Applying cyber physical system architecture concept to the design and manufacturing of blood glucose monitoring systems to provide man-machine interactions and intelligent automation

H Y Kuo, H Chang*, Y H Cheng, J S Shaw and R Lee

Graduate Institute of Manufacturing Technology, National Taipei University of Technology, No. 1, Sec. 3, Zhongxiao E. Rd., Da’an Dist., Taipei City, 10608, Taiwan
*Email: f10381@ntut.edu.tw

Abstract. The current design and manufacturing of blood glucose monitoring systems (BGMS) cannot resolve many current problems. Even with recent new advances on 100% non-damaging quality check and laser repair for the defective test strips found, it is still not enough. With the new internet, a new revolutionary architectural concept based on cyber physical system (CPS) is highly recommended to implement on the design and manufacturing of BGMS. This paper presents many unique benefits that can be achieved. The implementation of CPS to the design of BGMS interconnects the uses of glucose meters, test strips and control solutions with the manufacturing systems through internet to enhance the safety and performance of the BGMS, and to provide man-machine interactions and intelligent automation. Furthermore, the implementation of CPS to the manufacturing of BGMS further interconnects sensors and information feedbacks from different work stations to allow the manufacturing systems to be self-aware, self-adaptable and self-configurable, in order to reduce manpower, defective rate and production down time for better productivity. This new concept will bring in revolutionary approaches into the design and manufacturing of BGMS, in order to upgrade product performance, increase product competitiveness and create new business opportunities, by providing man-machine interactions and intelligent automation. Apart from that, the implementation of CPS architecture to the design and manufacturing of BGMS does not necessarily increase the costs of producing BGMS.

1. Current problems of BGMS

Electrochemical test strips [1] have used conductive electrodes to measure the electrical response from the electrochemical reaction to measure the concentration of the species in the blood analytes for than 40 years. Most of the blood glucose tests measured the electrical current, generated from the working and reference electrodes in the reaction zone in which enzyme solution is present to react with blood glucose under applied electric potential. This electrical current is proportional to the glucose level. For the analytes of same glucose level, only very close glucose readings can be obtained if there is no significant difference in electrical resistance of electrodes between different test strips. However, there is normally significant variance in electrical resistance of electrodes between different test strips with carbon electrodes. Therefore, it is difficult to be consistent in glucose measurement between the test strips. The most popular materials used for electrodes on the test strips now are carbon/silver or carbon, which are mostly made by screen printing process and are notorious for the inconsistency in electrical resistance between different test strips on the same panel, different panel and different lots. From the
practical points of view, it has been very difficult to produce test strips with electrodes of consistent
electrical resistance between test strips from screen printing process with carbon or silver pastes mixed
with solvent. As a result, carbon test strips may have different codes on every vial of test strips produced
to justify for the difference in electrical resistance of electrodes between test strips. The process of
coding the test strips is very time consuming, labor intensive, and tedious [2,3]. Moreover, many test
strips produced were discarded because they were out of the range of codes. Recently, to resolve the
inconsistence in the electrical resistance of electrodes between different test strips in carbon/silver or
carbon test strips, more and more glucose test strips are made of palladium or gold electrodes [4,5]
which are more consistent in the electrical resistance of electrodes between different test strips and have
been found to be more accurate in glucose measurement. However, gold test strips are normally made
of vacuum deposition or chemical etching, which is quite expensive, making it difficult to replace
carbon/silver test strips on costs. Apart from that, it is inevitable to have scratches on the gold electrodes
during the manufacturing process. Scratched test strips must be determined, justified or removed [6].
Apart from the above mentioned issues, the currently available BGMS also have the following major
inherent problems that need to be resolved:

- The current status and conditions of every individual glucose meter in use can hardly be monitored,
even if they have degraded or become defective. For example, the contact pins of the glucose meter
can fail to give correct reading due to metal fatigue after repeated use, or after repeated wear of the
gold coating. Furthermore, a glucose meter can fail to perform well with an electronic problem due
to the failure of electronic components. Altogether, in case if there is any meter failure for any reason,
the manufacturers now have no way to find out in order to stop use, trace the source of failure, and
to warn or recall the other glucose meters using the same lot of the same defective parts in the glucose
meters.

