assembly components are loosely combined and parts could be easily maintained and modified. These requirements can be fulfilled by the help of object oriented templates as it also helps to reduce the complexity of product development. For using these templates, first a model template is to be developed and afterwards an assembly model is made from it.

To fulfil the requirements of assembly modeling, a model should contain all the information such as structure of product, included parts and assembly unit. Fig. 2 describes a model template. This template contains high level assembly which includes low level sub-assemblies. There are classes of components, assembly sequence, assembly relation and constraints in each assembly. Each class is further divided to contain detailed attributes.

For assembly model template, topological relations can be defined individually. Fig. 3 shows the categorization of assembly relations. There is list of attributes for each class in template and the relations between two attributes of different class can be defined [23].

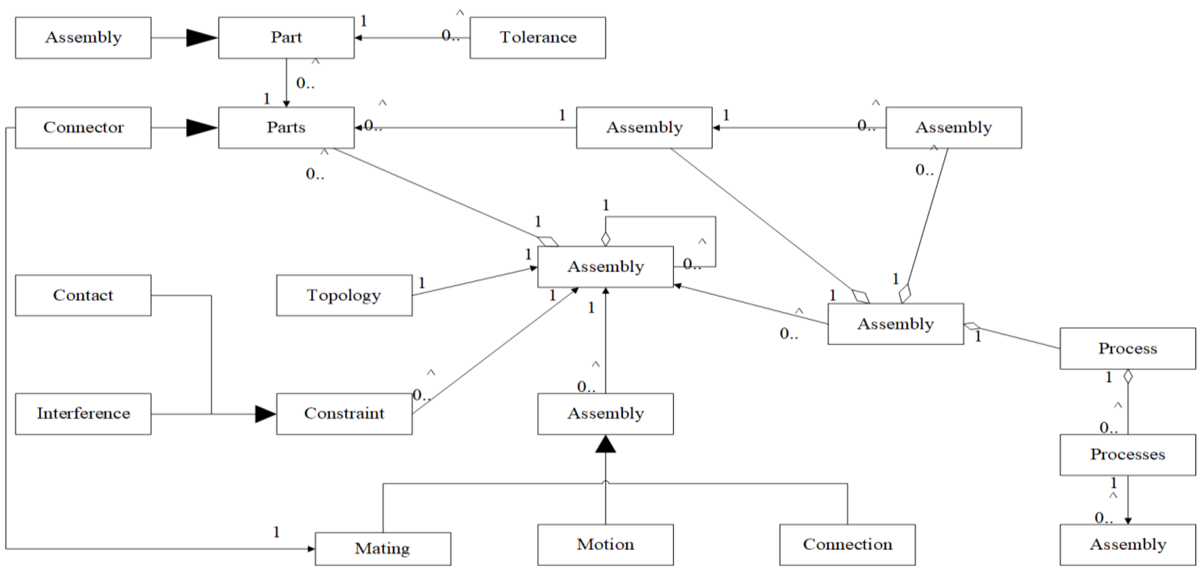

Fig. 2. Product model template

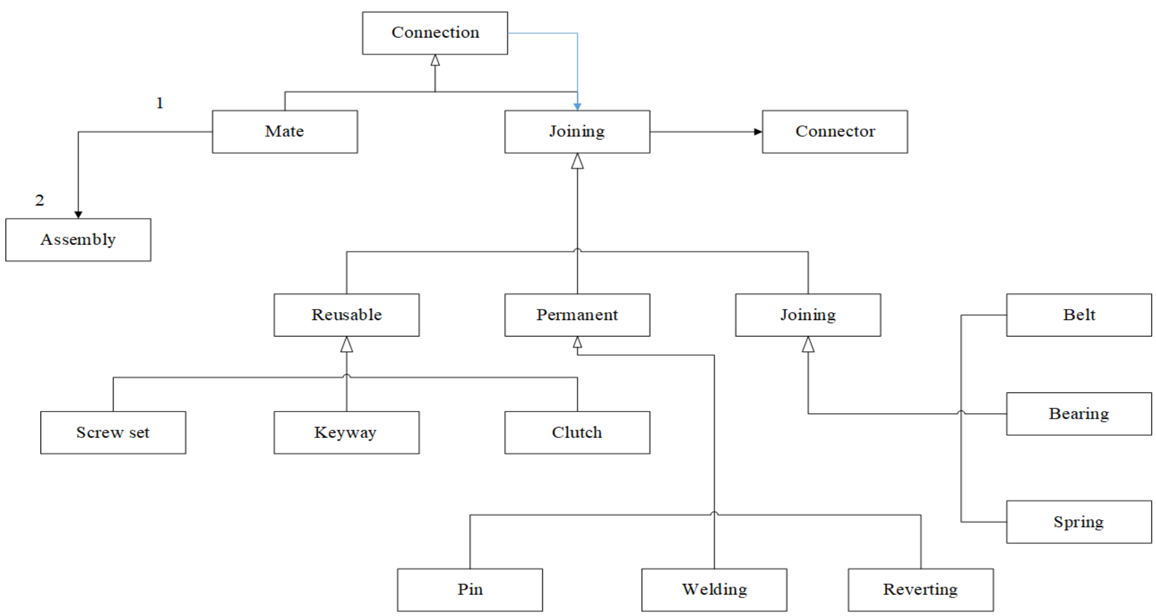

Fig. 3. assembly connection relation

IV. AUTOMATED ALGORITHM

The difficult task in assembly modeling is to define assembly relations in a product structure [24]. These relations are represented by matrices which can be automatically generated after defining the product template. In this section, relations among subassemblies and components are discussed and algorithm for automatically retrieving matrices id suggested.

- ***Matrix A for assembly relations***

Product having large number of features also have a complex structure which contains huge number of parts. These parts are classified on the basis of their function. The important information in assembly model is connection relation of parts or subassemblies. For differentiation the types of connection parts and their impact on assembly, contact and connection relations are used to make a new assembly relation matrix.

