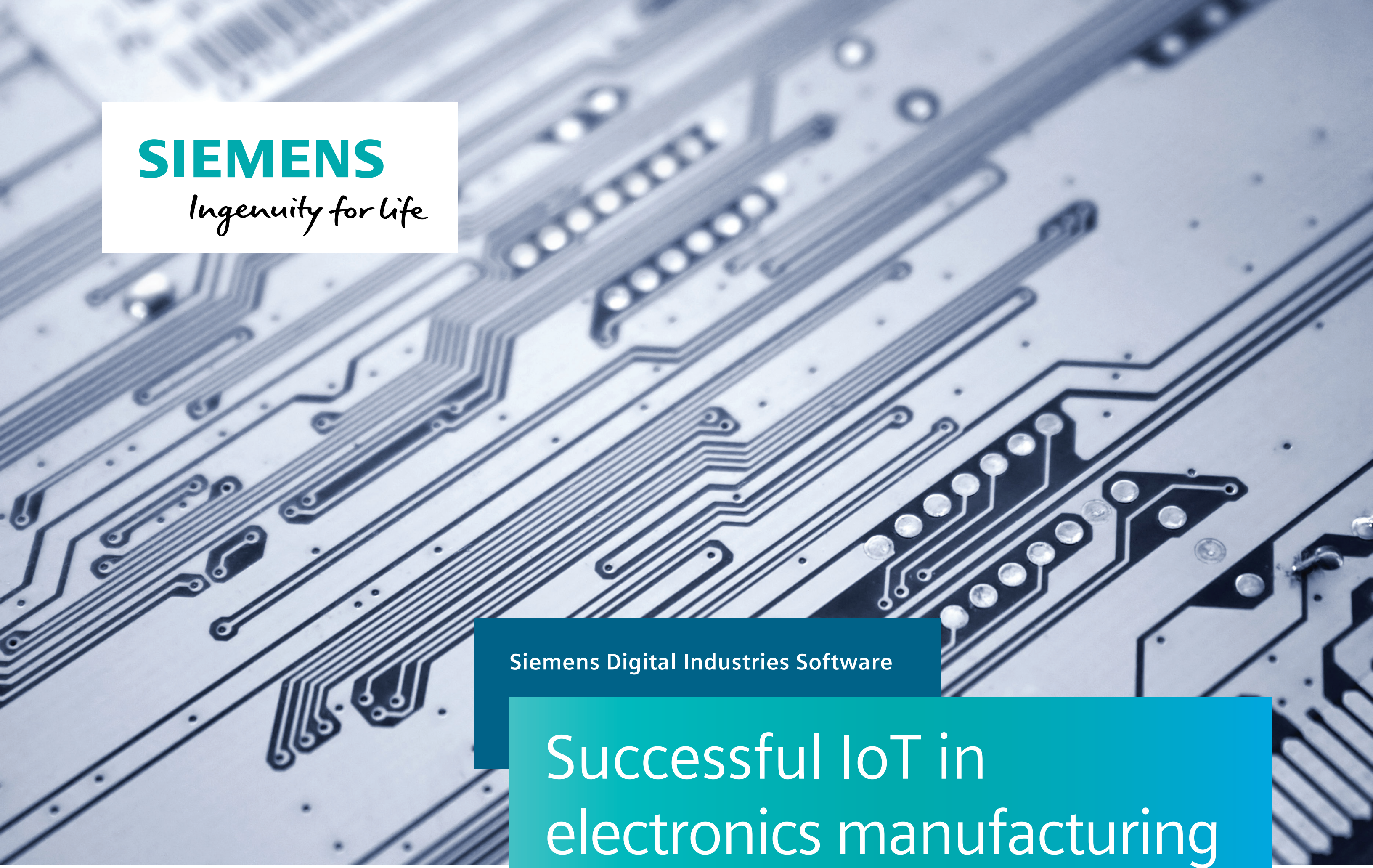

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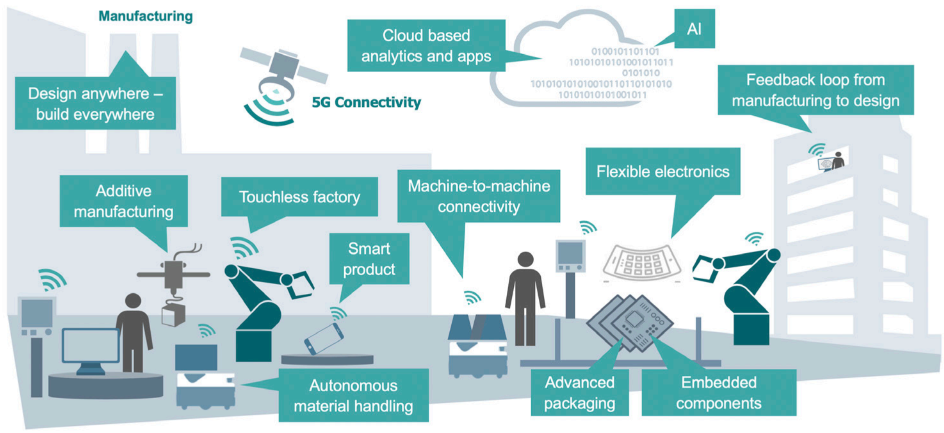
Successful IoT in electronics manufacturing

Executive summary

What has happened so far in the Internet of Things (IoT) for electronics manufacturing has been sparse and fragmented. IoT is meant to connect everything, not to create islands of automation. If practical mass adoption of IoT is going to happen as a realizable business model, the driving force must be that every entity throughout the entire factory benefits. The simultaneous connection of technology and business models is the way forward for the electronics manufacturing industry to experience a quiet yet powerful revolution towards Industry 4.0, with its real mandate.

This paper describes an example of Industry 4.0 – the Fraunhofer Future Packaging Line, introduced at the SMT Nuremberg show in 2017. The Fraunhofer display featured a concept of the world’s first open, multi-vendor, IoT-connected surface mount technology (SMT) line, demonstrating the technology and the mutually beneficial business model opportunities that arise from IoT connectivity.

The premise of Industry 4.0



At the highest level, the driver behind Industry 4.0 is the political agenda of the German government, which has led the practical innovation to support local manufacturing close to the market it serves, often called “reshoring” or “onshoring,” as opposed to the incumbent approach of high-volume, mass production in remote locations that offer minimum labor costs. This is essential to retain and even re-establish manufacturing jobs in local countries.

From a business stance, the remote mass-production business model is being weakened by the market trend of personalized products with the latest evolving technologies. This trend leads to many more variants of a product and a much shorter lifecycle, which is about one-quarter of what it once was.

