As an effect of globalization, product parts are manufactured more and more in different places. Due to the manufacturing processes, (sub-) products are being transported back and forth and rearranged until they can finally reach the consumer. Not only the environment is increasingly burdened, but also the natural resources are wasted increasingly thoughtless. One reason is certainly because for decades the industry has had only an inflexible concept for the inspection of (sub-) products, which cannot be easily adapted to changes in product layout, for example one robot with one sensor or one rigid structure with a fixed number of sensors for one specific inspection task. This rigid approach is unsuitable for the inspection of variant products. For these reasons, a new concept for 2D and 3D metric and logical quality monitoring with a more accurate, flexible, economical and efficient inspection station has been developed and tested in IOSB.

Keywords: Inspection Station, assistance system, configuration system, sensor magazine, quality monitoring, flexible, reconfigurable, multi sensors.

1. INTRODUCTION

The inspection of work piece surfaces and structural defects is one of the most important tasks for the quality monitoring in factories. Scratches, dents, pores, deformations and other kinds of defects on or below the surface should be detected and classified. Depending on the product type, the inspection checklist can be very long. A lot of measurement techniques and systems for the quality control are generally used for those inspection tasks.

Figure 1 shows a part of the traditional product circle for the production and inspection of manufacturing parts. Product parts are first transported for assembly from different satellite factories in the assembly plants (for example A and O). Each part must be checked carefully before being assembled. The assembled partial product must also be inspected carefully at the end of the assembly line in an assembly plant like A or O. In addition, the production and the assembling of the parts up to intermediate products or up to final products take place frequently at different places or factories, whereby the distance can extend over some meters up to hundreds of kilometers. A lot of difficult logistic tasks such as packaging, transportation, and vehicle routing etc. must be solved in the production process.

With the traditional production method not only the environment is increasingly burdened, but also the natural resources are wasted increasingly thoughtless. A new business model is needed for the reduction of transport costs and time as well as for an increased utilization of inspection systems. And new tools are also needed to realize the idea. How can some test tasks be summarized in a sensible way to save investment, while protecting the environment at the same time? How can the rest time of an inspection system be reduced? How can an existing inspection system be upgraded in order to carry out more testing tasks? … Many questions must be answered before developing a more accurate, flexible, economical and efficient inspection station. One of the contributions to the suppression of the investment costs can certainly be achieved by improving the functionality of the test station.

In this paper, a solution is presented to combat the waste of resources through a new concept in the field of automatic inspection of products. An inspection station can be used more intensively, efficiently and resource-friendly with the aid of an assistance system, a configuration system and an inspection system which is equipped with a sensor magazine. We call such a station a Green Inspection Station (GINS). The GINS is designed for both 2-D and 3-D metric and logical quality monitoring. All sensor systems are placed on the sensor magazine and are ready to use immediately after docking to the robot arm. By means of standardized interfaces, different kinds of hardware (sensors, light sources and so on) and
software library can be used easily, in order to master this task. The calibration of each inspection station must be done individually. Using an example, the reconfigurable GINS is explained in detail.

Some of the advantages and added values of GINS are listed as follows:

- Different test tasks can be performed on the same inspection station.
- Unnecessary transport costs and waiting time for quality monitoring can be minimized. Complicated and tedious logistics can be avoided.
- High frequency of use and easy adaptation to new tasks in the use of intelligent grip arms and a sensor magazine with standardized interfaces.
- Processing chains of different inspection tasks can be configured by the configuration system and tested on the inspection system.
- A configured processing chain can be reproduced for the same inspection task in factories on other Satellite-GINS. A Satellite-GINS has limited functionality of a model GINS. The conversion period for machines can be reduced considerably.
- The GINS may serve as a model station for research or laboratory investigation.

![Figure 1](image_url)

Figure 1: A part of the traditional product circle for the production and inspection of the manufacturing parts. Parts of products are first transported for assembly from different satellite factories in the assembly plants (for example A and O). All assembled partial products must then be transported to the main factory for final assembly. A lot of difficult logistic tasks such as packaging, transportation, and vehicle routing etc. must be solved in the production process. The environment is heavily burdened by the multitude of transports.

