Software Control System for Equipment of Integrated Circuit Layout Inspection

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Abstract. **This paper describes the main functions and architecture of software control system for equipment of critical sizes inspection for layouts of integrated circuit on basis of computer vision. Advantages of the developed architecture are described, as well as its application for image processing of integrated circuit layouts. The system allows identifying effectively defects what it is especially important for Very large-scale integration manufacturing based on submicron technology.**

Keywords: **image processing, VLSI, automatic layout inspection, control and measurement equipment**

I. Introduction

The equipment of integrated circuits (ICs)layout in section is characterized by a large diversity and essentially differs in degree of complexity: from simple visual inspection tools for mass production to the most complex automatic inspection and measurement systems which are used both in R&D of new technologies and devices, as well as in the large-scale production. Automatic inspection and measurement system for defects in semiconductor wafers is already used in microelectronics [5]. Scientific and technical group of dedicated designers, technicians and production engineers which develops and supplies special systems for realization of critical technologies in microelectronics and precise engineering are foundation for development and further growth of modern technology.

Modern means of developing ICsare aimed at reducing time for mastering and launching new products into production, as well as reducing cost of digital equipment during its mass production. Such an opportunity is provided by technological base, including machine (computer) vision systems, which are an integral part of modern technology for the design and production of ICs.

In connection with updating new submicron design standards and increasing complexity of the ICs themselves, it becomes necessary to solve problems of processing, storing, receiving and transmitting large amounts of data obtained during lithographic process of ICs design. Original approaches for image processing allow to fully complying with conditions of submicron manufacture of Very large-scale integration (VLSI) and to reduce cost of production. The object of the study is process of critical dimensions inspection on the photomasks and VLSI layouts. The processing consists of image analysis, generating reports based on the previous analysis results, controlling the focusing system, coordinate table and other external devices, as well as synthesis of routines for the automatic operation of control equipment for monitoring of layout critical sizes.

The developed Software Control System (SCS) for equipment of ICs layout inspection is based on machine vision and provides the following functions: image preprocessing taking into account design and technological constraints; image processing and analysis with support for third-party video camera equipment; image analysis to control design and technological constraints; storage and access to data with the ability to import and export data in various formats; program synthesis for automatic operation; management of third-party mechanisms; data visualization. The main analogs of the SCSare the Olympus MicroSuite FIVE software systems from Olympus Corporation (Japan) and NIS-Elements Microscope Imaging Software from Nikon Instruments Inc. (USA). Analogs of installations for monitoring critical dimensions and their approximate cost: LEICA LWM – 4.8 million dollars, KLA Tencor IPRO – 5 million dollars.

II. SCS Use Cases

Use cases can be divided into main and minor. The main cases consist of: loading an object (as emiconduct or wafer or its photomask) – preparing the object for further work (preliminary orientation in space, moving to the working area); unloading of the object – removal of the object from the working area to the storage (container, cassette); initialization of the installation and basing of mechanisms – loading data

Pattern Recognition and Information Processing (PRIP'2021) : Proceedings of the 15th International Conference, 21–24 Sept. 2021, Minsk, Belarus. – Minsk : UIIP NASB, 2021. – 246 p. – ISBN 978-985-7198-07-8.

describing the initial state of the equipment for solving a specific problem, and setting the mechanisms to the appropriate state/position; movement control of the coordinate table – formation of generalized commands to control the movement of the coordinate table; alignment and orientation – binding of the reference system and the coordinate system of the object to the coordinate system of the installation; control of dimensions – launching algorithms for control and measurement of dimensions; automatic measurement – launching algorithms for automatic measurement of dimensions; sizing of elements – launching algorithms for determining the size of the image; mechanism control – preparation of equipment control commands (meta-commands) and corresponding parameters; generating of control commands – transformation of meta-commands into the format required by microcontroller for equipment control; creation of a control program for automatic mode – generate a list of control actions with appropriate parameters and their saving as a file or record in a database (DB); creation of a map-structure of an object – preparation of a description of the structure of an object for its further study; save the results of control – the results of PC operation into a structure intended for further storage in the DB and the subsequent saving of the received data block using the DB.Minor use cases for user identification are required to delimit access to SCSfunctionality.