- The current status and conditions of the control solution test results can hardly be monitored and
justified. Advices were given in the user manuals of BGMS to perform control solution test prior to
blood glucose test, in order to determine if the glucose meter and test strips are working properly.
Failure to test with control solution before performing blood glucose test can be potentially risky, as
either the glucose meter or test strip can be defective. Even if control solution tests are performed,
the control solution results rely on the users to determine if the test results are within the range printed
on the label of the test strip vials. If there is anything wrong with the control solution for any reason,
neither the user nor the manufacturers have any way to find out in order to stop use, trace the source
of failure, and to warn or recall the other control solutions of the same lot.

- If the test strips have passed the expiration date, the test results obtained from test strips can be
misleading to endanger the life of the diabetes. It all depends on the users themselves to check the
expiration date. Right now, there is no mechanism available yet to automatically alert the users by
itself.

- If the test strips have passed the, say, 3 months expiration date after first opening, or, if the desiccant
in the test strip vial fails to perform properly to remove moisture present in the test strip vial, the test
strips will possibly be degraded. The current design methodology has no way to determine
the condition and validity of the test strips in the test strip vial.

- The precision and accuracy of the test strips partly depend upon how accurate the amount of enzyme
can be dispensed onto the reaction zone of the test strips. The accuracy of enzyme dispensing further
depend upon the volume or height [7] of the enzyme solution within the barrel containing enzyme
solution, the applied air pressure [8] inside the enzyme containing barrel, the speed the enzyme
solution drop is ejected out of the dispensing nozzle, the distance [9] between the dispensing nozzle
and test strip panels, etc. Normally, in order to ensure constant enzyme dispensing volume between
test strips, it is normally required to stop dispensing process every 3000 or 5000 enzyme drops to
confirm the dispensing volume and make necessary adjustment if needed. Such processes reduce the
efficiency of enzyme dispensing. For example, there is a manufacturer which has dispensing
machines that have to stop 2.6 hours for every 8 hours of work.

- For both carbon/silver test strips and gold test strips, it’s always difficult to produce test strips having
the same electrochemical characteristics on the same panel or from different production lot of test
strip panels. Test strips of different electrochemical characteristics normally will yield significantly different glucose readings. As a general practice, we must separate the test strips into a few different groups and assign them different codes for the glucose meter to use different software to produce the same glucose readings. The number of codes needed is different for different manufacturer, normally having 7 to 26 codes. Although there are some manufactures claiming that they have only one code or no coding, however, it’s just either that they put together test strips of the same code and sell to the same country using the same code or marking the test strips for the glucose meters to recognize the code of the test strips. In such quality assurance process, to determine and sort out the codes of test strips among different lots of test strip panels is tedious, labor intensive and, yet, damaging. In practice, although the average percentage of test strips needed to code test strips is between 4 % and 8 %, however, in general, 23% to 28% of the test strips produced are either tested and removed because they are out of the range of codes.

- Right after enzyme dispensing, the drying process with a continuous oven is an important part of the test strip production process. However, every parameter associated with this drying process are critical and have to be well controlled and monitored, not only with in-process control, but also with many outside process control parameters before and after the oven drying process. Poor control of the parameters for the drying process before, at, and after the drying process can lead to significantly non-uniform distribution of potassium ferricyanide crystals across the reaction zone which is situated over the working electrode, reference electrode, or counter electrode. Such non-uniform distribution of potassium ferricyanide crystals will give very poor electrochemical performance and hence poor precision and accuracy [10,11]. Moreover, depending upon the moisture content present in the drying room which houses the continuous oven, the potassium ferricyanide crystals may encapsulate moisture which will take weeks or even months of aging time to be released from the potassium ferricyanide crystals. The need to take weeks or months of aging process bothers many manufacturers. Therefore, there is an urgent need for a new drying process with which the potassium ferricyanide crystals may contain the least amount of moisture.