Consider a model template 'C' having 'N' number of parts, i.e., C= {c_1, c_2, c_3… c_n}. The integer b_{ij} represents a connection relation among parts c_i and c_j. Here the following definition can be given:

$$b_{ij} = \begin{cases} 0, \text{ if } c_i \text{ and } c_j \text{ are not connected} \\ 1, \text{ if } c_i \text{ and } c_j \text{ are function parts and are} \\ \quad \text{Contacted with each other} \\ 2, \text{ if } c_i \text{ and } c_j \text{ are function parts and are} \\ \quad \text{Connected with each other} \\ 3, \text{ if } c_i \text{ is connection part (screw/bolt)} \\ 4, \text{ if } c_i \text{ is a connection part (nut)} \\ 5, \text{ if } c_i \text{ is connection part (key)} \\ 6>=6, \text{ if } c_i \text{ is connection part (others)} \end{cases}$$

Thus, A= [b_{ij}] is an N $\times$ N matrix for assembly relation of products. It involves relationship between parts of assembly model.

- ***Analysis of interference while generating matrix A***

There can be different relations among parts while defining assembly relations. The relation among parts can be closed, interfered or touched. A touched relation would be when there is a physical contact among two parts without interference. Close relation between two parts will happen when the distance among them is less than the tooling size. When two parts share a spatial volume then the happening relation is interfered. But this relation is not always suitable. Take an example of a nut and a screw. There would be interfered relation among them so that the fastening works sufficiently but analyzing the interference is critical while determining the assembly plan.

The generation of matrix A of assembly relation with interference analyzation is show in Fig. 4. By the position of parts in assembly, matrices A's in assembly relations can be extracted. When a part is placed, its relation with all other parts can be determined correspondingly. For assembly planning these matrices can be linked with any computer software.