2. **SYSTEM OVERVIEW**

The GINS (see Figure 2) has four main components, namely an assistance system, a configuration system, an inspection system and a database system. Information about target tasks, system components and hardware parameters can be saved by the assistance system in the database system. For a request to a defined test task, the user gets a general suggestion from the assistance system about what kind of sensor system and software can be used for the test task. The user can confirm or change the suggestion. No expert system was used at the moment for an automatic Selection of the best hardware and software for a particular target task.
Initial hardware and software settings and task-specific processing chains for the inspection of objects can be well prepared and tested offline with the simulation functionalities in the configuration system. In a learning (setting-up) phase the optimal test route and sensor positions as well as system parameters and sensor parameters with light intensity will be specified and saved in the database system for later use. Using plug-in methods, image analysis chains which are necessary for the localization of test objects and for the automatic detection of anomalies to expose different product errors can be easily realized with the configuration system and tested with the inspection system.

For the navigation and position control of the robotic movement with regard to the imprecisely guided production as well as for the comparison of the observed actual topography with the target topography, reference models are required. These models can be built up with either CAD files or scan data (images) which are being obtained during the learning phase using suitable short- and wide-range sensors. The CAD files are sometimes not promptly updated. For this reason, the function for creating reference models during the learning phase is very important.

The inspection system contains all the hardware and software components and a sensor magazine for the execution of processing chains. The GINS can be easily duplicated (see Figure 2) as Satellite-GINS for satellite factories or assembly plants which have the same test task, use the same hardware and the same processing chains. A Satellite-GINS has limited functionality of a model GINS. Adaptation work like modification of hardware and software parameters can be done locally.

Four identical modules are used for test tasks in the configuration system and the inspection system. Figure 4 in [1] shows the four main modules in detail:

1. Localization of unfixed or fixed industrial test objects and calculation of test zones;
2. Automatic detection of anomalies or test zones;
3. Time-optimal dynamical path planning;

The four modules can be used completely or partly in a reasonable combination depending on the product and the test task. The final processing chain with fixed parameter set is defined using the configuration system.
Two kinds of sensors are used at the moment for the automatic detection of anomalies of test objects. Those are the 3-D laser triangulation sensors for the metric test task and short-range cameras with lighting systems for the logical test task. For the automated inspection of painted car surfaces, a compact sensor head will be developed which can be used for the deflectometric inspection principle [2].

3. CONFIGURATION SYSTEM WITH LEARNING STAGE

The main goal of the flexible configuration system for the inspection purposes is the generation of automated processing chains with regard to the specific work pieces under control. The preparation work for setting up a processing chain is carried out by using the assistant system. Some results of the assistant system are listed as following:

- Identification of the class of the test orders;
- Assignment of test orders and matching sensors (e.g. cameras, 3-D laser triangulation sensors, IR-sensors etc.),
  Selection of the appropriate sensor systems;
- Fault tolerances and defects of products which must be detected;
- Specification of regions to be inspected on details by short-range sensors;
- Suggestion of inspection methods and processing chains;
- Description of the trajectories for selected short-range sensors.

During the so-called learning phase, several work steps have to be performed to realize the process chains required for the test tasks and to configure the system parameters. The work steps are:

- Calibrating the different coordinate systems (sensors, hand-eye, handling system etc.) related to the world coordinates;
- Selection of desired master work pieces for the online learning task or download of existing CAD models for the simulation in order to train the GINS for the OK-case;
- Performing the learning stage with the configured system. The selected master work pieces or CAD Models must be referenced with;
- Automatic storage of learned model objects data and the inspection methods in the database system of GINS.

All steps listed above have to be carefully edited by trained operators with assistance of specialized system functions. The outcome of this procedure is a configured and trained system in accordance with the specified inspection tasks for quality control purposes.