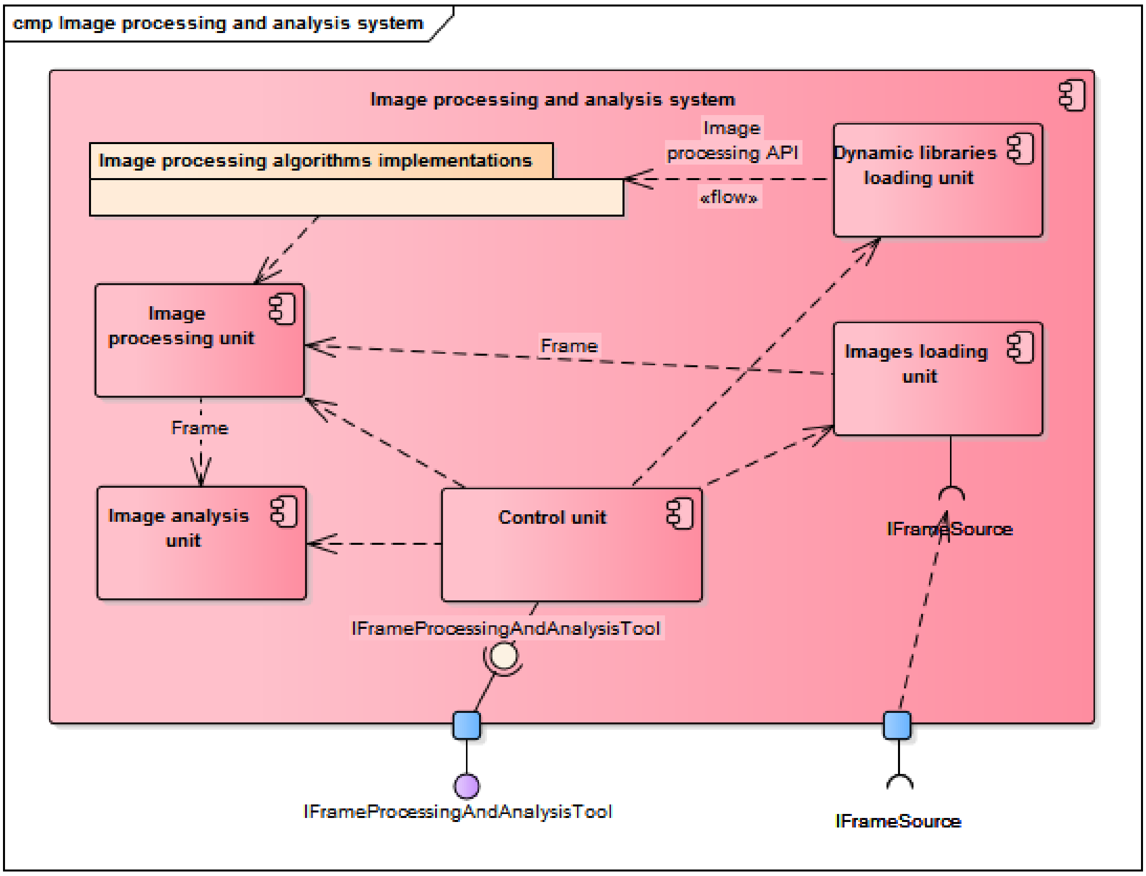

Fig. 1. Architecture of the image processing and analysis system

III. SCS ARCHITECTURE

SCSconsists of several subsystems; one of them is an image processing and analysis system. The architecture of the image processing and analysis system can be described in form of a diagram of its components (Fig. 1). The diagram (Fig. 1) describes composition and interconnections of image processing modules control module, which is designed to select algorithm implementations specified by parameters and coordinate for the interaction of the modules; the module for operation uses data received from source ICommandSource; the image loading module, which is used to retrieve individual images from an IFrameSource image source; the dynamic library loading module that loads dynamically loaded libraries containing implementations of various algorithms for image processing and analysis, and also provides a general interface for accessing the loaded functionality; the modules that implement image processing algorithms –they are dynamically loaded from libraries, as well as an interface processing algorithm that allows