- ***Extended matrix for paths of assembly***

The directions of assembly or dis-assembly can be determined by the help of extended matrix (EM). These directions are determined to avoid any interference in the assembly path. Yet there is no algorithm proposed which can automatically identify interference free path. While defining an EM, every part is placed by the help of its local coordinate system (LCS) which is located on the base feature of every part.

The assembly directions are specified by the help of Global coordinate system (GCS) or LCS.

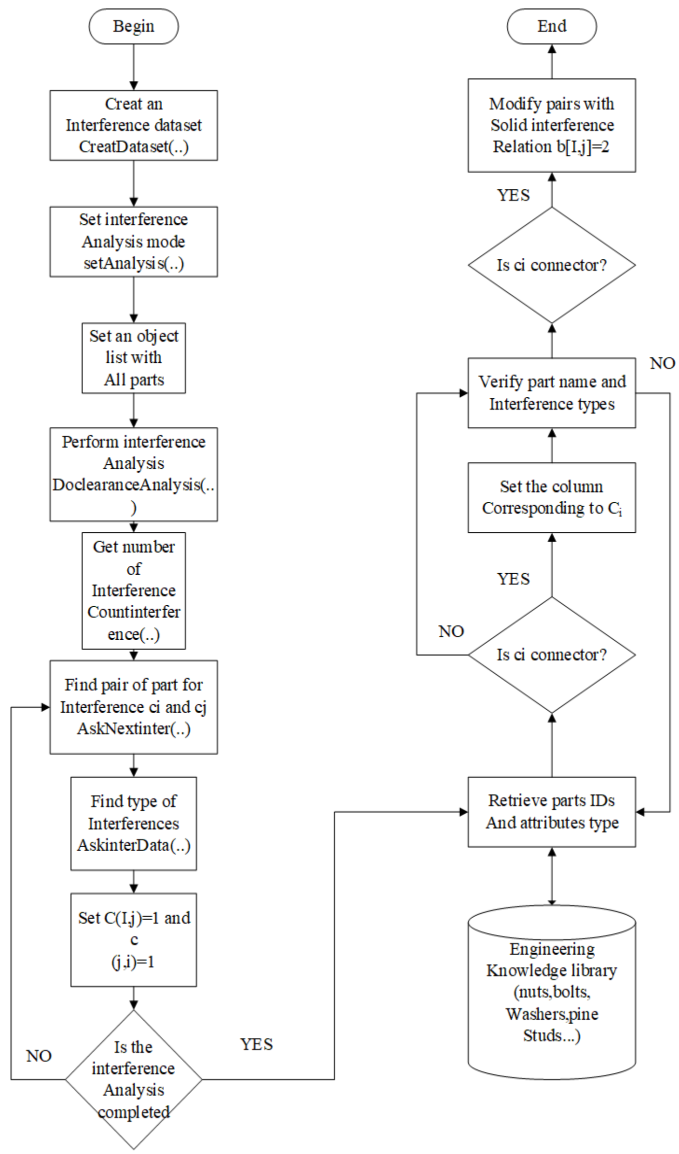

Fig. 4. Generating matrix of assembly relations

Now denote the axes (X_L, Y_L, Z_L) and (X_G, Y_G, Z_G) to LCS and GCS. Assembly direction of each part have the available operations ($-X_L$, $-Y_L$, $-Z_L$, $+X_L$, $+Y_L$, $+Z_L$) and ($-X_G$, $-Y_G$, $-Z_G$, $+X_G$, $+Y_G$, $+Z_G$). Here L and G represents LCS and GCS. Consider an assembly model A having N number of objects such that C= {c_1, c_2 … c_n}. Let em_{ij} for representing assembly/disassembly directions of c_i with respect to c_j. The options of directions are ($-X_G$, $-Y_G$, $-Z_G$, $+X_G$, $+Y_G$, $+Z_G$, $-X_L$, $-Y_L$, $-Z_L$, $+X_L$, $+Y_L$, $+Z_L$). Now extended matrix would be EM= $| em_{ij} |_{12 \times N \times N}$. Now consider an example of spool having inclined assembly direction as shown in figure 5. It has 4 connection parts and 3 functional parts. The functional parts are shown by solid lines whereas dotted lines show the connection parts.