The effect on business is extremely significant. For each product variant, additional stock must be kept, starting with raw materials through the entire supply and distribution chains until the final point of purchase. Because distribution chain costs are about half of the total retail price of a consumer product, the need to reduce the cost of stock is the most influential factor in the business plans of most products. In addition to the investment and logistics costs, the risk of depreciation as goods are transported can be a significant cost of the product’s lifecycle, which is the case for goods shipped from China using conventional methods.

An unexpected change in the market caused by a competitive product or technology can ruin the profitability of a product line. The costs saved by avoiding this scenario and building products locally with as direct shipping as possible to the customer, is financial advantage. The savings can surpass the increased manufacturing costs of local production, but only if manufacturing is done efficiently.

With as little stock as possible in the distribution chain, local factories must be extremely flexible to cope with almost daily variation in completion requirements.

Electronics manufacturing already is highly automated, but with individualized automations throughout the process. Humans orchestrate the operation, providing resource and material management as well as production planning and process modeling. With the transition to an ever-increasing mix, management by people has become a critical bottleneck to maintaining factory productivity at the same level as once enjoyed when producing in high volumes.

Computerization of these human management tasks as suggested by Industry 4.0 is a solution that enables carefully calculated and optimized digital modeling and simulation based on live and complete process information to replace the human decision-making, and it can be done in seconds and minutes rather than hours and days. Existing factory machines and employees, when connected together with Industry 4.0 computerizations, can perform flexibly, reliably, and with high productivity.