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you to call various algorithms sequentially; the image processing module that calls the selected implementation of the image processing algorithm (or their chain); the image analysis module that is designed to analyze processed images and transfer the analysis results to IProcessingResultStorage storage module.

The ability to use the dynamically loaded libraries provide a compatibility of the system with image processing algorithms that are implemented in form of such libraries. Thus, the system under development can use the following image processing algorithms [1–11]: ContrastCorrection; GammaCorrection; Invertion; LaplaceFiltration; MeanFiltration; MedianFiltration; Morphological Closing; MorphologicalDilatation; Morphological Erosion; Morphological Opening; ThresholdBinarization. The functioning of the system is carried out according to the generalized algorithm, the steps of which are given below.

Step 1. Loading operation parameters from the command source ICommandSource.

Step 2. Loading dynamic libraries.

Step 3. Preparation of the algorithms' implementations required for processing.

Step 4 If the images in the IFrameSource are still available, then go to step 5, otherwise go to step 10.

Step 5. Loading image from source.

Step 6. Image processing with the selected algorithm or algorithms.

Step 7. Analysis of the processed image.

Step 8. Saving the analysis result to the IProcessingResult Storage result storage.

Step 9. Go to step 4.

Step 10. Completion of work. As noted earlier, the software module for image processing and analysis, almost all elements of the SCS should be a set of dynamically loaded libraries containing supported functions. The following classes were implemented:

- interfaces: IFrameProcessor– interface for implementing image processing algorithms; IFrameAnalyser - interface for image analysis algorithms; IFrameProcessingAndAnalysisTool– interface of the control module;

- data classes: FrameProcessingState - the result of image processing; FrameAnalysisResult – result of image analysis; ProcessingAndAnalysisResultsContainer – combined result of image processing and analysis;

- class factories: FrameProcessorFabric – the factory for image processing algorithms; FrameAnalyserFabric – the factory for image analysis algorithms; FrameProcessingAndAnalysisToolFabric – control module implementations factory;

- processing/analysis chains: FrameProcessorChainProxy – a chain of image processing algorithms; FrameAnalyserChainProxy – image processing analysis chain; FrameProcessingAndAnalysisTool – implementation of the control module; DynamicLibraryLoader – module for loading dynamically loaded libraries; DynamicLibraryLoader::Handle – handle to the loaded dynamic library (the class is a subclass of the DynamicLibraryLoader class);

- classes that implement image processing algorithms: ContrastCorrection-FrameProcessor– contrast correction;GammaCorrectionFrameProcessor– gamma correction; InvertionFrameProcessor– color inversion; LaplaceFiltration-FrameProcessor– Laplace filter; MeanFiltrationFrame Processor – averaging filter; MedianFilterationFrame Processor – median filter; MorphologicalClosingFrameProcessor– morphological closure; Morphological-DilatationFrameProcessor – morphological dilatation; MorphologicalErosionFrameProcessor– morphological erosion; MorphologicalOpeningFrameProcessor – morphological opening; ThresholdBinarizationFrame-Processor – threshold binarization.