Figure 3 gives an impression of the realized human-machine-interface (HMI) for the fine tuning of the configuration system. On the left side, a contour of a master work piece with a marked inspection path and areas for a dedicated sensor system, which is selected for a specific inspection order, are shown. The Cartesian coordinates of the areas can either be edited by trained operators or downloaded from CAD data which are stored in the database system. The HMI has several tabbed views with zooming functions for convenient interoperability for all different tasks and sensor systems.

The trajectory planning for robot movements with selected sensor systems can be modified also with the same software tool in the configuration system. The robot paths are specified as linear or spline segments with start and end points as well as with intermediate points if necessary in the global Cartesian space. The dynamic path parameters such as jerk, acceleration, deceleration or velocity for all inspection trajectories can be easily set and modified with the software tool (see Figure 3 right hand side). The parameter settings for the chosen inspection sensors, e.g. lightning, gain, exposure time, data acquisition rate etc., are also controlled and tuned via specific E/A controls. Thus, all relevant parameters that can influence the test tasks can be completely controlled, changed and adapted by the trained operator.

Furthermore all subtasks needed for a dedicated automated inspection task can be programmed and configured with only some primitives by clicking and/or drag and drop the desired commands (see Figure 4). These primitive actions [3] and commands (like ‘Pick Sensor’, ‘Move To’, ‘Loop’, ‘Wait’, ‘Light On/Off’ ‘Drop Sensor’ etc.) are combined with complex sequences of numerous processing steps (inspection program segments). The robot movements and the dynamic path parameters as well as the selected sensors and their specific parameters (e.g. camera settings, lightning, tolerance
dimensions) can be easily configured and simply adapted if needed. These command sequences and parameters are then interpreted by the system in order to initiate the desired system behaviors. The complete configured processing steps and programmed commands and some sensor features can be simulated to get a fast feedback of the designed inspection task.

![Figure 3: One of the human-machine-interface (HMI) for the assistance planning and system configuration.](image)

Once all appropriate settings have been configured and macro programming has been completed, the so called learning stage can take place. Dedicated master work pieces or CAD data are presented to the configured system in order to gather all quality data and store them in a database for further reference purposes for the subsequent operating stage.

![Figure 4: An example of macro programming of complex inspection tasks with primitives.](image)
Also fine tunings of the configured system can be accomplished in some iterating steps. This learning stage takes place only once for a new inspection problem or, if an existing one is altered and adapted. After this stage the configured and tuned GINS is ready for use in production lines.

4. INSPECTION SYSTEM FOR OPERATION STAGE

The operating stage, which follows the learning stage, is used to automatically inspect each product part. All system modules (e.g. robot, short-range sensor system, 3-D laser triangulation sensor system, wide-range sensor system etc.) are connected to the inspection system via communication channels. Thus as highly flexible structure is achieved. Dedicated software modules can either run on one single computer, or can be distributed on several stations. This system structure is easy to maintain by several specialists. The interoperability is achieved by the defined communication protocols.

For a correct comparison between the present test object with the stored CAD data or the learned model object data the current location of the test object in the workspace must be determined online. The sensor signals are evaluated with preset fault tolerances to classify errors and rejections of the checked work pieces. The negative results of the inspection are signaled and displayed for the users (see Figure 5). The inspected work pieces are classified as OK or Not OK. Furthermore, the inspection results and measurements are stored in databases for documentation purposes. The system reactions are reliable, objective and not dependent on the mood of the users with their subjective judgments.

![Figure 5: Found difference between reference part and production. A clip was forgotten to mount.](image)

5. REALIZED EXAMPLES FOR INSPECTION TASKS

To prove the feasibility of the new concept for quality monitoring and the extensibility of the concept for the customer-specific testing tasks a development and demonstration platform (DDP) was developed, realized and equipped with short-range sensor systems as well as a wide-range sensor system (see Figure 6). An industry robot with a dedicated fast path planning interface for real time applications was used to control and position the required sensors during inspection. The robot wrist is equipped with a tool change system which is adapted for short-range sensors and integrated in the system concept. Next to the robot a sensor magazine is installed, which is a docking station for sensors and allows an easy use and flexible selection of several adequate short-range sensor systems.