2. Recent advances of BGMS

Figure 1 shows one of the recently most critical advances in manufacturing technology for test strips [12]. In Figure 1, there are two processes of manufacturing test strips, which are applicable to both carbon/silver test strips and gold test strips. One of the processes is shown on the left side of the process. The test strips panels first go through the enzyme dispensing process. Immediate after dispensing the enzyme solution, the test strips panel moves to a 100% non-damaging machine for quality check. This new process is very different from the current process of quality assurance, which performed quality assurance tests randomly on about 4% to 8% of the test strips produced with blood or control solution only after the enzyme solution is dried. This current process of quality tests is disadvantageous, as the test strips after tests can longer be used for further tests. Moreover, random check on the test strips produced cannot find out and remove the test strips hidden in the test strips. If, after quality tests, defective test strips are found, the same whole lot of test strips will be discarded, even if there are still good strips present inside the same lot. Apart from that, for some reasons associated with formulation or process non-conformity, if the test strips produced were found to be defective, a lot of test strips already produced will be discarded. This will not happen to the new process [12], which performed in time 100% non-damaging quality check on every test strips. After the 100% non-damaging quality check, the test strips are still good for further sale. Any hidden, abnormal test strips will be identified and trimmed with laser after oven drying. Most of the abnormal test strips can be repaired to become normal test strips for further tests after laser trimming. Very few of the test strips will be marked with laser and discarded if they have serious problem beyond repair with laser. There are two ways to do laser trimming on test strips [12]. The first method to do laser trimming is to trim the width of the conductor tracks to raise the electrical resistance to the level same as the other test strips. The second method to do laser trimming is to trim the big contact pad, which links to the reference electrode, to create some designated electrical resistance between two contact pins, in contact with the big contact pad, on the glucose meter. By recognizing the designated electrical resistance on the big contact pad, the glucose meter can then select the right software to produce proper test results. The second process of manufacturing test strips,
as shown in Figure 1, is on the right side process. The right side process combines 100% non-damaging quality check which applies only when the 100% non-damaging quality check process has found no test strip for laser trimming to repair. The process shown in Figure 1 in general can reduce the discarded test strips going through the quality check from 23%~28% to about 2% to 4%. Apart from that, the process shown in Figure 1 in general can also reduce the manpower required to perform quality assurance tests tremendously. The process shown in Figure 1 in general cannot be accomplished without the following the procedure shown in Figure 2, which is another new recent advanced technology [12]. The process shown in Figure 2 used a dispensing machine with three dispensers which dispensed a fixed amount of enzyme solution on every test strips on the test strip panel. The test strip panel has 25 o 50 test strips in the middle, and one test strip on the left hand side and one test strips on the right hand side respectively. The first dispenser dispenses enzyme solution A, which is a mixture of the enzyme solution for regular test strips with the low control solution, having control solution between 20~70 mg/dL (low glucose level). The second dispenser dispenses enzyme solution C, which is a combination of the enzyme solution for regular test strips with the high control solution, having control solution between 500~600 mg/dL (high glucose level). The third dispenser dispenses enzyme solution B, which is the enzyme solution for regular test strips. After the first dispenser dispenses enzyme solution A onto the left test strip, a fixed electric potential of 0.4V is applied to the test strip for about 4 to 7 seconds to measure its glucose reading of low glucose level. After the second dispenser dispenses enzyme solution C onto the right test strip, a fixed electric potential of 0.4V is applied to the test strip for about 4 to 7 seconds to measure its glucose reading of high glucose level. The glucose readings of low glucose level and high glucose level help to define the codes of this test strip panel. Furthermore, the third dispenser dispenses enzyme solution B onto the 25 or 50 test strips in the middle. Immediately after the enzyme solution B is dispensed onto the 25 or 50 test strips, every test strip is measured at 0.002 to 0.1 second from the second scan cycle at a scan rate of 4 second per cycle by Chronoamperometry (CA) for its electrical resistance from working electrode to reference electrode. Any test strip having significant difference in electrical resistance from the other test strips will be identified and trimmed with laser so that it will produce the similar glucose reading as the other test strips, instead of removing it from the rest of the test strip.

There are more and more manufacturers nowadays to compete for market share at the price of product quality which could possibly endanger the health of diabetes. Considering the latest changes in market development, it’s therefore important to reduce production cost, reduce manpower, and increase product yield rate, by improving the design and manufacturing process of BGMS. Furthermore, there have been numerous failed or undergoing attempts to develop noninvasive measurement of blood glucose [1]. However, at this time, frequent testing using invasive blood glucose determination via finger stick still provides the best information for diabetes management. As a matter of fact, apart from measuring glucose from blood, most noninvasive measurement measured glucose from body fluid which reflects glucose readings with many minutes of lag behind blood glucose measurement. This can be life...
threatening, particularly for low glucose diabetes that requires immediate medical attention and every second counts. It’s very likely that for many years to come, noninvasive measurement surely can’t replace fingertip blood glucose measurements.