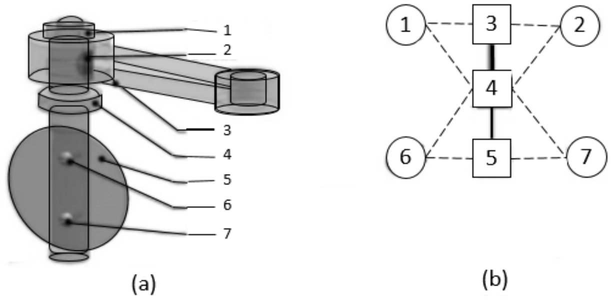

Fig. 5. (a) Spool having inclined assembly relations (b) contact relations

The EM of component along $+Z_l$ and $+Z_g$ is as follows:

Along Z_g:

$+Z_g$	1	2	3	4	5	6	7
1	0	0	1	1	0	0	0
2	0	0	1	1	0	0	0
3	1	1	0	1	0	0	0
4	1	1	1	0	1	1	1
5	0	0	0	1	0	1	1
6	0	0	0	1	1	0	0
7	0	0	0	1	1	0	0

Along Z_l:

$+Z_l$	1	2	3	4	5	6	7
1	0	0	4	4	0	0	0
2	0	0	5	5	0	0	0
3	1	1	0	2	0	0	0
4	1	1	2	0	1	1	1
5	0	0	0	1	0	1	1
6	0	0	0	3	3	0	0
7	0	0	0	3	3	0	0

Next step in assembly sequence planning is to define relation matrices *A's* and *EM's*. *A's* relation can be defining by the interference relations which are found in *EM's*. The generation of EM's relation is shown in Fig. 6.

As the relation A's and EM is defined the next step is to plan assembly process. C_i represents the current part which is to be analyzed and c_j represents the assembly relation with c_i.

After defining the relation A's and EM, planning of assembly processes takes place. This planning is made up of assembly paths, process schemes and assembly sequences. In assembly paths, a route for assembly operations is defined, while assembling resources and tolerances are defined in process schemes. In assembly sequences, an order is given for putting all the parts together to form a final product.

Adafruit cloud:

Adafruit cloud is used to store and retrieve all the data at any time. Cloud computing supporting many IoT based systems towards automation. Its central point that provides high resources for fast execution of assembly modeling processes [25].