The connection of machines in a sense is done simply using an all-encompassing data exchange model. However, value needs to be obtained from the data. The complete digital modeling and execution of the factory cannot be done by any one solution. The final result is an environment where machines and site-based Industry 4.0 solutions coexist, where critical elements communicate and cooperate openly to operate the complete digital factory.

What, then, is the technology that can make this happen? It needs to provide the normalized data conduit between all parties, bringing each the data with which to develop and implement Industry 4.0 functions. The demonstration at the Fraunhofer Future Packaging Line was the first testament to this realization.

Fraunhofer Future Packaging Line IoT structure and concept

The Future Packaging Line combines the latest machine and process technologies from many key companies in the industry. The showcase line executed real production during the show, highlighting the advanced individual process capabilities from each of the machines and enabling visitors to see the technologies in an actual operational environment. The choice of the "best tool for the job" is an important differentiator in electronics manufacturing, as unlike most other manufacturing industries, there is a vast range of product types and classifications, from simple throwaway devices to safety- and mission-critical systems, throughout the many industrial sectors in which electronics now plays a key role. Throughout the production line, machines from many different vendors are going to work together, each providing their unique capabilities and services.

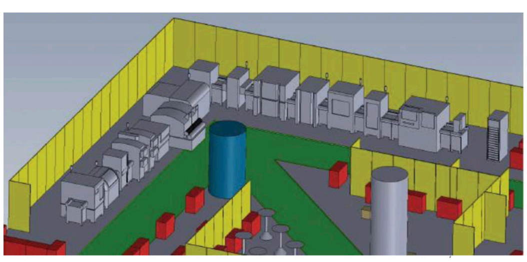
Previously, all of these machines and systems could not be connected successfully to provide visibility of what is happening second-by-second on the line as a whole. Industrial engineering, product flow, material supply and quality management have all been performed mostly by manual methods. With the introduction of ODB++Manufacturing, Mentor, a Siemens business, provided each machine vendor the capability to connect the machines together using the latest IoT technology.

Each machine in the Fraunhofer line used a Valor® IoT Manufacturing hardware networking interface in which is embedded an interface to the machine, providing the capability to exchange information about the machine operation. Ethernet cables connect all of the machines, which in turn are connected to a gateway through which any external system or application can access the data in real time.

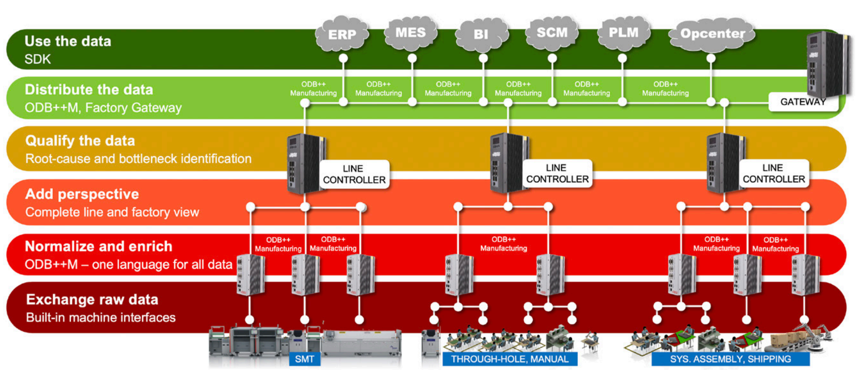
In the case of the Fraunhofer Future Packaging Line, the live data was displayed on a series of screens above the machines and was available on mobile devices. At the Mentor showcase area, the data was also displayed as a live operational dashboard, together with a demonstration of real-word Industry 4.0 site-level solutions.

An essential part of the IoT structure is that data does not only flow in one direction from the shop floor up: IoT data flow is omnidirectional. Individual machines can take data from other processes in the line, or from site-based resources that may include such data as live production status and flow, work-order sequence, product and process setup data, material and logistics data, quality information or any other form of interprocess communication. As owners of the individual technologies in the line, each machine vendor is in the best position to create and provide Industry 4.0 solutions that are related to that technology.

