IoT visualization of Smart Factory for Additive Manufacturing System (ISFAMS) with visual inspection and material handling processes

Sivabalakrishnan R¹, Kalaiarasan A², Ajithvishva M S³, Hemsri M⁴, G.M.Oorappan⁵, Yasodharan R⁶

¹, ⁵ Assistant Professor, Bannari Amman Institute of Technology, Department of Mechatronics, Erode, Tamil Nadu, India.
⁶ Assistant Professor, SNS College of Technology, Department of Mechatronics, Coimbatore, Tamil Nadu, India.
², ³, ⁴ Student, Bannari Amman Institute of Technology, Department of EEE, Erode, Tamilnadu, India.

sivaeinfo@gmail.com, kalaiarasan.ee18@bitsathy.ac.in, ajithvishva.ee18@bitsathy.ac.in, hemsri.ee18@bitsathy.ac.in, oorappan@bitsathy.ac.in, r.yasodharan@gmail.com

Abstract. The challenges in a manufacturing system are lack of timely, accurate, and lack of information to featured product prediction, shop floor resources, product flow, product inspection, product status to customer, product delivery status and factory adaption for customized product. The proposed idea is to design IoT visualization based Smart Factory for Additive Manufacturing System (ISFAMS) that creates a way towards progressively from traditional automation to a fully connected mass customization and flexible cyber-physical system. The ISFAMS utilize a consistent stream of information from associated tasks and creating frameworks to learn and adjust factory productions to new requests from the customer. The system utilizes the Industrial Controller to control the operation of individual systems and sequence of product flow in the Smart Factory setup. The wireless sensor network acquires real-time manufacturing information and information is stored, accessed and visualized using cloud computing. The vision system and automated platform enable the inspection of products shape and dimensions based on the machine learning approach and to transfer the product from section to section and separate the product for packaging section. This digitization of manufacturing system increases flexibility, reliability, smart sensing and control, resource wastage, easy access to manufacturing information and logistics management.

Keywords: Smart Factory, Control Panel, Internet of Things (IoT), Industrial Automation, SCARA Robot, Vision System, Additive Manufacturing, 3D Printing Technology.
1. Introduction

As one of the essential things in Industry 4.0, the smart factory utilizes the recent advanced technology such as the Internet of Things (IoT), Additive Manufacturing, Cloud computing, and Mass Customization for cyber-physical systems and automated machines to real-time monitor of physical process, information storage, visualization through virtual system and optimal decision making to improve the production and quality [1]. The individual systems in the manufacturing area are able to interact and cooperate with each other within a smart factory to perform optimal decision making. IoT is an interconnection of computing devices with the manufacturing system for sending and receiving the product manufacturing information [2].

In the smart factory, the resources, processes, and products can be characterized by cyber-physical systems (CPS). The CPS is similar to the IoT technology which gives the higher coordination of process between the physical system and computational system of manufacturing unit. The digitization of manufacturing process is integrated with the smart factory that infers the real-time data, and statistics can be analyzed based on the information stored using cloud computing [3]. The IoT device communicates with all other devices to exchange of information remotely for monitoring and controlling the process. The cloud computing technology provides a platform to access the stored information about the manufacturing process and products for monitoring, analyzing and gives feedback to the smart factory through API of IoT services [4].

The automated machines involved in the smart factory to carry out the process like additive manufacturing, material handling (Pick and Place), material transfer using conveyors, product assembly, visual inspection (size, shape, and defects), product separation, packaging, and logistics management [6]. These sequences can be tracked using wireless sensor network during each process and send the data to the IoT enabled computing device. The information about the inspection can be monitored and segregate the data’s like shape, dimensions, type of defects stored in cloud computing for ease of access by the authorized person (Both management and customer based on authorization level) [7]. The remote control is possible using the SCADA system interfaced PLC and IoT devices. The PLC performs the controlling operation by scanning the status of input terminal based on the ladder logic program stored in the memory.

![Figure 1: Annual preventive maintenance chart (APMC) (source: Excel die casting industry)](image-url)
HMI display is provided in a smart factory for operator control and visualizes the machine data. The advanced development of automation provides automatic control of every process in a smart factory. The challenges in a smart manufacturing system are facing a lack of information about the individual process in each section of the smart factory set up and product flow to the management and status of the product at each stage in the manufacturing unit to the customer [8]. The top can visually monitor the workers and machines involved in each process using CCTV camera and product flow at the instant of time. It is impossible to track the manufacturing operations such as timely process, machine operating periods, idle time and product status in each stage of the manufacturing process by using image processing or pattern recognition approach [10]. The survey on the industries like Die Casting Industry, Automation industry and automotive manufacturing industry, Chennai focuses the demand for the implementation of IIoT system for monitoring the machine parameter and creates an alert based on the annual preventive maintenance schedule of the conventional machine in their industry during industry visit for consultancy project shown in figure 1 and figure 2.