The SCS includes implementation of main function by special systems and subsystems: an image processing and analysis system, including a video camera subsystem for preparing data for use; a control system for functional linking of other systems and subsystems; the mechanism control system for generating unit control commands; graphic user interface for the user to control the functioning; subsystem of interaction with the DB for storing the results of inspection; a subsystem for control program generation (description preparation of the configurations of operation used in the automatic mode of operation). In addition, each of the systems must be implemented with a sufficiently high level of abstraction to ensure uniform operation when using different video equipment and control equipment. So when choosing an design pattern for software package, the following criteria were used: modularity; openness; configurability; separation of graphical user interface and functionality. The most convenient design pattern based on the listed before criteria is MVC (Model-View-Controller). MVC pattern with some modifications allows to take into account mentioned above criteria and requirements to the architecture of

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the SCS: the control system must be able to receive commands from several sources – an interface for receiving control commands is added for converting general view commands (meta-commands) into specific commands for such equipment; the control system must be able to receive a video stream from several sources – an interface for receiving video data is added, which converts various data formats to a single format an interface for receiving control commands is added for converting general view commands (meta-commands) into specific commands for such equipment, the virtual data model that stores a description of the state of the parameter control process is implemented.

The developed architecture of the SCS is shown on Fig. 2. The work of the SCS is carried out as follows:

1. Initialization of user work by issuing control actions to the control system (by the user interface or loading the configuration for automatic operation).

2. Transformation of control commands, if necessary.

3. Receiving data from video camera using the appropriate SDK, convert data for processing.

4. Processing and analysis of data by appropriate subsystems.

5.Transmission of video stream and analysis results in the control system, if necessary, format conversion.

6. Development of control actions by the decision-making subsystem (decision based on the received commands, video stream and analysis results).

7. Transferring of data at the control process to the virtual data model.

8. Signal transmission when changes the state of the model from the virtual data model to the graphical user interface.

9. Request the required data graphical user interface from the virtual data model and retrieving them.

10. Transmission commands of control to equipment by the decision-making subsystem through the appropriate next path (interface, the mechanism control system and the corresponding Software Development Kit (SDK)).