Barriers no longer exist and no longer does each combination of machines mean a different customization in several places on the line. The machine vendor's solutions coexist with each other in the line, each supporting the others. In turn, site-based systems provide complementary functions, providing data down to the machine level that describe site-based operations such as product data, planning, and materials, as well as monitoring the live data from the machines and results or requests from the machine Industry 4.0 functions. It is a synergistic environment in which many companies can work together to provide complementary, niche solutions, promoting opportunity and positive competition, which means greater choice for customers.



3D digital representation of the Fraunhofer Future Packaging Line.



Typical configuration of Opcenter Execution Electronics IoT (Valor IoT Manufacturing) in a factory.

Overview of ODB++Manufacturing data exchange

Using the ODB++ Manufacturing data exchange format, the data transferred through the IoT network is normalized. This means that the data coming out of the machines in the line is defined in a single standard way. Often, even machines of similar types or with similar elements in their functionality call similar events by different names. Machines from different companies will typically provide different communication interfaces for the same information. An example is with the failure of an SMT machine to pick up a component ready for placement. Differences such as a "pickup error," "pick-error," "vacuum error" or "recognition error" can mean the same thing, and they are defined within ODB++Manufacturing as the same event, independent of machine type. Care must be taken because the message implies a material loss; however, some machines will repeat a pick-up attempt so only the first message is significant for material spoilage and failure events. The other messages cannot be ignored for performance monitoring. The definition of the normalized messaging within ODB++Manufacturing is clear and precise so that events are described accurately. This normalization of data content means that any machine can be connected to any other machine without either of the machines knowing anything about the native language, content or nuance of any data messages. The following are some examples of the data content that flows through IoT using ODB++ Manufacturing.

Equipment configuration

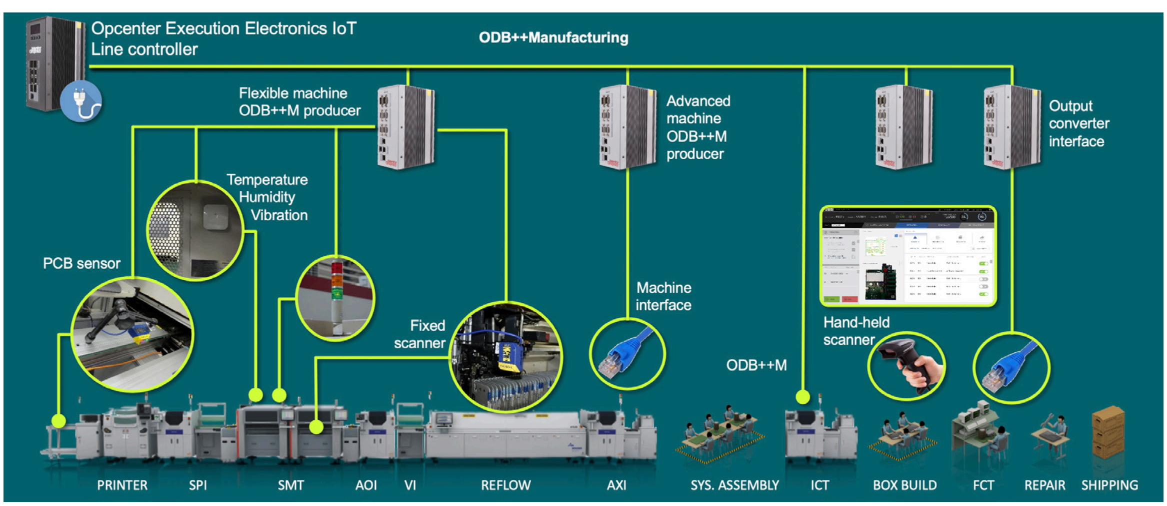
Determine the configuration of equipment type processes. In many smart Industry 4.0 applications, it is important to know the capability and limitations of machines that are part of the IoT network. For example, solutions designed to report automated optical inspection (AOI) machine results need to understand which of the machines in the factory are actually AOI machines or have an AOI function.