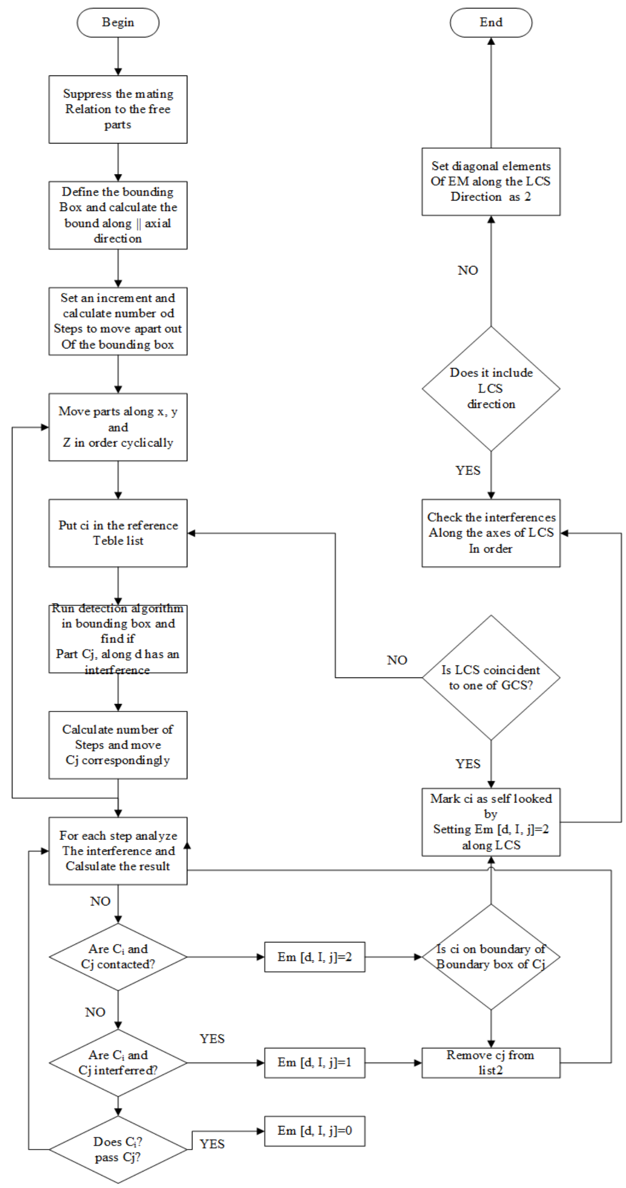

Fig. 6. Process of generation of EM

V. CASE STUDIES

Case Study 1: Aero engines:

Engines of aircrafts are best example of complex products because it contains more large number of parts [26]. There is no model available till now which can automate the assembly modeling. So for this purpose, a model template has been proposed and shown in figure 7 for developing the main bodies of an aero-gas engine. The main body contains several number of subassemblies including compressor, gas turbine and burning room. Each subassembly is further divided into several parts and subassemblies. For example, a gas turbine has subassembly of high, medium and low pressure turbine which are further divided into parts such as shafts and stators.

Subassembly of compressor contains high, medium and low pressure compressor and transmission case. And complex relations take place between parts and subassemblies. For example, turbine shaft and compressor with high pressure are connected to each other by the help of coupling, so that power can be transferred from turbine to compressor. The transmission case and input shaft are centrally aligned and are connected with spline which transfers power from turbine to transmission case. Each sub-assembly is assembled by the help of stators and the connectors contains different types of nuts and bolts.

This proposed model has capability to create assembly plans with information from solid models, to simulate and visualize the assembly processes and to evaluate the assembly plans.

Information of parts is extracted when the model is first loaded and an assembling tree is constructed. After that the bounding box is calculated for measuring the movement boundary of each part. Next, a partial coordinate axis is chosen which calculates the insertion points of each step according to their length. And during this process, generation of relation matrices A's and EM's takes place. These are generated by the help of proposed algorithms. A graphical user interface (GUI) helps users for accessing retrieved information. A very least time would be taken in finishing the steeping precision decision and detecting the interference mode and consistent direction. This shows that the relation matrices A's and EM's fits the real situation very well and also all the data is stored in Adafruit cloud so that users can access any data. As the matrices are defined, the related tasks such as sequence planning, simulation, and generation of exploded views can be completed by the help of automated assembly systems.