### 3. Future trends of the design and manufacturing of blood glucose monitoring systems

#### 3.1. Introduction to CPS concept

CPS is defined as transformative technologies to manage interconnected systems between the physical assets and computational capabilities [1]. With the recent advent of more available and affordable sensors, data acquisition systems and computation networks, the competitive nature of today’s glucose monitoring industry will drive more manufacturers toward the implementation of more high-tech methodologies. Therefore, the increasing use of sensors and networked machines have generated high volume data, known as Big Data [14,15]. CPS can thus be further exploited to better manage Big Data and the interconnectivity of machines to become intelligent, resilient and self-aware machines. Moreover, incorporating CPS with production, logistics, and services in the current business practices will certainly upgrade today’s factory to an Industry 4.0 factory with significant economic potential [16,17]. Report from the Fraunhofer and the industry association said that the gross value of German can be raised by a cumulative 267 billion euros after introducing Industry 4.0 [18]. Lee [19] proposed a CPS 5C architecture as the guideline for the application of CPS in manufacturing systems, saying that the CPS 5C architecture should consist of Smart Connection Level, Data to Information Conversion Level, Cyber Level, Cognition Level and Configuration Level, as shown in Figure 3. which is a step by step guideline for the development and deployment of CPS for the manufacturing systems. The proposed CPS 5C architecture defined from how to construct a CPS from the initial data acquisition, to analytics, and to the final value creation, through a workflow manner. Recently, CPS has been studied and applied to areas like transportation, smart home, robotic surgery, aviation defense, critical infrastructure, etc. CPS was also found to positively affect the manufacturing in the form of CPS production system in process automation and control [20,21]. Due to the great application potential of CPS, and yet the lack of common understanding of CPS in the design and manufacturing of BGMS, there is a need to systematically understand the current status and future applications. A new CPS incorporated manufacturing process is needed to use sensors to produce sensing data, to analyze the collected Big Data, and hence to take proper action to maintain the best and most consistent product qualities. There is an urgent need to have a CPS architecture for the manufacturing of test strips to incorporate sensors and information feedbacks from various processes of test strip production. The central information hub can collect all data feedback from several sensors to compare with the Big Data and determines the health condition as well as the remaining useful life of every processing unit, and take further actions to improve the quality and yield rate of the test strips produced. National or regional distributors of BGMS are in need of a new BGMS with which they can help reduce labor intensive human processing of orders, confirm medical prescriptions, and process medical reimbursement from insurance companies or government authorities. With internet connection available, either through wifi, blue tooth, or cable networks, processing with proper software to meet all these demands becomes possible. After having this new system, the national or regional distributors of BGMS will less likely be audited by the insurance companies or government authorities, as all electronic records are less likely to have problems. Furthermore, two ways internet communications between the computer of BGMS provider and BGMS users allow commercial sales promotion possible, which can generate additional revenue to subsidize the cost of purchasing glucose meters and test strips. Medical institutions, such as hospitals or nursing homes, etc., will be audited from time to time by the insurance companies or government authorities for the medical expenses and for the quality of medical care. If there exists a new BGMS incorporating CPS, the need to perform audit will less likely to be necessary, as all electronic records can hardly be altered. Software can also help process all the information needed by the insurance companies or government authorities with least manpower. Priority should be given to the development of a Quality Check (QC) device which performs 100% non-damaging tests on everything test strips produced, in order to remove defective test strips, if present. This 100% QC non-damaging device should be linked to a central information hub to send information data for further processing. The central information hub collects
all data feedback from several sensors to compare with the Big Data and determines the sources of defective test strips and, in the meantime, determines the percentage of test strips that are out of the ranges of codes, as well as the actions to be taken, such as using laser trimming technique to rectify them [12,13].

![5C architecture for implementation of CPS](image)

**Figure 3.** 5C architecture for implementation of CPS [19].

### 3.2. CPS 5C Architecture for the design and manufacturing of BGMS

There is, therefore, a need to apply a CPS architecture to create a new manufacturing management system to better manage and control the manufacturing process, which better incorporates not only within factory in-time process parameters, but also outside in-time feedbacks from every individual glucose meter in use. This new design and manufacturing of blood BGMS incorporating CPS architecture is discussed in more details as follows:

**Smart connection level:** On the Smart Connection Level, each individual glucose meters in use on the market acts as sensors to connect with the central information hub in the manufacturer’s facility to feedback the status and test conditions of every glucose meters in use. The feedback information includes the status of the glucose meters in use, such as the electronic problems from self-electronic check, the diagnostic check on the contact pins of the glucose meter in contact with the test strips for the depletion of gold plating, corrosion of phosphor bronze contact pins, and fatigue of the contact pins after repeated use. Feedback information from the glucose meters allows the central information hub to compare with the Big Data to determine the health condition of the glucose meter in use, to inform the user not to use the glucose meter to perform further tests by internet, to help the manufacturing units trace the serial number and the manufacturing records of the glucose meter and to take further actions to recall or warn users using the same lot or same key components as the defective glucose meter. The feedback from each individual glucose meter further includes the control solution and blood test results. If the blood test results have been abnormally high or low, the central information hub to compare with the Big Data to determine the health condition of the glucose meter in use and then either to inform the user to seek medical attention, or to help the manufacturing units trace the serial number and the manufacturing records of the glucose meter and to take further actions to warn users using the same lot or same key components as the defective glucose meter. On the other hand, if the control solution test results have been found to be out of the designated range listed on the test strip vial label, either the glucose meter, the test strip, or the control solution could be defective, indicating that further attention should be given to the status of the glucose meter. The feedback from the glucose meters will help the central information hub to compare with the Big Data to determine the health condition of the glucose meter, test strips, and control solution in use and then either to help the manufacturing units trace the serial number and the manufacturing records of the glucose meter, the lot numbers of the test strips and control solutions, and to take further actions to warn users using the same lot or same key components as the defective glucose meters, test strips and control solutions. One of the methods which can help determine the sources of non-conformity is given in Lee’s Taiwan patent [13]. The successful implementation of a CPS 5C architecture on the design of BGMS strongly depends upon the equipped design specifications of BGMS, taking into account the regulatory, performance, human factor, and risk analysis requirements from the very early stage of product design. In practice, numerous glucose meters present on the market will act as sensors, to feedback massive information messages to the central information hub for the central information hub to determine the health condition and remaining useful life of the glucose meters, as well as tracing the serial number and lot number of the glucose meters, test strips and control solution to warn users, through internet connection, using the same lot of test strips.
or, control solution, or to warn users sharing the same key components of glucose meters. By linking to the central information hub, each glucose meter becomes self-aware with configuration orders from the central information hub. The non-conformed quality found can be immediately traced back to the incoming quality check report, manufacturing record, and quality assurance report of the raw materials or key components concerned for the determination of the source of non-conformity. The successful implementation of a CPS 5C architecture on the manufacturing of BGMS strongly depends on the use of sensors and control systems installed on many work stations, interconnected with the central information hub to supply immediate and online information feedback. The sensor information includes, but not limited to, information from the pressure sensor, laser sensor which determines the height of the enzyme solution in the barrel, the noise sensor, which determines condition of the lubrication inside the enzyme injection nozzle, the stroke sensor, which determines the stroke of the injector in the enzyme injection nozzle, and information regarding the on-off time setting of the valve to allow enzyme to enter the enzyme injection nozzle, etc. The sensor information further includes oven air flow rate, oven humidity, oven temperature and oven speed sensors, as well as information from 100% QC check machine, and laser trimming machine for assigning codes [12].

Data to information conversion level: Useful information can be inferred from the data collected the Smart Connection Level. There are several methods and tools available to convert the collected data to useful information for the Data to Information Conversion Level. Recently, there have been many algorithms developed for the prognostics and health management of the systems concerned. By determining the health value and the estimated remaining useful life, the second level of CPS architecture helps bring self-awareness to the design and manufacturing of BGMS. At this Data to Information Conversion Level, the collected data will be converted to information regarding the health condition of the glucose meters, test strips and control solutions, to information to predict the degradation and performance of the components in the glucose meters, test strips or control solutions, and to multi-dimensional data correlation between test performance and various processes of incoming quality control, manufacturing process, quality assurance. Data feedback collected from the enzyme dispensing, oven drying, non-damaging quality check and code assigning processes will be correlated through internet networks to compare, and determine the health condition, degradation characteristics, and remaining useful life of the manufacturing processes.

Cyber level: This Cyber Level acts as the central information hub to receive information from connected glucose meters and process sensors on the many process machines and controls. After gathering massive information, specific analysis has to be applied to extract additional useful information that provides better insight into the status and conditions of every individual glucose meters and many process machines among the fleet. These analytics provides glucose meters and each process machines with self-comparison capability, where the performance of one individual glucose meter or process machines can be compared and rated with the others. Furthermore, similarities between performance and previous history of every glucose meter or process machines can be measured to predict their future behaviors.