Equipment status

An event is sent each time the equipment changes status. On equipment with multiple modules, some events will include the different module IDs. Equipment capable of multiple lanes will include the different lane IDs. A single production machine is complex with many simultaneous events. For example, when calculating key performance indicators (KPIs), many factors need to be accounted for, such as the sharing for feeders between two printed circuit board (PCB) lanes, which slows production of each PCB but does not necessarily imply lost time.

Item data

Data is captured for each the item (for example, a PCB) as it moves through the equipment. The item might be produced in a number of different phases. The data includes identification of each item and when the



equipment starts and stops working on the item. After an item is fully processed by the equipment, data is provided such as consumption data and cycle times. This data allows items to be individually tracked as they move through the equipment. These events are also sent in a pass-through mode when equipment or modules are not assigned any work. This data allows understanding the state of buffering within the machine and calculation of the true cycle time.

Recipe data
A recipe (also known as a program) can be set to active, meaning the equipment will now use the recipe for the next production of an item (for example, a PCB). Recipe data can also be prepared and made available offline (not active at the equipment). This can support the automated changeover of products based on the read of the barcode of the next unit coming into the machine for production.

Intelligent feeders
Intelligent feeders have internal memory that is programmed with a unique ID for each feeder. The equipment knows when each intelligent feeder is inserted or removed via an electrical contact. This can save significant production downtime. For example, manual effort when setting up the machine at changeover can be replaced by associating the material ID when loading material to a smart feeder in an off-line environment.

Equipment control
Equipment can be commanded remotely to perform specific actions, for example, equipment to be stopped, started, or put into a wait state. This can be useful as part of active quality management, where, in the event of a serious defect being detected, the line can automatically and safely stop production until it is confirmed that the cause of the defect has been eliminated.

Component handling
During the handling of components from the supply to the placement, the equipment can detect errors and events such as splicing points. This can be essential for systems where a digital traceability or build record is needed with a high degree of accuracy (for example, for compliance with IPC-1782 Level 4).

Manufacturing execution system (MES) material integration
ODB++Manufacturing provides MES-level integration with a verification or material system that runs at the equipment. These messages are used to make the integration benefit the MES system and the machine. The state of material logistics and details of materials intended for use at any production position allows the machine that will consume the material to plan in advance, for example, to adjust shape parameters slightly in the event that the incoming material is from a different vendor.

Item traceability data
In many cases, equipment can produce a traceability report for each item processed that includes the result of the processes, such as pass or fail, as well as test data, inspection data, fault codes, digital test, repair ticket and process parameters that are applicable to the process.

Identification
Reliable identification of products, materials, tools, equipment and other resources in the factory can be done by scanning barcode labels, radio frequency identification (RFID) tags or other markings. Control is possible to decide if items may enter a process at the shop floor. For example, a PCB may not be permitted to enter equipment because the barcode is not read correctly or it is not permitted for the correct route.

General
General messages provide support for areas such as sharing the deployed vendor interface version, configuration, system and machine health checking, debugging, etc.

Quality management
Data is collected from test and inspection equipment, as well as from manual repair stations.

Environment
Data is captured from sensors relaying the current environment, such as temperature, humidity and light levels.

Typical areas of IoT data utilization

Each vendor participating in the Fraunhofer Future Packaging Line brings a different and unique expertise. Many of these vendors provide machines of different types and with different technologies, so the use of IoT can extend beyond what may be relevant for the specific machines in the line demonstration. The companies that participated in the Fraunhofer Future Packaging Line explain some of the capabilities and solutions they bring to their customers for implementing a digital factory.

ASM Assembly Systems

The highly flexible smart SMT factory of the future will turn process-oriented integration of separate line components into a difference-making efficiency lever. As the supplier of DEK printers, revolutionary solder paste management systems such as ASM ProcessExpert, and SIPLACE placement machines, ASM took up this integration task early on. With OIB (Open Information Broker), ASM, DEK, and SIPLACE solutions today have available a modern, open and standardized interface.

OIB does not just allow access to data on the status of the machines. But the interface makes a bidirectional data exchange, event-driven communication, and external process control possible. Instead of giving out masses of disconnected raw data, via OIB, machine data can be edited at the station in a meaningful and process-oriented fashion before export. How this functionality can be used in a smart factory is shown by the example of ASM Line Monitor.