Figure 2: Die casting machines for parameter monitoring in control panel

The proposed system creates a solution for on-demand need of industries like internet based monitoring of production process, inventory management, material usage, and inspection result tracking and product status to the customer. Our proposed system consists of hardware and software contributions. In hardware, any manufacturing industries require four major sections like material storage, product fabrications, material handling, assembling, inspection and packaging. Similarly our ISFAMS consists of six sections such as Feeding section, 3D printing section, Conveyer, Assembling section, visual inspection section and packaging section. Along with this, our solution includes data visualization system integrated with manufacturing sections to track process, material position, product status and statistics. Our system interlinks the top level management to access complete status of manufacturing process and products.

2. Experimental setup

The conceptual design depicts that the customer can order the product with required specification details like variant, shape, dimensions through mobile or web application shown in Figure 3. The customer order and tracking the product status can be stored in a database through cloud computing using IoT device and API. The information is accessed, and the manufacturing process is planned by the data analysis application in a distributed computer system. The 3D printer starts printing the parts (toys, home appliance material, health care products, etc.) based on customer data.
After the part feeder will feed the part to the conveyor, then printed parts get transferred by the single arm to the conveyor. When the conveyor receives part 1 & part 2 and starts moving the part to the inspection section after the proximity sensor senses the availability of both parts. The conveyor stops when a part reaches the assembled section and parts are assembled by the SCARA arm for making it as a single product. The assembled product is further moved to the inspection section for identifying the product variant, shape, dimensions and defects. The finished product is packed by packaging section with barcode and the entire sequence is controlled by PLC. The corresponding information about product status, inspection data, manufacturing details, idle time, and maintenance report is stored and accessed by IIoT device integrated with this manufacturing system.

**Figure 3: Conceptual Design**

On viewing our progress towards project development based on the priority of hardware system of any manufacturing industry, we have developed

i) Feeding section

ii) 3D Printing section

iii) Conveyor section with semi-rotary arm actuation at the beginning of conveyor
Feeding section

Feeder unit has stack of ready-made parts. When the entire system is switched ON through HMI or IoT dashboard, the part is ejected from the stackholder using a pneumatic cylinder. The speed of cylinder actuation can be controlled by the flow control valve and meter in meter out circuit. PLC gives a signal to the solenoid valve to pick the part from the feeder unit and place it in the conveyor using a 1800 pneumatic operated rotary actuator.

![Figure 4: a. Feeder section, b. 3D printer](image)

3D printer section

3D printer consists of stepper motor, microcontroller, driver, linear guide rails, display, extruder and heat bed. CAD design can be converted into .stl file using REPTIER host. The 3D printer will start printing the 3D part variant after firmware gets order information from the client dashboard. Once the part is manufactured, the sensor triggers the PLC input to start the pneumatic actuator for placing the 3D part in the conveyor shown in figure 4.

Conveyor section with semi-rotary arm actuation

Conveyor has developed to transfer the product from one section to another section for every pulse frequency input from PLC to servo amplifier. The servomotor has run the conveyor PVC belt length of 1.5 meters and servomotor can be attached with two non-identical timing pulleys (Ratio of 1:2). The conveyor can move the product weight of nearly 500 ~ 700 gms.

![Figure 5: a. Conveyor with pneumatic arm, b. SCARA robot](image)
At the beginning of the conveyor, two semi-rotary arm actuation mechanisms are attached for the pick and place of product from one section to another. The arm can be actuated using 1800 rotary pneumatic actuator with controlled speed using flow control valve. The material can be grasped using suction cup and it will maintain the direction throughout the rotation shown in figure 5.

**SCARA Robot for assembly**

Conveyor transfers both the parts to assembly section. Photoelectric sensor detects the part that reaches the assembly section. Then PLC triggers the I/Os of four axis SCARA Robot that starts assemble the parts. SCARA I/O sends the signal to PLC input which indicates the completion of assembling process. Conveyor sends the assembled product to the inspection sections.