Cognition level: The implementation of CPS on the design and manufacturing of BGMS at this level generates a thorough understanding about the systems to be monitored. Proper actions to be taken depend upon the useful information generated from the acquired information. With comparative information and individual status information available, decision can be made on the priority of tasks to optimize the maintaining process. At this level, proper information graphics will be beneficial to the users or decision makers.

Configuration level: The configuration level takes care of the feedback from the cyber space to the physical space for the supervisory control to make machines self-configurable and self-adaptive. This stage acts as the resilience control system to apply the corrective and preventive actions which was made in the cognition level to the systems under monitoring.

Opportunities are always there for those who will consider taking different approaches by taking the recent advances in smart manufacturing or CPS concept. Table 1 lists the benefits of implementing CPS on the design and manufacturing of BGMS. From Table 1, it’s quite obvious that the new concept will bring in revolutionary approaches into the design and manufacturing of BGMS, in order to upgrade product performance, increase product competitiveness and create new business
opportunities. Over the years, the technological advancement in BGMS industries had not been progressing very much. But, it’s time to think hard to re-design a new BGMS with the new CPS architecture.

Table 1. The benefits of implementing CPS on the design and manufacturing of BGMS.

| Product Specification and Function                                                                 | Current Status | With CPS |
|--------------------------------------------------------------------------------------------------|----------------|----------|
| To know the health status and remaining service life of each glucose meter in use everywhere and to make glucose meters self-aware. | No.            | Yes.     |
| To know if the control solution test results can be trusted.                                      | No.            | Yes.     |
| To track glucose meters, test strips and control solution of the same lot as the one which is found defective to determine the root cause of non-conformity and take corrective actions. | No.            | Yes.     |
| To warn users of glucose meters, test strips and control solution of the same lot as the one which is found defective. | No.            | Yes.     |
| To know if the test strips have expired.                                                          | No.            | Yes.     |
| To help reduce labor intensive human processing of orders, confirm medical prescriptions, and process medical reimbursement from insurance companies or government authorities. | No.            | Yes.     |
| Distributors will less likely be audited by the insurance companies or government authorities.     | No.            | Yes.     |
| Allow commercial sales promotion from central information hub to glucose meter users.              | No.            | Yes.     |
| Provide medical institutions with electronic records for them less likely to be audited by the insurance company or government. | No.            | Yes.     |
| Self-aware, self-adaptive and self-configurable enzyme dispensing process.                         | No.            | Yes.     |
| A central information hub collects all data feedback from several sensors to compare with the Big Data to determine the health condition as well as the remaining useful life of every work station, and recommends further actions. | No.            | Yes.     |
| A central information hub collects all data feedback from the enzyme dispensing sensors, oven sensors, and 100% QC machine for another laser machine to trim on every individual tests strip to help every test strip yield consistent test results. | No.            | Yes.     |
| A central information hub collects all data feedback from the enzyme dispensing sensors, oven sensors, and 100% QC machine to determine the health condition and remaining useful life of every work station. | No.            | Yes.     |
| A central information hub collects all data feedback from the enzyme dispensing sensors, oven sensors, and 100% QC machine to make every work station self-aware, self-adaptive, and self-configurable. | No.            | Yes.     |
| Upgrade product performance, reduce cost, and create new business opportunities.                  | No.            | Yes.     |

4. Conclusions

Even with recent advances, however, the current inherent problems can’t be resolved without a revolutionary new approach of implementing CPS system architecture concept to the design and manufacturing technologies of BGMS. It’s obvious and practically possible to implement CPS architecture to the design and manufacturing of BGMS, in order to interconnect the uses of glucose meters, test strips and control solutions with the manufacturing systems through cyber space to enhance the safety and performance of the BGMS, to reduce the risks of the BGMS users and manufacturers, and to assist the tracking of defective glucose meters, test strips and control solutions present on the markets for warning and recall. The implementation of CPS to the design and manufacturing of BGMS further interconnects sensors and information feedbacks from different work stations to allow the manufacturing systems to be self-aware, self-adaptable and self-configurable, in order to reduce manpower, defective rate of test strips produced, and production down time, as well as enhancing the production efficiency. This new concept will bring in revolutionary approaches into the design and manufacturing of BGMS, in order to upgrade product performance, increase product competitiveness and create new business opportunities.

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