This system does not simply visualize the line's status, but also determines the next operator tasks and prioritizes them. For example, when a feeder track runs empty, the warning message is no longer delivered from the fill-level sensor as an isolated, dumb, minimum fill-level message. Instead, the system combines data about the fill-level control, placement performance of the machine, needed components according to the recipe of the PCBs produced on the line, and the remaining number of products to be completed for the order. The operator learns in advance which feeder track splicing is needed or if the small left-over amount would be insufficient to complete the job.

Isolated raw data can be aggregated to information in real time where it is created and needed in the process. This local intelligence and process-oriented integration is where ASM sees an advantage compared to pure big data concepts, which are based on data transfer and central handling. OIB allows electronics manufacturers to realize the integration of their production based on their processes or from the bottom up. At the same time, it is equally possible to export data from the machines – as raw data or already aggregated in KPIs – for process control, monitoring and traceability applications, as well as for sending it to superordinate IT systems or other machines for further analysis. Operators can access all ASM, DEK, and SIPLACE solutions using the OIB interface. The interface can be used for different ASM solutions once it has been set up. This makes the integration easier and lowers cost. For a number of applications, because of the internal mapping in OIB, an additional IoT box is unnecessary.

ATEcare Service

ATEcare provides a broad range of test and inspection systems, solutions and combinations of these, based on customer and product needs. All of these systems provide many test and measurement results in several forms and could be used for:

- Enterprise resource planning (ERP) system inputs and adaptations for production orders
- 2D and 3D measurements in process (solder paste inspection - SPI, AOI and automated X-ray inspection - AXI)
- Electrical measurement results based on in-circuit and function test (ICT/FCT), flying probe, and end-of-line (EOL) test

- Process control including closed-loop and feed-forward steps (in-line and offline)
- Interactions between handling, robots and human interfaces (in-line and offline)
- Visualization of system results (statistics, process-relevant events, line stops, etc.)
- Interaction with other vendor processes and inspection systems
- Visualization for verification and repair processes
- Database outputs and access
- Long-time data and picture archiving
- Information to MES, quality and traceability systems

Brady

Smart manufacturing machines and systems generate, analyze and use data to optimize production efficiency, create flexible manufacturing processes and respond quickly and at low cost to changes in demand. A true Industry 4.0 smart factory employs only systems that are interconnected and able to send or receive data from other systems in the supply chain.

With durable product labels that remain legible throughout entire production cycles, applied by accurate, automated print and apply systems, Brady can connect every circuit board in production to the smart factory. Every circuit board becomes a data generator to send information to the MES, to other machines and production cycles, or to the supply chain up- and downstream.

Quick, precise, and consistent solutions are needed for the identification of components for traceability purposes. The best results are delivered by the combination of easy-to-use, high-end applicators with label materials specifically developed for automatic processing.

Material quality accounts for almost 80 percent of reliability during the automatic application of labels. The Brady R&D department has developed purpose-built, polyimide materials for automated labeling of PC boards, components and products.

Other challenges to reach maximum productivity are label print quality and scanner readability. Brady offers specialized UltraTemp™ labels, developed specifically for the electronics industry, to meet these challenges. UltraTemp is available both as on-site printable and preprinted labels.

Brady offers a series of different printing systems for manual labeling. Flexible and compact label feeders support fast and precise application of already-printed UltraTemp labels. The system fits every common pick-and-apply machine and is easy to use.

Brady's automatic print and labeling innovation is the BSP™61 Print and Apply System with a small footprint and exceptionally easy production line integration. BSP61 is capable of putting a lot of information onto a tiny label and placing it with extreme accuracy.

Fuji Europe Corporation

Fuji is an established global leader of intelligent, digitally networked systems that manage and execute self-organized production as far as is possible. Using the smart service Fuji app, customers are able to enjoy the following:

- Provide the required information anywhere, whenever needed
- Monitor status with a terminal
- Enhanced analysis and support service
- Strong data-security system

Fuji is also one of the original members at Smart Electronic Factory e.V. (SEF), founded in 2014. A key objective of the SEF is to create, test, and validate solutions of Industry 4.0 in a real production environment.