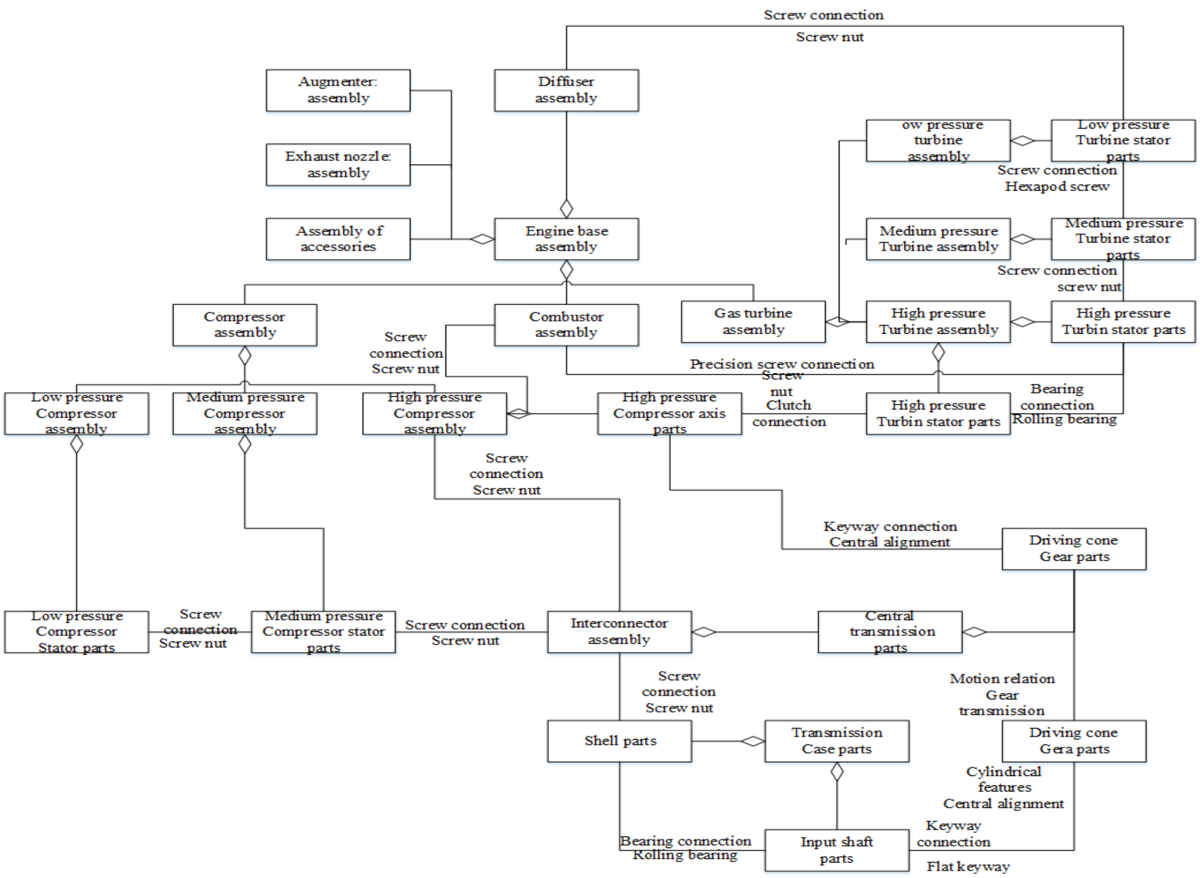

Fig. 7. Model Template of Gas Engines

Case study 2: Diesel engines:

A diesel engine also consists of hundreds of parts. It mainly consists of engine body, shaft, piston and fuel pump. These are further divided into subassemblies and parts [27]. It is not so much complex like gas turbine engine but modeling process can be enhanced using the proposed solutions. For this purpose, relational matrices A's and EM's are generated by the help of proposed algorithms. Then they are used to extract the information of parts and to construct an assembling tree. After that the bounding box is calculated for measuring the movement boundary of each part. A graphical user interface (GUI) helps users for accessing retrieved information. A very least time would be taken in finishing the steeping precision decision and detecting the interference mode and consistent direction. This shows that the requirements A's and EM's fits situation very well and fulfill the requirements of assembly modeling. All the data is stored on Adafruit cloud so that users can access any data.

System from product models and it also generates assembly sequences. The proposed matrix A helps to integrate contact and connection relation matrices from functional parts. Extended matrix EM helps to solve the problem which was not previously solved by interference matrix. It analyzes the parts in arbitrary directions. Relational matrices are generated by static interference analysis whereas Ems are generated by dynamic interference analysis. Adafruit cloud is used to store all the data which helps the users to access it in supporting decision making. The proposed model fulfilled the requirements of modularization, decentralization and automation for adaption of IOT infrastructure.