**Vision inspection system**

Once the product reached inspection section, the visions system ensure the correctness of shape and dimension as well as quality of the product using image processing techniques. If a product does not have any defect, it will go automatically to packing process. If a product has defect in it, then the vision system I/O will send the information about the defect product and registered in admin dashboard to improve product quality shown in figure 6.

---

3. **Methodology**

The methodology describes the flow of data or information tracked from the each section of the proposed system through Ethernet switch and updated in the cloud database by acquiring the data from the corresponding address specified in the Delta PLC shown in figure 7. The Client and admin Dashboard has been created using PHP and Database information retrieval and storage using MYSQL. The client should log-in to his account and place an order for required product. In addition to this, client dashboard has the provision for client to track the status of his ordered product. Admin can control the smart factory machineries through net from anywhere. Admin can also track the product flow, raw material usage, product status, and inspection data, and machine operation, factory conditions like temperature, delivery status, defect products and product quality with respect to time. These data's can be analysed to improve production rate, product quality and reduce the wastage of materials. This dashboard implementation helps the management to get real insights from shop floor, machineries and manufacturing process and also provides the production control through plant head. The utilization of resources and waste management is possible by the collecting and analysing the IoT data.
Figure 7: Conceptual flow of control algorithm
4. Result and discussion

The proposed system was designed and fully automated by the programmable logic controller which takes care of the control towards each system in the corresponding section shown in figure 8. It will track the flow of material in the conveyor by using the sensor. The vision data was captured and identified the faulty product and information is sent to the IoT dashboard and the user can diagnosis the fault and rectifies the system malfunction by analysing the previous process data of manufacturing system. The customer can order the product from the remote location and monitor their product build status and expected completion.

Figure 8: Smart factory layout for additive manufacturing system

The customer can pre-plan their work according to the timely information getting from the ISFAMS. The supervisor is eliminated by implementing the proposed idea in every manufacturing system. IoT dashboard has individually built for client and management. The data visualization was unique for the each dashboard based on their hierarchy level in industry and customer visualization is limited to the product status.

Figure 9: Admin and client IoT dashboard
The IoT admin dashboard shown figure 10 and 11 gives all the information about the production status like resource available, material wastage, number of product finished based on time history, faulty products and its reason, number of pending orders, products demands, priority of products. Based on this information, the management can be focused towards the planning of business to the market trends, customer needs, product demand and IoT interconnected industry for predicting market strategies. The IoT visualization helps the maintenance engineer to get updated for predictive maintenance schedule alert like replacement of oil, diagnosis of machineries, and calibration of 3D printing, optimal duration of operation and numbers.

Figure 10: Client visualization for ISFAMS

The priority is assigned for the newly order product based on analyzing the previous data of the same product variant on the basis of most maximum satisfactory condition to the benefits of concern with less span of time and material availability. The priority assigning algorithm will assign weight to each ordered product by comparing the past data with higher possibility of delivering product with short span of time. The sample set of ten products and its production data analyzed in the given table 1 and priority for each product was assigned in the table. This priority data has to utilized by our IoT application and create weight for newly ordered product.
| PR. ID. | Order in nos. | Delivered in nos. | Processing time in hours | Material availability | Due period in Days | Required number of products | Priority assign |
|---------|---------------|-------------------|--------------------------|----------------------|-------------------|-----------------------------|-----------------|
| PRD001. | 20            | 20                | 2                        | Less                 | 10                | 20                          | 9               |
| PRD002. | 40            | 20                | 3                        | Enough               | 15                | 25                          | 4               |
| PRD003. | 30            | 25                | 2                        | Enough               | 20                | 25                          | 3               |
| PRD004. | 25            | 25                | 3.5                      | Enough               | 21                | 30                          | 5               |
| PRD005. | 40            | 30                | 1.5                      | Enough               | 30                | 45                          | 2               |
| PRD006. | 20            | 20                | 1.2                      | Enough               | 10                | 50                          | 1               |
| PRD007. | 15            | 15                | 2.5                      | Enough               | 25                | 10                          | 7               |
| PRD008. | 40            | 20                | 3                        | Enough               | 20                | 20                          | 6               |
| PRD009. | 40            | 35                | 2                        | Less                 | 20                | 25                          | 8               |
| PRD010. | 35            | 35                | 5                        | Less                 | 10                | 30                          | 10              |