Since April 2016, Fuji is also an official member of the PULSE Community, providing real-time data using a smart watch:

- Error/warning messages delivered in real time
- Eliminate avoidable standstill of machines and increase equipment productivity through clear real-time messaging
- Keep track of the entire production process and display all machines at the same time

- Integration of independent machine manufacturers and systems
- Reduce reaction and waiting times, plan tasks optimally
- Reduce energy consumption

Fuji has proven commitment to the latest IoT and Industry 4.0 solutions and is proud to have been part of the Fraunhofer Future Packaging Line, featuring IoT connected manufacturing.

IBL Tech

Using the Opcenter Execution Electronics IoT (Valor IoT Manufacturing) hardware and providing ODB++Manufacturing data, IBL systems can be easily integrated in the latest Industry 4.0 environment. Customer-specified interfaces and integration to MESs are already realized by the IBL engineering team. All IBL premium machines can be connected to the company network and work from one database without the need for any additional devices. This provides the following advantages:

- Traceability of every cycle with process, recipe, and product data
- Errors, messages, and events in real time
- Tracking of the entire production process through a barcode function
- Unlimited recipe storage

IPTE Factory Automation

All IPTE equipment comes with a common TS1 touchscreen human-machine interface (HMI) and creates process and product information with a link to MES for manufacturing control. Using MES allows IPTE systems to base the execution of the manufacturing on the upstream (previous) results, while adding product information that can be used for downstream processes. This information is made available using the Computer-Aided Manufacturing using XML (CAMX) interface, which is then converted into ODB++Manufacturing.

The test lines are controlled and monitored using the Cell Process Controller software and offers various Pareto charts for product information as well as process information. Even the repair process can be assisted using the Guided Repair System software that uses its own tester-independent database to store test results.

IPTE uses a 3D modeling software package that is used to simulate dynamics behavior of manufacturing lines and results in a virtual image of the manufacturing line.

LPKF Laser & Electronics

The MicroLine 2000 Ci laser depaneling system seamlessly integrates into existing MES systems. The laser system accepts process instruction data, and in turn delivers data representing the values for the actual cutting process. The integrated LPKF traceability tool supplies operative parameters, machine data, tracking and tracing values as well as information about individual production runs. Via the ODB++Manufacturing interface and the IoT infrastructure provided by the production line, machine-to-machine communication and bidirectional machine-to-MES communication is easily implemented.

The MicroLine 2000 laser system is capable of reading and writing data matrix codes or barcodes on the PCB – a valuable feature for complete end-to-end tracking and tracing solutions. The laser process is completely software controlled. Varying materials or cutting contours are easily considered through adapting the processing parameters and laser paths.

In the case of laser cutting with the UV laser, no appreciable mechanical or thermal stresses occur. Even sensitive substrates can be precisely processed. The laser beam merely requires a few micrometers as a cutting channel. The heat-affected zone is already negligible, just a few micrometers away from the cutting channel edge. More components can thus be placed on a panel. Using specialized LPKF laser sources, the depaneling system effectively performs tab cuts or full-section contour cuts in 1.6mm FR4 material. Even cuts below components are possible. All of these features and values are reflected through the IoT data connection.

Mentor, a Siemens business

Real-time data from machines and processes is critical for the control and management of the factory shop floor. The advantage of using ODB++Manufacturing is that the data is already normalized. Only one interface is required no matter where the information may have originated, whether from a machine, manual process or other transaction. This also means that any new machines added into the factory will be "plug and play," supporting ODB++Manufacturing natively or through the Opcenter Execution Electronics IoT box. This not only eliminates the cost of development of machine interfaces, but also eliminates the lead time required to develop the interfaces, which can be a challenge when customers want quick, painless and reliable system implementation.