VI. CONCLUSIONS

The advancement of assembly modeling depends upon the IT infrastructure. Modularization, decentralization, and automation of enterprise systems can be done by adopting IoT. Enterprise systems should be designed in such a way that they should be automated and less complex. In this research paper, an internet of things-based approach is presented to automate the process of assembly modeling systems. Object oriented templates are considered to fulfill the necessities of enterprise systems. Two case studies are illustrated with proposed approach to show the complexity and error rate reduction.

REFERENCES

[1] C. Wan, B. Gu, Y. Sun, and J. Chen, “Assembly oriented product semantic modeling,” in *ICCASM 2010 - 2010 International Conference on Computer Application and System Modeling, Proceedings*, 2010, vol. 10.

[2] K. Lupinetti, J. P. Pernot, M. Monti, and F. Giannini, “Content-based CAD assembly model retrieval: Survey and future challenges,” *CAD Comput. Aided Des.*, vol. 113, pp. 62–81, Aug. 2019.

[3] D. N. Rocheleau and K. Lee, “System for interactive assembly modelling,” *Comput. Des.*, vol. 19, no. 2, pp. 65–72, 1987.

[4] C. R. Boër, P. Pedrazzoli, M. Sacco, R. Rinaldi, G. De Pascale, and A. Avai, “Integrated computer aided design for assembly systems,” *CIRP Ann. - Manuf. Technol.*, vol. 50, no. 1, pp. 17–20, 2001.

[5] O. Kuhn, H. Liese, and J. Stjepandic, “Methodology for knowledge-based engineering template update,” in *IFIP Advances in Information and Communication Technology*, 2011, vol. 355 AICT, pp. 178–191.

[6] B. Lee and K. Saitou, “Integrated synthesis of assembly and fixture scheme for properly constrained assembly,” *IEEE Trans. Autom. Sci. Eng.*, vol. 2, no. 3, pp. 250–261, Jul. 2005.

[7] “Complexity: Theory and Applications by Nam P. Suh, 2005 | Online Research Library: Questia.” .

[8] Y. Koren *et al.*, “Reconfigurable manufacturing systems,” *CIRP Ann. - Manuf. Technol.*, vol. 48, no. 2, pp. 527–540, 1999.

[9] C. Wang, Z. Bi, and L. Da Xu, “IoT and cloud computing in automation of assembly modeling systems,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 2, pp. 1426–1434, 2014.

[10] M. Ali, S. Hafeez, M. K. Paracha, and T. Liaqat, “IOT Based Architecture for Basketball Supervision,” *LGU Res. J. Comput. Sci. IT*, vol. 3, no. 4, pp. 30–36, 2019.

[11] W. He and S. Member, “Integration of Distributed Enterprise Applications: A Survey,” *IEEE Trans. Knowl. Data Eng.*, no. c, pp. 1–9, 2011.

[12] L. Da Xu, “Information architecture for supply chain quality management,” *Int. J. Prod. Res.*, vol. 49, no. 1, pp. 183–198, Jan. 2011.

[13] N. Li, W. Yi, Z. Bi, H. Kong, and G. Gong, “An optimisation method for complex product design,” *Enterp. Inf. Syst.*, vol. 7, no. 4, pp. 470–489, Nov. 2013.

[14] P. Basanta-Val and M. Garcia-Valls, “A distributed real-time Java-centric architecture for industrial systems,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 1, pp. 27–34, Feb. 2014.

[15] T. Vollmer, M. Manic, and O. Linda, “Autonomic intelligent cyber-sensor to support industrial control network awareness,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 2, pp. 1647–1658, 2014.

[16] S. Borkar and A. A. Chien, “The future of microprocessors,” *Commun. ACM*, vol. 54, no. 5, pp. 67–77, May 2011.

[17] G. Dini and M. Santochi, “Automated Sequencing and Subassembly Detection in Assembly Planning,” *CIRP Ann. - Manuf. Technol.*, vol. 41, no. 1, pp. 1–4, 1992.