Table 1 Priority assignment for the ordered product

**Figure 11**: Admin visualization for ISFAMS
5. Conclusion

The ISFAMS creates novel layout for additive manufacturing system and its enables process and data visualization to the management and products status updates to the remote customer. The system proposes the idea of accessing the machine, process data from Data register in Delta PLC by specifying its address. The retrieved data is to be uploaded in cloud for monitoring and visualization and future analytics purpose to determine the product demand, market strategies, resource utilization, waste material management and predictive maintenance schedule monitoring and alert based on implementation of IIoT technologies. The data based been visualized in the both admin and client dashboard prepared using PhP and python integration. The current status and material flow as indicated in the admin dashboard with pictorial representation for the monitoring purpose of top level management. The future scope to the system is to implement and interconnecting of multiple IIoT industries to predict the market demand and enables integrated product manufacturing.

Acknowledgement

This research was supported by the Mechatronics Department that was provided Bannari Amman Institute of Technology, Erode and was recognized in the Delta Cup and Mitsubishi Electric Cup 2020.

References

[1] Kumar, A., 2018. Methods and materials for smart manufacturing: additive manufacturing, internet of things, flexible sensors and soft robotics. Manufacturing Letters, 15, pp.122-125.
[2] Zhong, R.Y., Xu, X. and Wang, L., 2017. IoT-enabled smart factory visibility and traceability using laser-scanners. Procedia Manufacturing, 10, pp.1-14.
[3] Haleem, A. and Javaid, M., 2019. Additive manufacturing applications in industry 4.0: a review. Journal of Industrial Integration and Management, 4(04), p.1930001.
[4] Wang, S., Wan, J., Li, D. and Zhang, C., 2016. Implementing smart factory of industrie 4.0: an outlook. International journal of distributed sensor networks, 12(1), p.3159805.
[5] Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M. and Yin, B., 2017. Smart factory of industry 4.0: Key technologies, application case, and challenges. IEEE Access, 6, pp.6505-6519.
[6] Bahrin, M.A.K., Othman, M.F., Azli, N.H.N. and Talib, M.F., 2016. Industry 4.0: A review on industrial automation and robotic. Jurnal Teknologi, 78(6-13).
[7] Dilberoglu, U.M., Gharehpapagh, B., Yaman, U. and Dolen, M., 2017. The role of additive manufacturing in the era of industry 4.0. Procedia Manufacturing, 11, pp.545-554.
[8] Kang, H.S., Do Noh, S., Son, J.Y., Kim, H., Park, J.H. and Lee, J.Y., 2018. The FaaS system using additive manufacturing for personalized production. Rapid Prototyping Journal.
[9] Mehrpouya, M., Dehghanhadikolaei, A., Fotovvati, B., Vosooghnia, A., Emamian, S.S. and Gisario, A., 2019. The potential of additive manufacturing in the smart factory industrial 4.0: A review. Applied Sciences, 9(18), p.3865.
[10] Rong, W., Vanan, G.T. and Phillips, M., 2016, September. The internet of things (IoT) and transformation of the smart factory. In 2016 International Electronics Symposium (IES) (pp. 399-402). IEEE.
[11] Mabkhot, M.M., Al-Ahmari, A.M., Salah, B. and Alkhalefah, H., 2018. Requirements of the smart factory system: a survey and perspective. Machines, 6(2), p.23.
[12] Chen, B., Wan, J., Celesti, A., Li, D., Abbas, H. and Zhang, Q., 2018. Edge computing in IoT-based manufacturing. IEEE Communications Magazine, 56(9), pp.103-109.
[13] Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H. and Do Noh, S., 2016. Smart manufacturing: Past research, present findings, and future directions. International journal of precision engineering and manufacturing-green technology, 3(1), pp.111-128.
[14] Osterrieder, P., Buddle, L. and Friedli, T., 2020. The smart factory as a key construct of industry 4.0: A systematic literature review. International Journal of Production Economics, 221, p.107476.
[15] Sivabalakrishnan, R., Dineshkumar, M., Sharon, P.B., Naveen Kumar, P. and Vignesh, S., 2019. Design and fabrication of 3D printed Acrylonitrile Butadiene Styrene (ABS) dam automation structure with integrated flood monitoring system using data analysis and computation techniques, Springer LNME (No. 2215). EasyChair.
[16] Yasodharan, R., Sivabalakrishnan, R. and Devendran, P., 2015. Trusted routing with an efficient
certificate revocation for mobile Ad Hoc Network. International Journal of Innovative Science, Engineering and Technology, ISSN, pp. 2348-7698.