Data in the past was mainly intended for humans to use, in the form of reporting, dashboards and alerts; humans would consider the data, make phone calls and have meetings before coming to decisions about taking action to remedy a problem or take the opportunity to make an improvement. Because of the high reliability and integrity of ODB++Manufacturing data, Valor computerizations can make decisions without the need for human confirmation at every stage. This means that actions to address any issues or opportunities can be made immediately, before significant losses are incurred. Examples are to recommend re-planning of production where production flow bottlenecks have been detected, either on a machine or line level, or whenever it is found that greater-than-expected planning losses will occur. Lean material logistic management can be automated through the generation of pull signals to bring materials to the lines and machines as needed, avoiding the need for wasteful, multiple kit preparation. Traceability of all process and materials data can be collected to provide the full digital twin of products that are being made.

In addition to the consumption of data from the machines and processes on the shop floor, the infrastructure that the Valor software provides can also be of significant value to the machines and processes. This includes information about the sequence of work orders assigned to the line and specific engineering information required for setting up machines and processes on the line. The flow of production can also be managed through the control and communication of such aspects as changeover management, bad marks and quality and test/inspection measurement data. Specific information about materials can also be provided, such as the vendor and exact dimensions, orientation, and supply format for SMT placement machines so that they can automatically adjust where there are variations in the shape of a part number across different vendors or where substitute parts are used.

While the Opcenter Execution Electronics IoT (Valor IoT Manufacturing) hardware with ODB++Manufacturing data can provide the infrastructure and bridge between shop-floor processes and enterprise systems such as ERP and MES, the Valor® Material Management software can provide a significant increase in value through the provision of advanced Industry 4.0 features in the intermediate layer. These include dynamic finite production planning, lean supply-chain material management, active quality management tools and business intelligence.

Conclusion

The 2017 SMT Nuremberg Fraunhofer Future Packaging Line has demonstrated the first, open, real-world digital IoT solution for electronics SMT and assembly production. The demonstration had many layers, starting with the IoT technology. The use of ODB++Manufacturing and the Opcenter Execution Electronics IoT hardware has provided a standard IoT platform and infrastructure through which information between all processes and systems can be shared in a way that is vendor-independent. Visibility of the data using dashboards shows the wide scope of information that can be included. Each machine vendor in the line now has access to all of the data throughout the line and factory, and in their own way contribute the data as a whole from their process.

The business case for this support is clear for the machine vendors. ODB++Manufacturing can potentially replace all other custom interfaces, saving time, money and resources. Customers have machines from many vendors in their factories and the same business case applies because support for many interfaces created vendor-by-vendor can be consolidated into one ODB++Manufacturing interface. As well as cost savings, machine vendors can create smart process improvement and Industry 4.0 solutions of their own, specific to their machine technology, while offering customers additional value through add-on options to the machines. Machine vendors in the line can coexist in a complementary way without artificially competitive elements that restricted certain companies or machines from working together in the best way. Customers are free to choose the best tool for the job, bringing affordable variation to drive flexibility.

At the site level, solutions such as Valor software can establish an effective and reliable single interface flow to every machine on the shop floor, taking live data with which to provide computerized Industry 4.0 functions such as finite production planning, lean supply-chain material management and active quality management. In return, information about production progress, changing delivery-demand requirements that drive changes in the plan day-by-day, can be effectively and immediately communicated to machines so that the local machine software can prepare for optimized changeover cycles. Communication with enterprise systems (ERP, MOM, PLM) is enhanced, providing live feedback of material consumption, production progress and a complete digital product build record for each product made.

Over time as more machines vendors adopt the ODB++Manufacturing communication capability, either natively or through the Opcenter Execution Electronics IoT hardware, the entire IoT experience becomes easier. Existing machines and processes, and even those that do not sign up for ODB++Manufacturing support, can be included through the use of the flexible interfacing provided by the Opcenter Execution Electronics IoT hardware. This can also be used and integrated into custom-bespoke processes such as functional test, using the software development kit (SDK) provided with each interface unit.

The complexity of the electronics industry has meant that the adoption of Industry 4.0 has been a challenge. Because electronics are an increasing part of products across a broad range of industries, an inability keep up with business needs and national initiatives would have been a serious issue on a vast scale. This Fraunhofer Future Packaging Line IoT demonstration was a first step, an initial proof of concept that can be expanded and accelerated to meet the challenge.

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