Practical examples were investigated to demonstrate the advantages of the reconfigurable GINS. As test objects a big object like a fuselage shell of an aircraft and a small object like a mold were selected. The test task can be as follows: are all the rivets correct on the fuselage shell? Is the surface of the fuselage shell damaged? Are all construction units present? Is the depth of the mold correct? And so on.

A wide-range sensor system was used for situation analyses, 3-D object localization and matching of coordinates for the subsystems interacting (e.g. robot, short-range sensors, etc.). The wide-range sensor system supplies the GINS with current information about the location of the test object in the 6-D space [4] [5]. These localization data is automatically requested by the inspection system in order to correct the preconfigured inspection paths. The correction data is used by a Denavit-Hartenberg-Transformation procedure [6] for matching the real current test object position with the predefined...
coordinates used in the configuration system. The mismatch of the predefined coordinates and the positions in reality originate from the flexible hanging of the test objects. The possibility to correct such effects is one advantage of the presented concept. Furthermore, the wide-range camera system gives a quick and rough overview of the test objects during the step for the localization. It can be used to detect regions of interest (ROIs) which differ from the learned optical appearances or CAD-descriptions of the master work piece. The detected ROIs are transferred to the inspection system for detailed inspections with adequate short-range sensor systems.

A short-range camera with a lighting system was used for the logical test tasks. In the learning stage a master work piece was photographed from different sides to gather reference data from the work piece. This stage is also used to establish the trajectories which are necessary to guide the different precise short-range sensors and to gather all desired reference information. In the following operational phase, all installed components or the detected ROIs were automatically inspected according to the specification. Small structures, scratches, pores, deformations or optical abnormalities were detected by applying the image evaluation methods [7] [8] [9] and the reference data from the master work piece. The results of the quality controls were stored in a quality management system which forms part of the database system in GINS. Errors and warnings for detected anomalies are available for further analysis. For example, the class ‘Not OK’ may be separated into ‘Refinishing’ or ‘Waste’ using a classifier with multiple classes.

A 3-D laser triangulation sensor with two laser line projectors for the metric test task was also used as a short-range sensor. The geometric structures of a master work piece were scanned. These data was collected by the inspection system in order to verify against reference scans. Mismatched, displaced or missing structures can be also detected. The use of several laser line projectors is an advanced improvement of the functionality of the inspection methods of GINS. The advantages of the improvement are versatile [10]:

- Reduce occlusion effects;
- Reduce inspection time and energy consumption;
- Reduce additional investment cost;
- 3-D measurement with higher quality.

6. CONCLUSIONS

This paper has presented a reconfigurable, cost reducing and resource-friendly inspection station that is provided with an array of test-specific short-range sensors which makes the logical quality monitoring and the metric inspection process
more accurate and flexible. The GINS consists of an assistance system, a configuration system, an inspection system which is equipped with a sensor magazine, and a database system. Its flexibility allows problem-specific application coupled with economical and efficient improvements. An inspection station can be used with high frequency and efficiency. The waste of time, energy, space and money etc. can be minimized. These improvements are achieved thanks to the new conception, the applied methodology and the use of sensor magazine in combination with an adequate handing system.

One of our main goals for the creation of the GINS is to investigate, optimize and demonstrate to our potential cooperation partners how to apply the GINS in order to reduce effort and to increase accuracy and flexibility. It can be used for the introduction of learning capable evaluation processes, as a tool for user interaction, as well as for the flexible networking and integration of various short- and wide-range sensors. Depending on products and the test task, the presented four modules can be used either completely or partly in a reasonable combination. Its modular and hence flexible structure is a modern basis for future requirements and/or add-ons.

An additional inspection sensor, which is based on the deflectometric inspection principle, will be developed to be used together with the sensor magazine and made available for the inspection of painted car surfaces.

REFERENCES