11. Save the results of control in the DB.

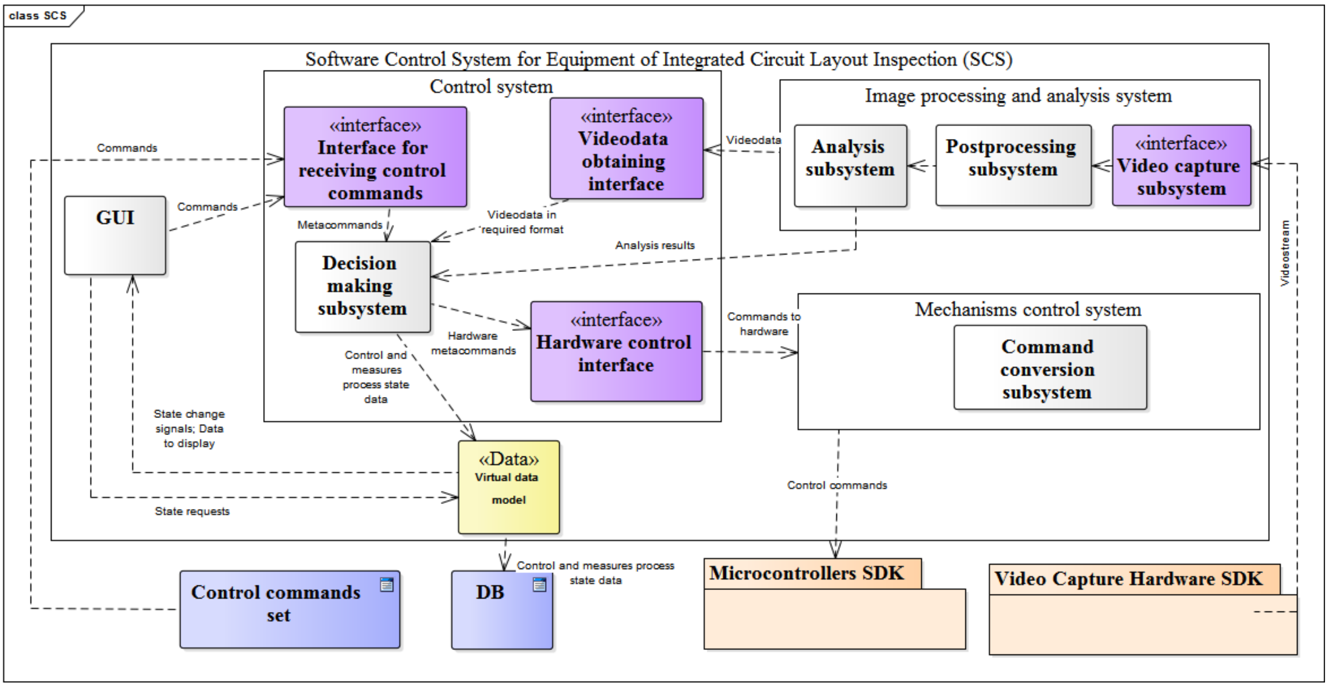

Fig. 2. Architecture of the SCS

IV. Conclusion

The general architecture of program complex for control of equipment for monitoring of critical size based on machine vision systems has been developed, which allows working with big input data and easily adapted to specific equipment.

In this paper, the requirements and the structure of the SCSare described. technology allows identifying effectively defects that is especially important for software engineering for equipment of critical sizes inspection of VLSI manufacturing based on submicron technology.

The developed software provides the following functions:

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- image preprocessing taking into account design and technological restrictions;
- image processing and analysis with support of different video equipment;
- image analysis for inspections of manufacturing operations;
- storage and access to data with the ability to import and export data in various formats;
- synthesis of the program for automatic operation mode;
- control of different mechanisms;
- data visualization.

The architecture of the software system was developed, providing possibility of flexible adjustment of general algorithm of image processing and analysis. The user can independently compose chains of simple algorithms to obtain more complex ones. It is also possible to connect external routines. The operation parameters and automatic processing programs are stored in the database.

The software is used in production of competitive precision equipment for VLSI manufacturing what determines its practical importance: for automatic photometry with precision laser focusing system; for automated microsize inspection system; for mask pattern coordinates measurement system, equipment for mask pattern generation and inspection.

A significant advantage of equipment of the controlled of SCS and developed by JSC Planar for the production of VLSI over foreign counterparts is that it is designed on a single design and technological base, realizing full hardware, software and metrological compatibility of the entire set of installations operating in a single technological cycle for Embodiments in silicon of critical technologies of the microelectronic industry.

References

[1] R. Gonzalez, R. Woods, The world of digital processing, Digital image processing, Moscow, Technosphere, 2005, p. 660.

[2] V. V. Starovoitov, Local geometric methods of digital image processing and analysis, Minsk, In-t techn. Cybernetics, p. 282, 1997 (In Russian)

[3] V. A. Soifer, Theoretical foundations of digital image processing : Textbook, Samara, SSAU, 2000, p. 255.

[4] A. A. Dudkin, A. A. Voronov, E. Marushko, Algorithm for stitching frames of the VLSI topology layer by key points, Bulletin of the Brest State Technical University, 2015, No. 5 (94): Physics, mathematics, computer science, pp. 11-14 (In Russian)

[5] A. P. Dostanko, S. M. Avakov, O. A. Ageev, M. P. Batura Technological complexes of integrated processes for the production of electronic products, Minsk, Belorusskaya Navuka, 2016, pp. 251.

[6] M. Fowler, Architecture of corporate software applications, Moscow, Publishing house "Williams", 2006.

[7] L. Craig, Application of UML 2.0 and design patterns, Ed. 3-E, Moscow, Izd. house "Williams", 2013.

[8] G. Erich, Techniques of object-oriented design, SPb. Ed. house "Peter", 2015, pp. 368.

[9] E. Evans, Domain-oriented design (DDD): structuring of complex software systems, Moscow, "Williams", 2011.

[10] D. Spinellis, G. Gusios, Ideal architecture. Leading experts on the beauty of software architectures, St. Petersburg, Symbol-Plus, 2010.

[11] N. Ford, R. Parsons, P. Kua, Building evolutionary architecture (Support constant change), St. Petersburg: Symbol-Plus, 2019.

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