[18] Y. M. Huang and C. T. Huang, “Disassembly matrix for disassembly processes of products,” *Int. J. Prod. Res.*, vol. 40, no. 2, pp. 255–273, Jan. 2002.

[19] J. P. Yu, C. G. Wang, H. Yu, and W. L. Zhang, “Generation of Optimized Assembly Sequences Based on Priority Rules Screening,” *Appl. Mech. Mater.*, vol. 16–19, pp. 130–134, Oct. 2009.

[20] Y. Wang and J. Liu, “Subassembly identification for assembly sequence planning,” *Int. J. Adv. Manuf. Technol.*, vol. 68, no. 1–4, pp. 781–793, 2013.

[21] B. Lee and K. Saitou, “Integrated Synthesis of Assembly and Fixture Scheme for Properly Constrained Assembly,” vol. 3, pp. 1–13, 2004.

[22] M. Ali and M. K. Paracha, “An IoT Based Approach for Monitoring Solar Power Consumption with Adafruit Cloud,” *Int. J. Eng. Appl. Sci. Technol.*, vol. 4, no. 9, pp. 335–341, 2020.

[23] R. Krishnamurthy and J. Cecil, “A next-generation IoT-based collaborative framework for electronics assembly,” *Int. J. Adv. Manuf. Technol.*, vol. 96, no. 1–4, pp. 39–52, Apr. 2018.

[24] K. Lupinetti, F. Giannini, M. Monti, and J. P. Pernot, “Content-based multi-criteria similarity assessment of CAD assembly models,” *Comput. Ind.*, vol. 112, p. 103111, Nov. 2019.

[25] G. Peng, H. Wang, and H. Zhang, “Knowledge-based intelligent assembly of complex products in a cloud CPS-based system,” in *Proceedings of the 2019 IEEE 23rd International Conference on Computer Supported Cooperative Work in Design, CSCWD 2019*, 2019, pp. 135–139.

[26] S. Wang, H. Yang, and R. Mo, “Research and design of assembly manufacturing execution system for aero-engine,” in *Proceedings of the 2011 2nd International Conference on Digital Manufacturing and Automation, ICDMA 2011*, 2011, pp. 911–915.

[27] Y. Huang, X. Gao, H. Zhou, K. Wang, and Y. Qu, “Design and implementation of distributed collaborative virtual assembly system with three-dimensional force feedback,” in *Proceedings - 2012 IEEE 2nd International Conference on Cloud Computing and Intelligence Systems, IEEE CCIS 2012*, 2013, vol. 2, pp. 941–945.

Mahnoor Khalid Paracha completed her MSCS from Bahauddin Zakariya University, Multan, Pakistan. Currently she is affiliated with Punjab School Education Department (PSED) and serving in multiple institutions as a visiting faculty member. Her research areas are Computer Networks, Data Communication, Machine Learning and Internet of things.

Mubashir Ali received his MCS and MS degree in Computer Science from Bahauddin Zakariya University Multan, Pakistan. He is currently associated as a Lecturer with Department of Software Engineering, Lahore Garrison University, Pakistan. His work has appeared in many leading journals and international conferences. His research interests include Design and Analysis of Complex Algorithms, Internet of Things, Deep Learning, Wireless Sensor Networks and Cloud Computing.

Aneela Mehmood completed her MPhil degree in Computer Science from Kinnaird College for Women University, Lahore, Pakistan. She is currently working as a lecturer in Lahore Garrison University, Pakistan. Her area of Interests are Machine learning, Data Mining, Data structures and Algorithms.

Mehreen Qamar received her MPhil degree in Computer Science from Kinnaird College for Women University, Lahore. She is currently associated as a lecturer in Lahore Garrison University, Pakistan. Her area of interests include Machine learning, Data Mining, Database Management Systems, Algorithm Analysis, Computer Networks, Data warehouse and Information Retrieval.